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# The Changing Geography of the International Diffusion of Technological Knowledge

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## Abstract

This paper examines the evolving geography of international technological knowledge diffusion over the last four decades using multiple patent-based indicators. We first review the main mechanisms through which knowledge diffuses across borders—including trade and global value chains, foreign direct investment, skilled migration, global science, and markets for technology—highlighting their complementarities and the role of domestic capabilities. We then provide new empirical evidence based on cross-border patent citations, technological trajectories defined by IPC recombinations, patent-to-science linkages, and international patent families. The results reveal persistent asymmetries, with a small group of advanced economies remaining central knowledge hubs, alongside the rising role of emerging countries, especially China. Science-based technologies diffuse farther and faster, while capability constraints continue to limit integration for many regions.

**Keywords:** technological knowledge diffusion, geography, patents, citations, technological trajectories, science, patent families

**JEL Codes:** O34, O33, F14, F23, R12

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## Table of contents

Table of contents .....	2
List of figures .....	3
List of tables .....	4
1. Introduction .....	5
2. Mechanisms of international technology diffusion.....	7
Technological knowledge embodied in traded goods.....	7
Technologies embodied in capital and equipment investments .....	9
Technological knowledge diffusion embodied in moving people.....	10
Technologies based on global science .....	12
Technology diffusion, markets for technology, and international patent protection .....	14
Capabilities .....	15
3. How can we measure international technology diffusion? .....	16
4. The changing geography and pace of international technology diffusion ..	20
International technological knowledge diffusion as measured by patent citations.....	20
Technological trajectories as IPC combinations in patents .....	26
Reliance on global science .....	35
Patent families and international knowledge diffusion.....	39
5. Conclusion.....	45
References .....	47
Appendices.....	59
Appendix A: List of country codes and world region names.....	59

## List of figures

Figure 1. Citation flows of technologies across countries/territories.....	21
Figure 2. Average time to the first citation received across territory pairs .....	25
Figure 3. Flows of technological knowledge across countries.....	29
Figure 4. Flows of technological knowledge across countries in the first 5 years of the development of each technological trajectory.....	30
Figure 5. Flows of technological knowledge across countries in 6 to 10 years of the development of each technological trajectory.....	30
Figure 6. Flows of technological knowledge across countries in 11 to 20 years of the development of each technological trajectory.....	31
Figure 7. Flows of technological knowledge across countries, for those trajectories that originated in the timeframe 1985-1995.....	32
Figure 8. Flows of technological knowledge across countries, for those trajectories that originated in the timeframe 1996-2005.....	32
Figure 9. Flows of technological knowledge across countries for the sub-sample of trajectories originating from highly cited patents.....	33
Figure 10. Flows of technological knowledge across countries for the sub-sample of trajectories originating low cited patents.....	33
Figure 11. Average time to the arrival of a trajectory in the destination territory. ....	34
Figure 12. Number of trajectories that arrives at the destination territories from the origin territories.....	34
Figure 13. Flows between countries generating science and countries applying that science to produce technologies. ....	35
Figure 14. Flows between countries generating science and countries applying that science to produce technologies when the paper cited is published in the time window 1985-1995.....	37
Figure 15. Flows between countries generating science and countries applying that science to produce technologies when the paper cited is published in the time window 1996-2005.....	37
Figure 16. Flows between countries generating science and countries applying that science to produce technologies when the paper cited is published in the time window 2006-2015.....	37
Figure 17. Flows between countries generating science and countries applying that science to produce technologies when the paper cited is published in the time window 2016-2022.....	38
Figure 18. Average time taken by scientific papers written in the origin territories and to be cited by patents in the destination territories. ....	39
Figure 19. Number of scientific papers written in the origin territories and cited by patents in the destination territories.....	39
Figure 20. International patent family links by destination .....	42
Figure 21. International patent family links by origin.....	44

## List of tables

Table 1. The top-10 bilateral corridors of patent citation flows. ....	20
Table 2. Most prevalent technology diffused (IPC4).....	24
Table 3. The top-10 sender and receiver countries of the technological trajectories. ..	27
Table 4. The most frequent IPC code involved in the technological flow sender-receiver country pair.....	29
Table 5. The most frequent IPC code to which the technologies in country j, citing papers published in country i, are classified.....	36
Table 6. The top-10 bilateral links within international patent families, 1985-2022 .....	41

## 1. Introduction

The aim of this paper is to describe the patterns and trends of the international diffusion of technological knowledge, over a long time period and using different proxies, from a global perspective. Technological knowledge can be defined as the codified and embodied set of problem-solving principles, techniques, and capabilities (often times in application of scientific knowledge) that enable the creation, improvement, and application of products, processes, or services – made observable through documented inventions, particularly those disclosed in patents and categorized by technological domains via the International Patent Classification (IPC) system or similar classifications (Dosi, 1982; Rosenberg, 1982).

Economists have long understood that innovation is the major source of technological advance – the generation and application of knowledge applied to improving productivity and the quality and variety of an economy’s output (Crescenzi et al., 2019). This, in turn, nurtures economic growth and catching up across countries (Aghion and Howitt, 1992; Gerschenkron, 1962; Keller, 2004; Lucas Jr., 1988; Nelson and Phelps, 1966; Nelson and Winter, 1982; Romer, 1990, 1986; Schumpeter, 1939). This is well documented empirically by Clark and Feenstra (2003) and Klenow and Rodriguez-Clare (1997), who argue that cross-country differences in income per capita during the 20<sup>th</sup> century are mostly attributable to differences in total factor productivity (TFP) growth. Yet innovation is not equally distributed across countries, nor territories therein. The literature has consistently found that knowledge travels with difficulties across space (Audretsch and Feldman, 1996; Jaffe et al., 1993; Keller, 2002; WIPO, 2019). This has been found to be related to its tacit components – as opposed to codified elements. Tacit knowledge can mostly be shared through face-to-face interactions (Storper and Venables, 2004), and through specialized networks of professionals (Breschi and Lissoni, 2009) – which tend to be localized in space too. Indeed, geographical proximity alone does not explain diffusion; what matters is the right combination of different types of proximities (Boschma, 2005). Yet, geography still makes technological knowledge difficult to transmit over long distances unless people (and goods where this knowledge is embodied) move, or knowledge is eventually codified (Cowan and Foray, 1997). Despite the increasing use of technologies facilitating human interaction over long distances and remote work approaches (Barrero et al., 2023; Choudhury et al., 2024), the diffusion of ideas, knowledge and technological change seem still be governed by the Law of Geography (Holl et al., 2024; Kalyani et al., 2025).<sup>1</sup>

In this context, international knowledge diffusion plays a crucial role in shaping global economic dynamics (Eaton and Kortum, 1996). For instance, the diffusion of major technologies has been regarded to be pivotal in the diffusion of the Industrial Revolution across countries (Comin and Mestieri, 2014), and the distribution of cross-country income per capita in the past two centuries (Comin and Mestieri, 2018). For instance, Berkes et al. (2022) estimate the causal effect of innovation induced by international spillovers (measured by patent-to-patent citations) on sectoral output per worker and TFP growth in a panel of country-

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<sup>1</sup> The Law Of Geography reads as “Everything is related to everything else, but near things are more related than distant things” (Tobler, 1970).

sectors from 2000 to 2014, as well as on aggregate income per capita since 1960, finding a strong relationship.

Developing economies, in particular, benefit from adopting and adapting knowledge generated in more advanced countries, thereby narrowing productivity gaps and accelerating convergence. As Nelson (2004) argues, however, successful catch-up is not about importing technology, but about building an innovation system that enables learning, adaptation, and indigenous capability formation. That is to say, the capacity to use, adapt, and eventually improve foreign technologies must be built domestically.

Next, international knowledge diffusion occurs through various channels: trade in goods, foreign direct investments (FDI), licensing agreements, migration of skilled labor, and global value chains (Fu and Soete, 2010). These mechanisms allow recipient countries to leverage frontier/innovative knowledge without incurring the full cost of invention. However, the absorption of foreign ideas depends critically on domestic factors such as human capital, institutional quality, national and local capabilities, research capacity (Abramovitz, 1986; Lee and Malerba, 2017; Nelson, 2004), and, broadly speaking, absorptive capacity (Cohen and Levinthal, 1990). Thus, knowledge diffusion is not automatic; it is mediated by absorptive capacity and policy frameworks. In turn, differences across fields are also critical in determining their diffusion pace and geographical scope.

Understanding the process of international technological knowledge diffusion is fundamental for policymakers aiming to foster innovation-led growth, reduce global inequality, and enhance productivity. As globalization continues to evolve, the pace and direction of knowledge flows will remain central to debates on economic development and global competitiveness.

Against this backdrop, this paper aims to review the main mechanisms of international technological knowledge diffusion, and what scholars have found about them. It also aims to suggest a number of ways to measure and map international diffusion, through the involvement of patent data. When doing so, it also aims to uncover whether the different proxies may measure different aspects of international diffusion, and how this diffusion may have changed over time. More particularly, the paper aims to answer questions such as:

- 1) Which countries are more involved in the diffusion of technological knowledge?
- 2) Are there big imbalances between sender and receiver countries of technological knowledge (i.e., net receivers – net senders)?
- 3) Are countries becoming more open or more closed in the way in which they source technological knowledge?
- 4) Are development and diffusion cycles of technological knowledge shortening over time and to the same extent for all fields and in all countries?
- 5) Are there differences in the geography of diffusion between scientific (measured by patents citing science) and technological (measured by patents citing patents) knowledge?

The remainder of the paper is organized as follows: Section 2 reviews the relevant literature on the mechanisms behind international technological knowledge diffusion. Section 3 suggests different methodological approaches to measure technological knowledge diffusion, with a focus on the ones used in this paper. Section 4 presents our results, using different proxies, while Section 5 concludes.

## **2. Mechanisms of international technology diffusion**

There is an abundant literature describing the channels through which technological knowledge diffuses (most recently surveyed by Keller, 2021). Both theoretically and empirically, scholars have devoted attention to better understand (i) the extent of knowledge diffusion (and its international dimension), and (ii) the ways in which this knowledge travels across borders. While a complete survey is beyond the scope of our analysis, we will briefly mention the most popular channels identified, and what the pioneering and most recent contributions have found about them. These mechanisms are trade, including the role of Global Value Chains (GVC), international capital investments (i.e., FDI), mobility of knowledgeable individuals, global scientific knowledge, and international markets for technologies.

### **Technological knowledge embodied in traded goods**

This section summarizes key insights on the relationship between international trade and international technology diffusion. Early contributions to the topic correspond to Grossman and Helpman (1995) as well as Coe et al. (1997). These authors established that domestic firms can learn from the foreign goods they import by reverse engineering the technological innovations embodied in these goods. They found that national growth and productivity is strongly influenced by R&D investments done in other countries with which the focal country has strong trade relationships.

A burgeoning literature emerged after them on the relationship between trade, diffusion, and innovation. For recent surveys, see Shu and Steinwender (2019) and Akgigit and Melitz (2022). See also Melitz and Redding (2021). These latter authors identify four mechanisms through which international trade affects endogenous innovation and growth: (i) market size; (ii) competition; (iii) comparative advantage; and (iv) knowledge spillovers. Concerning the latter, the authors review the theoretical models and state that international knowledge spillovers can affect innovation through various mechanisms, such as (i) serendipitously, and independently from the flow of goods (e.g. through research publications); (ii) promoted through flows of goods (as in the reverse-engineering of products); (iii) as a result of investments: in knowledge acquisition directly, or in imitation (as in models of the product lifecycle).

A recent contribution by Cai et al. (2022) provides a unified theoretical framework for quantifying the cross-country and cross-sector interactions among trade, innovation, and knowledge diffusion. Their analysis shows that a reduction in trade costs induces a reallocation of R&D and comparative advantage across sectors. Besides, recent empirical contributions demonstrate the quantitative

importance of international technology diffusion for the gains from trade and aggregate growth (see, for example, Buera and Oberfield, 2020; Cai et al., 2022; and Sampson, 2023). More recently, patent-to-patent citations has been used to relate diffusion, innovation and trade. Ayerst et al. (2023) investigate how technology spreads across borders through imported goods. Using patents, citations, trade, and input–output data, they track knowledge embodied in imports from the US. Their analysis shows that innovation is still heavily concentrated in advanced economies, but imports can transmit technology internationally. They find that when countries import inputs rich in knowledge, their patenting activity rises noticeably, while imports measured only by production value have a much smaller effect. The same pattern holds for diffusion outcomes: knowledge-intensive imports significantly boost links to US inventions, whereas production-weighted imports matter far less. In short, the study highlights trade in knowledge-embedded goods as a powerful driver of global technology diffusion.

Next, the trade literature has also evolved to studies analyzing countries branching into related products (Hausmann et al., 2024; Hidalgo et al., 2007; Hidalgo and Hausmann, 2009). As a matter of example, Bahar et al. (2014) confirm that knowledge diffusion decays with distance, and the probability that a product is added to a country's export basket is, on average, 65% larger if a neighboring country is a successful exporter of that same product. This literature states that countries develop new comparative advantages mainly in products that are related (in the product space sense) to what their neighbors already export, consistent with international knowledge diffusion that is geographically bounded and path-dependent. Bahar et al. (2014) add to this picture that countries learn what to produce from other countries, but in a (geographically) localized way. Related diversification is thus stronger among geographically close countries, when neighbors are more advanced, and weaker across unrelated activities. However, countries only diversify where they have sufficient capabilities, because knowledge diffusion expands opportunities, not guarantees outcomes

Beyond arm's-length trade in final goods, a large literature emphasizes global value chains (GVCs) as a key organizational form through which international trade shapes production and knowledge diffusion. GVCs fragment production across borders, with countries specializing in specific tasks that are coordinated through repeated trade in intermediate goods and services. As such, GVCs can be seen as an extension of trade in intermediates, where learning arises from sustained buyer–supplier relationships, quality requirements, and production coordination. This literature shows that participation in GVCs can facilitate learning-by-doing, process upgrading, and the diffusion of tacit production knowledge, particularly for firms and countries far from the technological frontier (Gereffi, 2019; Gereffi et al., 2005). However, while GVCs can act as powerful channels of international knowledge diffusion through trade, learning outcomes remain highly heterogeneous and conditional on domestic capabilities, firm strategies, and institutional environments (Humphrey and Schmitz, 2002; Morrison et al., 2008; Pietrobelli and Rabellotti, 2011). This perspective reinforces the view that trade expands technological opportunities, but does not guarantee upgrading.

## **Technologies embodied in capital and equipment investments**

Next, in the economics literature, FDI has long been recognized as a major conduit of international knowledge diffusion, too (Keller, 2010). Classic contributions emphasize how multinational enterprises (MNEs) bring advanced production techniques, organizational practices, and technological capabilities to host countries, creating potential “spillovers” for local firms through channels such as competition, labor mobility, and supplier linkages (Blomström and Kokko, 1998; Javorcik, 2004). Yet such spillovers are not automatic: they depend critically on domestic absorptive capacity—determined by R&D intensity, human capital, and institutional quality—which shapes whether foreign knowledge is effectively internalized (Cohen and Levinthal, 1990; Keller, 2010).

International business scholarship complements this view by analyzing the firm- and strategy-level determinants of knowledge transfer. Dunning’s eclectic paradigm, for instance, highlights that MNEs internationalize to exploit ownership advantages, often knowledge-based, in foreign markets (Dunning, 2001, 2000, 1998). Whether knowledge actually diffuses depends on the chosen entry mode (e.g., wholly owned subsidiaries vs. joint ventures), the MNE’s strategic intent (sharing vs. safeguarding), and the institutional embeddedness of affiliates in local networks. From this perspective, FDI is not a neutral transmission belt of technology but part of a co-evolutionary process where global and local actors engage in reciprocal learning.

Innovation system approaches extend the analysis further by embedding FDI within national and regional innovation frameworks. Here, FDI supports “knowledge upgrading” by linking domestic firms into global production and innovation networks, though outcomes depend on complementary institutions and policies such as education, R&D incentives, and intellectual property protection (Archibugi and Coco, 2004; Lundvall, 1992). In developing economies, foreign investment may accelerate industrial catch-up, while in advanced contexts it typically deepens specialization and fosters international research collaboration. Across these perspectives, FDI consistently emerges as both a driver of global knowledge diffusion and a mechanism by which domestic firms and institutions reposition themselves within the international knowledge economy.

Empirical evidence shows that affiliates of foreign MNEs often act as pipelines through which technological know-how flows across borders (Veugelers and Cassiman, 2004). Knowledge may diffuse intentionally, for example via licensing or R&D collaborations, or involuntarily through informal contacts and labor mobility (Oettl and Agrawal, 2008). However, MNEs may deliberately curb knowledge leakage by raising wages to reduce personnel turnover, or selecting entry modes that minimize spillovers. Eclectic theory suggests precisely that MNEs choose FDI over licensing to retain control over their proprietary

knowledge, implying that technology transfer to local firms may be more limited than often assumed (Dunning, 2000; Veugelers and Cassiman, 2004).

Recent work pushes the frontier further. Crescenzi et al. (2022), combining nearly four decades of patent data with socioeconomic information worldwide, show that foreign R&D activities can trigger the emergence of new regional innovation clusters. Fons-Rosen et al. (2017) likewise find that FDI generates positive productivity spillovers only when foreign and domestic firms share similar technological bases, with inventor mobility acting as a key transfer channel. Using matched datasets and instrumental-variable approaches, these studies highlight not only the heterogeneous effects of FDI but also the conditions under which it contributes most effectively to host-country innovation.

Taken together, this literature shows that while FDI is a well-established channel of international knowledge diffusion, its impacts are highly contingent. Knowledge flows may arise from both deliberate collaborations and unintended leakages, but whether they translate into local upgrading depends, again, on firm strategies, absorptive capacities, and the broader institutional and policy environment.

### **Technological knowledge diffusion embodied in moving people**

Research on migration and innovation highlights the pivotal role of skilled migrants, especially inventors and scientists, in shaping global knowledge diffusion. Historically, cross-border mobility has been tied to major technological shifts—from the spread of Huguenot craftsmen in early modern Europe (Hornung, 2014; Scoville, 1951) to the forced migration of Jewish scientists to the United States during the 1930s (Moser et al., 2014). These episodes demonstrate how the relocation of even small groups of highly skilled individuals could dramatically alter the global geography of knowledge. Today, the international circulation of STEM talent toward R&D-intensive economies such as the United States and Europe continues this tradition, with migrant scientists and inventors playing a disproportionate role in frontier science and technology, and cross-border collaboration (Kerr et al., 2016; Kerr, 2018).

Thus, among the mechanisms through which migration influences knowledge creation, diffusion has attracted particular attention. Migrants act as knowledge brokers: by building new ties in host countries and maintaining connections to their countries of origin, they bridge otherwise disconnected communities (Agrawal et al., 2011; Breschi et al., 2017; Kerr, 2008). This role is especially salient across international borders, which represent high barriers to knowledge circulation (Lissoni and Miguelez, 2024). Skilled migrants not only bring knowledge, but also are capable to direct the technological path of sending and receiving societies (Bahar et al., 2020; Di Iasio and Miguelez, 2022), especially when it comes to introducing technologies otherwise unreachable for regions and countries (Di Iasio and Miguelez, 2022; Diodato et al., 2022; Miguelez and Morrison, 2023) While permanent migration has been central, temporary mobility—such as international business travel—also contributes significantly (Coscia et al., 2020; Hovhannisyan and Keller, 2015; Vivarelli et al., 2025).

Among skilled migrants, migrant inventors stand out. They are systematically more global in orientation than their native peers: they rely more heavily on foreign prior art, receive more international citations (Bernstein et al., 2022; Lissoni and Miguelez, 2024), and connect host economies to global technological frontiers (Breschi et al., 2017). Diaspora networks and return migration reinforce these diffusion processes. Migrants who sustain ties to their home countries facilitate co-patenting (Ito et al., 2025; Kerr and Kerr, 2018; Miguelez, 2018), co-publications, and technology transfer, while mobile inventors contribute to new technological specializations in origin countries (Bahar et al., 2020; Di lasio and Miguelez, 2022). This perspective emphasizes “brain circulation” rather than “brain drain”: even when emigrants do not return, their networks reduce informational barriers, support trade and investment in knowledge-intensive sectors, and integrate national systems into global innovation flows (Fackler et al., 2020; Miguelez and Temgoua, 2020).

Building on this literature, Bahar et al. (2024) provide new empirical evidence on migrant inventors as conduits of international knowledge flows. Using detailed patent data from the USPTO, they trace inventor careers and show that cross-border mobility systematically reshapes the geography of inventive activity. That is, the authors find that the origin and rise of a country’s inventive activity in specific fields can be systematically traced back to geographically mobile inventors transferring knowledge from abroad. This pattern is much more pronounced when these inventors have previous experience patenting that same technology abroad before moving, suggesting that they function as a vector of diffusion of knowledge across borders. Crucially, the study also highlights the local absorption of foreign knowledge. The arrival of mobile inventors strengthens host ecosystems by embedding international expertise into domestic research practices: local collaborators are more likely to integrate foreign technological inputs, and regions with higher concentrations of mobile inventors exhibit greater international embeddedness in their knowledge bases. In this sense, mobile inventors do not merely transfer knowledge but also enhance the absorptive capacity of local innovation systems.

Taken together, these results seem to point that flexible visa regimes and student-to-work pathways are critical to attract and integrate skilled migrants (Cristelli and Lissoni, 2020; Kerr and Lincoln, 2010). Moser and San use the US Immigration Quota Acts of the 1920s as a natural experiment to identify the causal effect of immigration on science and invention. These quotas drastically reduced immigration from specific countries—especially those that were major sources of scientific and technical talent. Their key finding is stark: Immigration restrictions sharply reduce innovation by cutting off access to foreign scientific talent, showing that the international mobility of people is a crucial channel for knowledge diffusion and invention (Moser and San, 2020). Moving to more recent times, it has been found that restrictions on high-skilled immigration lead firms to reorganize the geography of innovation, shifting R&D and knowledge-intensive activities abroad rather than reducing their overall innovative effort (Glennon, 2024a, 2024b).

For origin countries, the challenge is to turn skilled emigration into an opportunity by leveraging diaspora ties, encouraging return migration, and investing in local absorptive capacity (Di lasio and Miguelez, 2022). At both ends, strengthening education, R&D infrastructure, and international collaboration is key to translating migration-driven mobility into sustained knowledge flows. Skilled migration is therefore not a zero-sum game but a cornerstone of global knowledge circulation, one that can be harnessed strategically for inclusive and mutually beneficial innovation.

### **Technologies based on global science**

It is well recognized that innovation is closely linked to basic science (Nelson, 1959). Scholars and policymakers alike frequently credit basic science with stimulating technological innovation and with economic growth (Sorenson and Fleming, 2004). Macroeconomic studies have linked GDP growth in the United States to higher scientific employment (Sveikauskas, 1981) as well as to increased private and public expenditures on research and development (Adams, 1990; Mansfield, 1995). Science-based technologies have gained importance in recent decades (Tijssen, 2002). In turn, several examples confirm the importance of technological applications resulting from fundamental scientific discoveries (Nelson and Winter, 1982; Rosenberg and Nelson, 1994).

Countries and regions constitute repositories of scientific research, and investments in science and education enhance the territories ability to develop novel technologies and innovations in new fields (Balland and Boschma, 2022; Catalán et al., 2022; Hausmann et al., 2024; Pugliese et al., 2019; Stojkoski et al., 2023). However, determining how, when, and where public funding and incentives should be allocated remains a challenge for policymakers.

Yet, uncovering science and technology links has been an area of research interest for many years now (Ahmadpoor and Jones, 2017; Arora et al., 2023; Lissoni et al., 2013; Maraut and Martínez, 2014; Marx and Fuegi, 2022, 2020; Stephan, 1996) and policymakers increasingly look for evidence in the academic community for the design and evaluation of their policies (OECD, 2023). The growing availability of databases with micro level data on links between scientific discoveries and technological innovation, and the increasing sophistication of data management methods to analyze them, has opened the path to new ways of looking at the subject, where digital competencies combined with strong economic and policy training are crucial to make relevant contributions (Motohashi et al., 2024). In parallel, science production is increasingly team-dominated (Jones, 2009; Wuchty et al., 2007), and team-based science is more international and produced in an increasing number of territories (WIPO, 2019).

However, extant literature has a limited understanding of the effect of science on the geographical diffusion of technologies – let alone its international dimension. An exception is Sorenson and Fleming's work (2004), which looks at the geographical visibility of inventions. They find that science-based inventions attract more citations from patents listing inventors who are located farther away in space than non-science-based inventions. Their explanation for this result is that the scientific information on which inventions rely travels farther in space than non-scientific information. More recently, Pezzoni et al. (2023) and Pezzoni et al. (2022) investigate how science affects the evolution over time and space of technological trajectories. Looking at the temporal dimension, the authors find that technologies with a high scientific content take longer to take off but have a higher impact in the long run. Looking at the spatial dimension, technologies with a higher scientific content travel longer distances and are more likely to generate new inventors' clusters than technologies with low scientific content, especially in their growth and maturity phases.

Recent evidence suggests that these global patterns are reinforced by profound changes in the organization and geography of scientific production. Over the past decades, science has become increasingly international, team-based, and integrated across countries, reducing the spatial frictions traditionally associated with the diffusion of frontier knowledge (Jones, 2009; Wagner et al., 2015; Wuchty et al., 2007). This transformation has coincided with the rapid rise of new scientific powerhouses, most notably China, which has moved from a peripheral to a central position in global scientific collaboration networks and leadership roles within research teams (Baker, 2023; Wu et al., 2025; Xie et al., 2014; Zhou and Leydesdorff, 2006). The emergence of new scientific centers expands the global pool of knowledge production and increases the likelihood that science-based technologies originate, diffuse, and recombine across a wider set of countries and regions.

An important channel linking global science to the international diffusion of technology is the mobility of scientists. A growing scientometric literature shows that contemporary scientific production is increasingly shaped by cross-border movements of researchers, including both long-term migration and more temporary forms of circulation. Using large-scale bibliometric data, Robinson-Garcia et al. (2019) document that a non-negligible share of scientists are internationally mobile and propose a distinction between migrants, who relocate permanently across countries, and travelers, who maintain affiliations in multiple locations. These different forms of mobility contribute to the integration of global scientific communities by facilitating repeated interaction, collaboration, and the transmission of tacit knowledge across borders. Importantly, mobile scientists—particularly migrants—tend to have higher scientific impact, suggesting that mobility amplifies the reach and influence of frontier scientific knowledge. Through these mechanisms, scientist mobility strengthens cross-country knowledge flows, helps connect emerging scientific centers to the global research frontier, and contributes to the spatial diffusion of science-based technologies.

## **Technology diffusion, markets for technology, and international patent protection**

Since the end of the XIXth century, when the Paris Convention was signed ensuring the recognition of priority rights across patent offices, international patent protection has gradually become one of the most important ways to reach foreign markets for novel technologies (Harhoff et al., 2003; Martinez, 2010; Martínez, 2011). The higher the expected market value of an invention, the larger the patent family would be and the more important the markets where protection would be sought (Putnam, 1996). International patent protection has also evolved over time, and has become widespread since the 1970s thanks to international treaties, such as WIPO's Patent Cooperation Treaty at the global level, and at the regional level to the founding agreements of the European Patent Office (EPO), the African Regional Intellectual Property Organization (ARIPO), the African Intellectual Property Organization (OAPI), the Eurasian Patent Organization (EAPO) and the Gulf Cooperation Council (GCC).

Following these developments, transnational patents (also known as non-resident patents, foreign patents or cross-border patents) are thought to play a vital role in protecting innovations abroad (Yang et al., 2021). The evolving technological revolution and internationalization of production triggered a shift from capital and tangible assets to intangible assets and technology (Archontakis and Varsakelis, 2017). Knowledge and technology are no longer limited to geographical restrictions. Therefore, companies have to exploit internationally dispersed knowledge assets to integrate resources and strengthen their competitiveness (Schmiele, 2012).

Patent protection in foreign markets also facilitates the emergence and development of international markets for technology, via licensing and transfer of rights to domestic entities. Patent trade improves the overall welfare and innovation, as it enhances innovation activity, knowledge diffusion and the emergence of specialized inventors, by stimulating the geographic spread of technology (de Rassenfosse et al., 2016; Drivas and Economidou, 2015; Lamoreaux and Sokoloff, 2001; Marco et al., 2017). However, even if markets for technology are a crucial mechanism of technology diffusion nationally and internationally (Arora et al., 2021; Ciaramella et al., 2017; De Marco et al., 2017; Galasso et al., 2013; Gambardella et al., 2014; Gäßler, 2016; Graham et al., 2018; Serrano, 2010), uncertainty tends to be more pronounced when technology trade takes place across national boundaries. Three levels of uncertainty that characterize technology deals have been found to greatly limit the geographical reach of technology trade, and are responsible for the dominant role of nearness in patent transactions: uncertainty about the property rights, about the value of the technology and about the patent trading process (Arora and Gambardella, 2010). Thus, international patent protection is a pre-requisite to even consider patent transactions and ways to alleviate them in foreign countries.

## Capabilities

A central insight from the literature on catching up and innovation is that access to external knowledge does not automatically translate into technological convergence. Classic contributions emphasize that economic backwardness creates opportunities for rapid growth only when countries possess sufficient “social capability” to absorb and exploit frontier technologies (Abramovitz, 1986). Subsequent work has formalized and measured this idea, showing that differences in technological, social, and institutional capabilities explain a substantial share of cross-country variation in income levels and growth performance, often more so than trade openness or capital accumulation alone (Fagerberg and Srholec, 2007). From this perspective, the concentration of scientific and technological diffusion in a small core of countries reflects not only unequal access to knowledge, but also persistent differences in national capabilities that condition whether knowledge inflows are transformed into sustained innovation and productivity growth.

A complementary strand of research on technological capabilities and industrial policy in developing economies further clarifies why some countries succeed in building such capabilities while others do not. Studies of East Asian industrialization stress that markets alone tend to underprovide learning and capability accumulation, given the uncertainty, risk, and externalities involved in technological upgrading (Lall, 2006). Successful latecomers such as South Korea—and more recently China—combined openness to global knowledge with selective and disciplined state intervention, using industrial policy to push firms into activities beyond their existing comparative advantage while conditioning support on performance and learning outcomes. More recent work highlights that catch-up is neither linear nor automatic, but occurs in cycles, often during windows of opportunity created by technological and market discontinuities, which only countries with adequate pre-existing capabilities and strategic responses are able to exploit (Lee and Malerba, 2017). Taken together, this literature suggests that the emergence of new players in global scientific and technological trajectories is fundamentally shaped by the slow and uneven accumulation of capabilities, rather than by globalization or knowledge diffusion alone.

Policies directed to improving transport infrastructure, both within and across countries, can catalyze knowledge diffusion too, both inside and outside countries (Agrawal et al., 2017; Bahar et al., 2023; Catalini et al., 2020; Tsiachtsiras et al., 2025).

The local and national absorptive capacity, as well as human capital, play a role, too (Cohen and Levinthal, 1990, 1989; Miguelez and Moreno, 2015). Local and national capabilities play a role in the capacity of transforming knowledge inflows into productivity growth and well-being, which has been well investigated by the complexity literature (Hausmann et al., 2024, 2014). In shaping the speed and direction of technology adoption and emergence, the existing capabilities of countries matter, and a burgeoning branch of studies have started to show this consistently (Bahar et al., 2014; Balland et al., 2019; Hausmann et al., 2014; Hidalgo et al., 2007; Hidalgo and Hausmann, 2009).

Taken together, the mechanisms discussed above should not be viewed as independent channels, but as interconnected dimensions of a multiplex system through which international technology diffusion unfolds. High-skilled migration, for instance, often operates through multinational firms, as engineers and scientists move across borders within MNE networks, linking FDI, GVC participation, and labor mobility into a single learning process. Similarly, the global diffusion of scientific knowledge—captured by international citations in patents and publications—is partly driven by the circulation and return migration of scientists, who embed frontier knowledge into domestic research and innovation systems while maintaining transnational collaboration ties (Robinson-Garcia et al., 2019; Saxenian, 2006). Patterns of FDI and offshoring are likewise shaped by migrant networks and “new Argonauts,” which facilitate cross-border knowledge transfer, reduce informational frictions, and influence firms’ location choices for R&D and innovation activities (Kerr, 2008; Bahar et al., 2020; Glennon, 2024). These complementarities suggest that international technology diffusion emerges from the joint operation of multiple, mutually reinforcing mechanisms, whose effectiveness ultimately depends on domestic capabilities, institutional environments, and policy frameworks that shape how trade, investment, mobility, and science interact.

### **3. How can we measure international technology diffusion?**

Paul Krugman’s famous assertion in his 1991 book *Geography and Trade* that knowledge spillovers are an agglomeration force that leave “no paper trail by which they can be measured and tracked” (pp. 53) served as a direct challenge to economists, spurring a decades-long quest to find empirical proxies for this invisible phenomenon of knowledge spillovers and, more generally, knowledge flows.

In his 1989 work, Adam B. Jaffe proposed a “Knowledge Production Function” (KPF) that modeled the generation of private-sector patents as a function of both private and public (university) R&D spending. By using the geographic location of patents and R&D, he found a significant positive relationship, suggesting that local university research spilled over to stimulate commercial innovation and patenting in nearby firms. His KPF approach has been widely extended to understand whether knowledge travels along the space, and what is its geographical scope (Bottazzi and Peri, 2003). The subfield of spatial econometrics has been particularly productive, and has exploited these advanced techniques (Anselin, 1988; Anselin et al., 1997) to measure knowledge diffusion across the space (Autant-Bernard, 2012; Autant-Bernard et al., 2013; Suriñach et al., 2009).

Trade and innovation geography scholars have also addressed knowledge diffusion from a spatial, aggregate perspective. The trade literature have consistently shown that countries diversify into exports of which they have related expertise (Hidalgo et al., 2007). Yet, this product diversification is also related to the exports of geographically neighboring countries, suggesting the existence of

knowledge diffusion between nearby countries (Bahar et al., 2014). This idea has been confirmed using patents and technologies, in a number of papers (Balland et al., 2019; Petralia et al., 2017).

However, the primary response to Krugman's statement has been to use patent data, and specifically patent citations, as that paper trail, operationalizing the idea that a citation from a new invention to a prior patent represents a flow of knowledge from the old to the new. The seminal methodology developed by Jaffe et al. (1993) (JTH, for short) involved constructing a matched case-control sample, comparing the geographic distance between citing and cited patents to the distance between a control set of technologically similar but non-citing patents, thereby testing if citations are geographically localized beyond what technology alone would predict.<sup>2</sup> This approach, along with variations that control for inventor mobility, social networks, and the origin of citations (applicant vs. examiner), represents the dominant strategy for making the invisible visible, albeit amidst ongoing debates about the strategic noise and institutional constraints embedded within the patent system itself.

The use of patent citation data come with their own cost, too. For instance, Thompson and Fox-Kean (2005) revealed that the technological classes used in the JTH matching procedure were too coarse, potentially conflating technological proximity with geographic proximity and invalidating their findings of localization. This sparked a lasting debate on how to properly control for technological similarity when using patent data to measure knowledge flows. The critique of JTH led to alternative approaches, most notably from Thompson (2006), who argued that citations added by applicants (inventors/attorneys) are more likely to represent genuine knowledge flows than those added by patent examiners. This initiated a literature focused on disentangling citation origins. However, this applicant/examiner distinction is itself problematic: applicants often act strategically, sometimes withholding citations, while examiners outside the U.S. operate under different rules (Lampe, 2012). Consequently, examiner citations do not necessarily "weaken the measurement of knowledge flows." Thus, empirical evidence is mixed: while some studies find applicant citations show stronger geographic localization, others find examiner citations from certain

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<sup>2</sup> Even before patent citation data, the use of patent data in economic research, championed by Zvi Griliches (Griliches, 1990), offers significant advantages as it provides a rich, quantifiable, and publicly available record of inventive output. Patents are meticulously classified by technology, include detailed information on inventors and applicants, and are filed over a long time horizon, allowing researchers to track the geography, timing, and nature of innovation across the globe. This makes patents an invaluable, albeit imperfect, proxy for measuring innovation and investigating the drivers of technological change, filling a critical need for data on an otherwise intangible process. The disadvantages of patent data are substantial and stem from two core issues. First, the propensity to patent varies enormously across industries and firms, with many valuable innovations kept as trade secrets, leading to selection bias in what gets recorded. Second, and more critically, the economic value of patents is extremely right-skewed; a small fraction of patents hold immense value while the majority are worthless, making simple patent counts a noisy and often misleading measure of innovative output. More recently, scholars have experimented with other intellectual property indicators to depict the geography of innovation and knowledge diffusion, opening up promising avenues of research (Castaldi, 2020; Castaldi and Drivas, 2023; Castaldi, Carolina et al., 2019).

offices (like the EPO) can be good proxies of knowledge diffusion, too. The emerging consensus is that citations are a flawed and institutionally mediated measure, and their interpretation requires careful consideration of the patent office and the strategic incentives of the actors involved. Yet, despite being an imperfect measure of knowledge spillovers, patent citations provide a useful quantifiable benchmark that can be easily measured and used in our empirical analysis, and they continue being the workhorse on the empirical literature on knowledge diffusion, both within and cross countries (Belenzon and Schankerman, 2013; Duguet and MacGarvie, 2005; MacGarvie, 2005; Murata et al., 2013; Peri, 2005; Singh and Marx, 2013).

The first subsection of our empirical contribution (Section 4) uses cross-border patent citations to depict international technological knowledge diffusion. Data is taken from the EPO PATSTAT database (Autumn 2024 version). Following WIPO (2019), the unit of analysis is the first filing for a set of patent documents filed in one or more countries and claiming the same invention. Each set containing one first and, potentially, several subsequent filings is defined as a patent family (Martinez, 2010). Patent families can be split into those oriented internationally and those oriented only domestically. Internationally-oriented patent families refer to applicants seeking patent protection in at least two jurisdictions. These include patent families containing only patent documents filed at the EPO or through the PCT. Conversely, domestic patent families refer only to filings in a home country, for instance, a Japan-based applicant filing only at the Japan Patent Office.

For the current analysis, only internationally-oriented families are used, with priority year between 1981 to 2020. We collect all patent citations across the applications contained in the citing and cited families, aggregate them at the family-pair level and collect the country codes of the inventors in both the citing and the cited family, to compute a number of indicators (see section 4).

Instead of only using countries, we make an arbitrary combination of countries and areas (entailing more than one country each), which we label as *territories*. We consider the territory classification reported in Appendix A.

In the second subsection of Section 4, we depict the diffusion of technological knowledge using the concept of *reuse*, and track technological trajectories over time (Rogers et al., 2014; Rogers, 1998). Technological trajectories can be mapped using combinations of IPC codes (Pezzoni et al., 2023, 2022), adopting the idea that the generation of ideas and subsequent economic growth stems from an evolutionary process of recombination (Weitzman, 1998). Following the assumption that novel technologies emerge when pre-existing components combine for the first time (Arthur, 2009; Fleming, 2001; Verhoeven et al., 2016), we rely on the methodology developed by Pezzoni et al. (2022, 2023) using patent data and, building on the patent classification codes used at the EPO (IPC codes) as proxies for the pre-existing components at the base of a technology, mark the origin of a technological trajectory as the appearance of the first patent listing a novel combination of two EPO IPC codes. Having identified the origin of each trajectory, we follow its evolution by linking together all the patents reusing the

same combination of IPC codes introduced by the patent at the origin of such trajectory.

As an example, the transgenic mammal technology, i.e., the technology at the base of the genetically modified mice used in labs to develop treatments for diseases such as cancer or Alzheimer, originated in 1985 when the 'onco-mouse' was patented at Harvard listing for the first time the IPC codes corresponding to the technological classes "gene isolation" and "injection of material into animals". Subsequently, multiple patents reusing the same combination of IPC codes were filed. For instance, the 'diabetic mouse' was patented in 1996 at Seoul National University. All those subsequent inventions classified under the same combination of IPC codes are part of the same technological trajectory.

For our analysis, we retrieve all EPO applications and, using the information about the year of patent applications and the location of the inventors, together with IPC combinations, we follow the evolution over time and space of each trajectory.

In the third subsection of Section 4, we study patent citations to scientific articles, a data source that has been largely used to track scientific contributions to technology production (Ahmadpoor and Jones, 2017; Arora et al., 2018; Marx and Fuegi, 2022, 2020).

Finally, we conclude our empirical contribution in the fourth subsection of Section 4 by looking at the composition of international patent families, using priority filings and international extensions as an additional indicator of the direction of international technological knowledge diffusion over time. Indeed, patent families can help trace technological knowledge diffusion flows, given the territorial character of patent protection, by connecting the priority patent offices (where an invention is first protected worldwide) and the subsequent patent offices where international extensions are filed. Patent families provide information on those connections by pooling together all the patent applications with the same priority applications, based on the priority links declared by the patent applicants in their applications (Martinez, 2010, 2011). There are mainly two reasons behind the use of patent families as an indicator of technological knowledge flows. First, innovators extend patent protection for their most valuable inventions (Putnam, 1996), given the higher cost involved compared to protecting only in their home countries (which is generally also the country of the priority office). Second, the countries chosen for the international extension as destination patent offices would be those with jurisdiction in the territories where the applicant intends to enforce patent protection. The latter can be done in different ways and would entail some form of exploitation of the invention in the destination territory raising the need to protect the invention, via international trade and/or FDI or licensing to local producers, and the diffusion/spillover of the underlying technological knowledge in the country to some extent. This protection may also be motivated by the presence of competitors capable of reproducing the technology in that jurisdiction, even if those competitors are not primarily targeting that specific market.

To carry out this last part of our analysis, we rely on simple (docdb) patent families having priority years in 1985-2022, as reported in PATSTAT Autumn 2024, and focus our analysis on combinations of priority and destination patent offices of the family members that are direct patent filings and PCT national/regional phase entries (excluding PCT filings at the international phase). We do this to ensure that applicants aim to seek protection in the jurisdiction of destination and have filed an application at the relevant patent office (national or regional). As in the previous analyses, we group together patent offices into world territories, but given that now we deal with patent offices and not countries of inventors as before, we consider Europe as a single region, pooling together EPO and national offices of Western and Eastern Europe countries, and we do not report individual countries within Europe in the list of origin or destination territories.

#### 4. The changing geography and pace of international technology diffusion

##### International technological knowledge diffusion as measured by patent citations

Using the methods and data sources described in section 3, we describe here the worldwide cross-country patent citations, for different time windows. **Table 1** lists the sender and receiver countries/territories, along with the corresponding cross-country number of citations, for 4 different decades. As can be seen, overall the number of international citations (and therefore international technology flows) have been increasing steadily. The United States is among the main sender of technological knowledge abroad throughout the 4 decades. It is also, however, one of the most important receivers of knowledge. The remaining top-10 corridors across territories/countries include the usual suspects, with China showing up in the top-10 countries of technological knowledge receivers only in the third decade (2001-2010), and becomes a sender also in the last decade.

**Table 1. The top-10 bilateral corridors of patent citation flows.**

1981-1990			1991-2000		
Origin	Destination	Knowledge flows	Origin	Destination	Knowledge flows
United States	Japan	100,528	Western Europe	United States	547,410
United States	Western Europe	94,289	United States	Western Europe	546,767
Japan	United States	88,419	Japan	United States	543,323
Western Europe	United States	83,494	United States	Japan	399,324
Japan	Western Europe	52,596	United States	Germany	260,743
Western Europe	Germany	51,253	Germany	United States	248,682
Germany	Western Europe	50,873	Japan	Western Europe	225,522
United States	Germany	50,276	Western Europe	Germany	209,068
Western Europe	Japan	49,889	Germany	Western Europe	189,021
Germany	United States	44,162	Japan	Germany	166,722
2001-2010			2011-2020		
Origin	Destination	Knowledge flows	Origin	Destination	Knowledge flows
United States	Western Europe	1,889,381	Western Europe	United States	2,823,023
Western Europe	United States	1,877,261	United States	Western Europe	2,568,914
Japan	United States	1,472,366	Japan	United States	1,903,898
United States	Japan	989,865	United States	China	1,400,088
United States	Germany	881,125	Germany	United States	1,205,840
Germany	United States	811,073	United States	Japan	1,122,282
Japan	Western Europe	631,431	United States	Germany	1,067,686
Western Europe	Germany	604,257	China	United States	918,118

Figure 1 shows a number of heatmaps (3 decades, 1991-2020) with the bilateral flows across country/territory pairs. Each cell [i,j] counts the number of citations made by country/territory j to country/territory i (that is, the flows of technologies from i to j), divided by the total number of international patents in country/territory i that have been cited at least once (set of heatmaps 1.1). Note that when a patent from country i is cited by country j (including i among j's) for the first time, we do not count the following citations to that same cited patent in that pair of territories (we count the flow of knowledge only once). As can be seen, in all 1.1's figures, the main diagonal is the darkest one, meaning that in all territories, their technological knowledge is diffused there. This is particularly the case for big, technologically traditional countries, such as the United States, Germany, Western Europe, Japan, etc. Second, the column corresponding to the United States (and, to a lesser extent, Western Europe) is also darkish, which indicates that all territories send a large proportion of their produced knowledge to these territories. That is, the United States largely benefits from the technological knowledge produced around the world. Finally, it is interesting to see how some territories have become heavier users of their own knowledge, as the values of the main diagonal for these specific cases have been increasing over decades. This is the case of China, Republic of Korea and, to a lesser extent, India.

Figure 1.2 complements the analysis by dividing the knowledge flows over the knowledge produced in the destination country/territory j. Reading by columns, one can see from where all the territories source their ideas. Again, the main diagonal is always the darkest area. However, the United States line is also dark, with percentages which are even darker than the main diagonal for main territories, witnessing the fact that the US is the bigger provider of global technological ideas, too.

### Figure 1. Citation flows of technologies across countries/territories

#### Figure 1.1.a. Where is knowledge being used? 1991-2000

		Destination territories													
		Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Origin territories	Africa	26.7	5.2	7.6	33.3	4.2	24.3	4.6	11.8	11.5	6.7	2.4	67.6	5.9	55.9
	CEE	1.7	26.7	5.0	36.4	2.5	26.5	2.3	8.5	6.5	5.9	1.7	55.7	5.5	48.9
	China	1.5	3.5	28.4	23.8	4.9	41.5	2.8	10.0	5.6	14.9	4.7	66.2	5.5	41.5
	Germany	1.0	3.0	3.3	70.2	1.3	33.1	1.9	6.5	4.3	5.0	1.3	53.3	2.9	55.0
	India	2.5	4.9	17.2	29.7	26.9	40.8	4.6	13.8	6.5	14.8	4.5	85.4	9.1	48.8
	Japan	0.7	2.4	5.9	30.8	2.0	85.0	1.4	6.7	3.7	15.8	2.1	60.6	3.5	40.3
	LAC	2.9	3.8	6.1	33.2	3.8	28.1	22.1	11.8	7.9	8.5	2.4	68.8	6.1	57.7
	Northern America	1.8	4.2	6.6	31.5	3.0	33.7	3.5	42.1	9.2	8.6	2.3	78.9	6.4	54.0
	Oceania	2.6	3.6	4.8	30.8	1.6	24.1	3.1	13.5	39.8	5.3	2.0	61.8	5.4	53.8
	Rep. Korea	0.6	2.1	9.9	20.4	3.0	59.0	1.5	5.6	2.8	47.9	3.4	51.3	3.3	32.3
	SCSE Asia	1.3	4.2	13.7	28.0	6.5	44.6	2.9	9.6	7.0	15.4	20.1	69.5	6.1	48.9
	United States	1.6	4.4	8.1	35.7	4.1	44.5	3.6	15.4	7.9	11.3	3.3	90.7	7.7	55.5
	Western Asia	1.8	5.2	6.3	32.1	3.6	35.4	2.9	14.0	8.9	8.8	3.0	74.8	42.0	53.6
	Western Europe	1.4	3.7	4.6	41.2	2.1	31.9	2.6	9.6	6.6	6.6	1.8	60.4	4.4	72.3

**Figure 1.1.b. Where is knowledge being used? 2001-2010**

Origin territories	Destination territories														
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe	
Africa	26.5	12.0	26.4	37.4	16.2	28.9	9.0	22.2	14.2	18.4	9.6	68.4	11.4	64.4	
CEE	3.3	37.1	26.0	38.6	14.6	31.5	6.1	17.4	7.7	19.8	7.2	61.6	10.4	57.0	
China	2.1	6.6	59.7	21.6	11.9	36.8	3.7	13.5	4.7	28.0	7.7	55.4	6.2	36.8	
Germany	1.9	8.3	17.4	76.4	7.4	33.8	4.7	12.2	5.9	12.8	4.6	55.7	6.2	60.9	
India	5.7	15.3	40.8	32.8	46.1	39.2	7.8	25.1	8.3	30.0	12.5	76.8	15.1	57.3	
Japan	1.5	6.3	29.1	32.8	8.5	83.9	3.1	12.0	4.3	32.4	5.7	56.5	5.9	43.0	
LAC	4.3	11.0	25.2	37.6	13.9	29.2	29.6	20.5	10.7	16.7	8.0	71.6	11.5	60.7	
Northern America	4.2	11.6	32.3	39.8	16.2	37.0	8.4	51.4	12.5	22.6	8.8	81.4	12.8	63.4	
Oceania	4.3	9.2	23.3	37.5	10.6	29.3	7.5	23.0	41.5	15.2	7.7	72.0	10.5	64.8	
Rep. Korea	1.7	6.2	35.6	21.2	10.3	48.3	2.9	11.7	3.4	67.8	6.6	51.4	6.0	35.2	
SCSE Asia	3.7	9.8	39.7	34.3	17.4	43.5	6.4	20.0	8.4	30.5	30.7	69.9	10.2	54.3	
United States	4.3	13.0	35.7	45.2	19.3	43.4	9.4	29.5	13.1	25.0	10.5	89.1	15.1	66.6	
Western Asia	3.7	12.0	28.8	37.0	16.3	33.6	7.0	22.6	10.9	21.5	8.3	75.3	44.6	60.1	
Western Europe	3.2	9.8	23.8	47.4	11.5	33.1	6.6	18.0	9.2	16.9	6.7	64.9	9.1	77.2	

**Figure 1.1.c. Where is knowledge being used? 2011-2020**

Origin territories	Destination territories														
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe	
Africa	24.5	16.7	47.8	40.0	21.8	35.9	11.1	22.4	15.7	29.3	13.9	73.0	20.0	66.1	
CEE	3.0	39.9	43.6	39.5	16.4	33.7	6.9	16.4	7.0	26.0	8.9	60.1	14.1	56.6	
China	1.3	5.2	84.7	16.8	9.9	28.2	2.4	9.1	3.0	26.6	6.7	43.4	5.8	29.3	
Germany	1.9	13.2	38.0	78.8	11.5	39.5	5.6	13.0	5.7	22.1	6.4	59.4	9.6	64.1	
India	4.9	16.1	58.1	35.4	47.9	40.2	8.2	22.1	8.2	37.5	15.4	77.6	18.9	58.0	
Japan	1.3	6.9	51.2	31.0	9.7	91.4	3.1	9.8	3.4	40.0	6.9	51.9	7.0	40.0	
LAC	4.2	14.4	41.9	38.6	19.2	33.8	33.6	19.9	10.7	24.3	11.3	69.8	16.8	60.4	
Northern America	4.4	17.7	59.9	45.2	24.7	44.8	11.0	54.3	14.5	35.9	13.7	85.9	21.3	68.6	
Oceania	5.1	14.7	48.6	41.8	17.2	37.5	11.4	26.6	42.9	25.4	12.9	79.5	17.9	68.9	
Rep. Korea	1.5	6.8	60.0	22.3	12.1	46.9	2.9	10.5	3.2	78.9	7.9	52.7	7.6	35.3	
SCSE Asia	3.5	12.0	59.9	34.8	21.7	43.5	6.8	17.9	8.0	36.4	34.1	72.6	15.3	55.4	
United States	4.6	17.7	63.8	48.3	28.2	49.4	11.3	30.4	13.5	38.3	15.4	91.3	22.8	69.7	
Western Asia	3.6	15.0	50.4	37.3	20.4	36.8	8.2	21.8	10.0	30.9	11.3	74.5	52.6	60.1	
Western Europe	3.0	14.0	45.9	48.4	16.1	38.1	7.8	18.4	9.0	25.0	9.0	68.9	14.2	79.4	

**Figure 1.2.a. What are the sources of knowledge? 1991-2000**

Origin territories	Destination territories														
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe	
Africa	3.7	0.3	0.2	0.2	0.2	0.1	0.4	0.2	0.4	0.1	0.2	0.2	0.2	0.2	
CEE	0.9	4.6	0.6	0.7	0.5	0.4	0.6	0.5	0.7	0.4	0.4	0.6	0.7	0.6	
China	1.0	0.8	3.5	0.5	1.2	0.7	0.9	0.8	0.8	1.1	1.6	0.7	0.9	0.6	
Germany	10.8	12.1	8.3	24.6	7.7	10.8	10.6	9.1	10.1	7.2	7.9	12.3	8.1	15.0	
India	0.5	0.3	0.5	0.2	2.0	0.2	0.4	0.3	0.2	0.3	0.4	0.2	0.4	0.2	
Japan	12.9	17.0	24.2	19.7	19.6	37.8	13.6	16.3	15.1	34.7	21.7	24.1	17.5	19.5	
LAC	0.6	0.3	0.3	0.2	0.4	0.2	2.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3	
Northern America	2.8	2.2	2.0	1.5	1.9	1.4	2.6	6.9	2.8	1.5	1.9	1.9	2.4	1.8	
Oceania	2.1	1.0	0.8	0.8	0.6	0.6	1.2	1.2	5.5	0.5	0.9	0.9	1.0	1.0	
Rep. Korea	0.9	1.1	2.8	1.0	1.9	2.2	1.1	1.0	0.9	6.8	2.7	1.4	1.2	1.2	
SCSE Asia	0.2	0.3	0.4	0.1	0.5	0.2	0.3	0.2	0.3	0.3	1.8	0.2	0.3	0.2	
United States	38.4	36.3	38.3	26.7	45.4	28.8	42.8	42.2	38.3	32.1	41.9	36.2	43.7	29.5	
Western Asia	0.9	0.9	0.7	0.5	0.8	0.5	0.7	0.8	0.9	0.5	0.8	0.6	4.3	0.6	
Western Europe	24.4	22.8	17.4	23.2	17.3	16.1	22.5	20.3	23.7	14.2	17.5	20.4	18.8	29.3	

**Figure 1.2.b. What are the sources of knowledge? 2001-2010**

Origin territories	Destination territories													
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Africa	2.3	0.3	0.2	0.2	0.3	0.2	0.4	0.3	0.4	0.2	0.3	0.2	0.3	0.3
CEE	1.0	3.6	0.8	0.8	1.1	0.6	1.0	0.8	0.9	0.7	0.9	0.8	1.0	0.9
China	3.2	3.0	7.6	2.1	3.9	3.2	2.7	3.0	2.4	4.6	4.4	3.1	2.8	2.5
Germany	7.9	10.3	7.6	20.8	7.1	8.9	9.2	7.7	8.4	6.3	7.5	10.6	7.7	12.9
India	1.9	1.6	1.2	0.7	3.4	0.7	1.3	1.2	1.0	1.1	1.6	0.9	1.5	0.8
Japan	11.8	15.6	22.6	18.1	15.9	37.4	11.9	14.9	11.9	29.7	17.9	21.1	14.5	18.0
LAC	0.7	0.5	0.4	0.4	0.5	0.3	2.2	0.5	0.6	0.3	0.5	0.4	0.5	0.5
Northern America	3.4	2.8	2.5	2.1	2.9	1.8	3.3	6.1	3.4	2.1	2.7	2.6	3.1	2.5
Oceania	1.6	1.0	0.9	1.0	0.9	0.7	1.4	1.3	5.2	0.7	1.1	1.1	1.2	1.2
Rep. Korea	3.1	3.5	5.7	2.6	4.4	5.1	2.6	3.2	2.2	12.8	4.7	3.8	3.3	3.2
SCSE Asia	0.8	0.6	0.8	0.5	0.8	0.5	0.6	0.6	0.6	0.7	2.4	0.5	0.6	0.5
United States	40.2	36.5	33.2	28.9	40.6	26.3	42.0	41.6	41.6	27.3	38.0	35.2	41.5	31.0
Western Asia	1.4	1.3	1.0	0.9	1.3	0.7	1.3	1.2	1.4	0.9	1.2	1.1	4.5	1.0
Western Europe	20.6	19.1	15.6	20.8	16.9	13.6	20.1	17.5	20.1	12.7	16.7	18.4	17.5	24.7

**Figure 1.2.c. What are the sources of knowledge? 2011-2020**

Origin countries	Destination territories													
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Africa	2.2	0.3	0.2	0.2	0.3	0.1	0.4	0.3	0.5	0.2	0.3	0.3	0.3	0.3
CEE	1.4	4.2	0.9	1.1	1.2	0.7	1.3	1.1	1.1	0.9	1.1	1.0	1.3	1.2
China	6.2	5.5	18.4	4.7	7.6	6.1	4.6	6.2	4.8	9.1	8.8	7.2	5.4	5.8
Germany	7.4	11.3	6.7	21.3	7.0	7.5	9.0	7.4	7.5	6.1	6.6	9.1	7.4	11.8
India	2.7	2.0	1.5	1.2	4.4	1.1	1.9	1.8	1.6	1.5	2.3	1.6	2.1	1.4
Japan	10.8	12.5	19.9	16.3	12.6	41.1	10.4	11.7	9.6	24.6	15.4	16.8	11.3	15.2
LAC	0.8	0.7	0.4	0.5	0.6	0.3	2.9	0.6	0.8	0.4	0.6	0.6	0.7	0.6
Northern America	3.3	3.0	2.2	2.2	3.0	1.7	3.4	6.6	3.8	2.0	2.8	2.8	3.2	2.5
Oceania	1.8	1.1	0.8	0.9	1.0	0.6	1.6	1.4	5.7	0.6	1.2	1.1	1.3	1.2
Rep. Korea	4.6	4.5	8.6	4.0	5.8	6.8	3.6	4.6	3.3	18.3	6.5	5.7	4.5	4.6
SCSE Asia	1.1	0.8	0.9	0.7	1.1	0.6	0.9	0.8	0.8	0.8	2.9	0.8	0.9	0.8
United States	37.9	33.3	25.4	26.4	38.0	20.9	38.9	38.8	39.5	23.4	34.8	34.3	38.8	29.1
Western Asia	1.7	1.6	1.1	1.1	1.6	0.9	1.6	1.6	1.7	1.1	1.5	1.4	5.5	1.4
Western Europe	18.1	19.2	13.1	19.5	15.8	11.4	19.7	17.0	19.3	11.1	15.0	17.2	17.4	24.3

Yet, looking at the dominant role of certain countries or territories and its evolution over time is exciting, but one must account for their potential as generators of technological knowledge, too.

Next, Table 2 shows the most frequent IPC codes (4-digit level) in knowledge diffusion across country/territory pairs. Across the three decades examined, a relatively small set of IPC classes accounts for the bulk of cross-regional patent citations. The most recurrent are pharmaceuticals and biotechnology codes such as A61K (medical and chemical preparations), A61P (therapeutic activity), C12N (biotechnology, microorganisms and enzymes), and chemical classes like C07D and C07K (heterocycles, peptides and proteins). These dominate citation exchanges between most regions, from Africa and Latin America to Western Europe and North America. Alongside them, a consistent second cluster emerges in information and communication technologies: H01L (semiconductors), H04N/L/W (imaging, digital communications, and wireless networks), and G06F (digital data processing). Medical devices (A61B, A61M) and some environmental and materials technologies (B01D, separation processes; C04B, cements and mortars; C02F, water treatment) appear more selectively, often linked to Oceania, Western Asia, or Africa.

The temporal evolution reveals a marked shift. In the 1990s, cross-regional citations were highly fragmented, reflecting a multipolar technology base that included ICT (e.g. speech processing G10L, telecommunications H04 codes), basic chemistry, polymers (C08), and early biotechnology (C12). In the 2000s, the picture consolidated around life sciences: pharmaceuticals and biotech classes, especially A61K, became ubiquitous in exchanges between nearly all territories, while ICT activity concentrated in East Asia, notably Japan, Republic of Korea, and Southeast Asia, through H01L and H04 codes. By the 2010s, biotechnology and pharmaceuticals remained dominant worldwide, but ICT re-emerged in a more diversified form, with G06F (computing) and H04N/L/W (digital communications) frequently cited, especially in flows involving China, Republic of Korea, and North America. In parallel, environmental and materials codes such as B01D, C02F, and C04B began to surface, often linked to citations involving Africa or Western Asia. The overall trajectory thus suggests a transition from a fragmented landscape in the 1990s, to a strong life-science hegemony in the 2000s, and to a more balanced configuration in the 2010s where biotechnology, ICT, and emerging environmental technologies all play visible roles across regions.

**Table 2. Most prevalent technology diffused (IPC4)**

**Table 2.a. 1991-2000**

	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Africa	A61K	A61K	A61K	A61K	A61K	H01L	A61K	A61K	A61K	H01L	H01L	A61K	A61K	A61K
CEE	A61K	A61K	A61K	A61K	A61K	A61K	A61K	A61K	A61K	G02F	H01L	A61K	A61K	A61K
China	A61K	A61K	H01L	H01L	H01L	H01L	A61K	A61K	A61K	H01L	H01L	A61K	A61K	A61K
Germany	A61K	A61K	A61K		A61K	H01L	C07D	A61K	A61K	H01L	H01L	A61K	A61K	A61K
India	A61K	A61K	H01L	A61K		H01L	A61K	A61K	A61K	H01L	H01L	A61K	A61K	A61K
Japan	H01L	H01L	H01L	H01L	H01L		A61K	G06F	B41J	H01L	H01L	H01L	H04N	H01L
LAC	A61K	A61K	A61K	A61K	A61K	A61K	A61K	A61K	A61K	H01L	A61K	A61K	A61K	A61K
Northern America	A61K	A61K	A61K	A61K	A61K	H04L	A61K		A61K	H04L	A61K	A61K	H04L	A61K
Oceania	A61K	A61K	A61K	A61K	A61K	A61K	A61K	A61K	A61M	H04L	C12N	A61K	A61K	A61K
Rep. Korea	H01L	A61K	H01L	H01L	H01L	H01L	A61K	A61K	G06F		H01L	H01L	H04B	H04N
SCSE Asia	A61K	H01L	H01L	H01L	H01L	H01L	A61K	A61K	A61K	H01L	H01L	H01L	H04L	A61K
United States	A61K	A61K	H01L	A61K	A61K	G06F	A61K	A61K	A61K	H01L	H01L	A61K	A61B	A61K
Western Asia	C07C	A61K	H04B	A61K	A61K	G06F	A61K	A61K	A61K	H04L	H04L	A61K	A61K	A61K
Western Europe	A61K	A61K	A61K	A61K	A61K	A61K	A61K	A61K	A61K	H04L	A61K	A61K	A61K	A61K

NOTE: Each cell[i,j] reports the most frequent IPC class among cross country citations between territories *i* and *j*

**Table 2.b. 2001-2010**

	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Africa	A61K	A61K	H04L	A61K	H04L	H04L	A61K	A61K	A61K	H04L	H04L	A61K	H04L	A61K
CEE	A61K	A61K	A61K	A61K	A61K	H01L	A61K	A61K	A61K	H04L	A61K	A61K	A61K	A61K
China	A61K	A61K	H01L	A61K	H04L	H01L	A61K	H04L	A61K	H01L	H01L	H01L	H04L	A61K
Germany	A61K	A61K	A61K		A61K	H01L	A61K	A61K	A61K	H01L	H01L	A61K	A61K	A61K
India	H04L	A61K	H04L	A61K		H01L	A61K	H04L	A61K	H04L	H04L	H04L	H04L	A61K
Japan	H01L	H01L	H01L	H01L	H01L		A61K	G06F	G06F	H01L	H01L	H01L	G06F	H01L
LAC	A61K	A61K	A61K	A61K	A61K	A61K	A61K	A61K	A61K	H04L	A61K	A61K	A61K	A61K
Northern America	A61K	A61K	H04L	A61K	H04L	H04L	A61K		A61K	H04L	H04L	A61K	H04L	A61K
Oceania	A61K	A61K	A61K	A61K	A61K	G06F	A61K	A61K	A61M	G06F	A61K	A61K	A61K	A61K
Rep. Korea	H04B	H01L	H01L	H01L	H04B	H01L	H04W	H04B	H04B		H01L	H01L	H04L	H04B
SCSE Asia	H04L	H01L	H01L	H01L	H04L	H01L	A61K	H04L	A61K	H01L	H01L	H01L	H04L	A61K
United States	A61K	A61K	H01L	A61K	H04L	G06F	A61K	A61K	A61K	H04L	H01L	A61K	A61B	A61K
Western Asia	H04L	A61K	H04L	A61K	H04L	G06F	A61K	G06F	A61K	H04L	H04L	A61B	H04L	A61K
Western Europe	A61K	A61K	A61K	A61K	A61K	A61K	A61K	A61K	A61K	H04L	A61K	A61K	A61K	A61K

NOTE: Each cell[i,j] reports the most frequent IPC class among cross country citations between territories *i* and *j*

**Table 2.c. 2011-2020**

	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Africa	A61K	A61K	H04W	A61K	H04W	H01L	A61K	H04W	H04L	H01L	H01L	A61K	G06F	A61K
CEE	H01L	A61K	H04L	A61K	H01L	H01L	A61K	A61K	A61K	H01L	H01L	G06F	G06F	A61K
China	H01L	H01L	H01L	H04W	H01L	H01L	A61K	H04W	A61K	H01L	H01L	H01L	G06F	H01L
Germany	A61K	A61K	H01L		A61K	H01L	A61K	A61K	A61K	H01L	H01L	A61K	A61B	A61K
India	H01L	A61K	H04W	A61K		H01L	A61K	H04W	A61K	H01L	H01L	G06F	G06F	H01L
Japan	H01L	H01L	H01L	H01L	H01L		H01L	G06F	G06F	H01L	H01L	H01L	H01L	H01L
LAC	A61K	A61K	A61K	A61K	A61K	H01L	A61K	A61K	A61K	H01L	A61K	A61K	A61K	E21B
Northern America	H04L	G06F	H04W	A61K	H04L	G06F	A61K		A61K	H04W	H04W	G06F	G06F	A61K
Oceania	A61K	A61K	G06F	A61K	A61K	G06F	A61K	A61K	A61M	G06F	A61M	A61K	A61K	A61K
Rep. Korea	H01L	H01L	H01L	H01L	H01L	H01L	H01L	H04W	H04W		H01L	H01L	G06F	H01L
SCSE Asia	H01L	H01L	H01L	H01L	H01L	H01L	A61K	H04L	A61K	H01L	H01L	H01L	G06F	H01L
United States	G06F	G06F	G06F	A61K	G06F	H01L	A61K	G06F	A61K	H01L	H01L	A61B	A61B	A61K
Western Asia	G06F	G06F	G06F	G06F	G06F	G06F	A61K	G06F	A61B	G06F	H01L	A61B	G06F	G06F
Western Europe	A61K	A61K	H04W	A61K	A61K	H01L	A61K	A61K	A61K	H01L	A61K	A61K	G06F	A61K

NOTE: Each cell[i,j] reports the most frequent IPC class among cross country citations between territories *i* and *j*

Figure 2 looks at the average time lapsed from the priority year of a cited patent and the first time it is cited elsewhere (including its home country/territory). The matrix is not symmetric, as average times could differ from country/territory *i* to *j* to country/territory *j* to *i*. The figure shows numerous curiosities and facts. To mention a few: (1) as expected, the main diagonal show the lightest yellows of the matrix (as geography matters); (2) both lines and columns in countries like Japan, Republic of Korea and Germany (plus Africa, Latin America and Oceania to a lesser extend) seem to show the darkest yellows, confirming again the relative isolation of these areas in terms of the global diffusion of technological knowledge. In this case, not only geographical distance matters, but also differences in cultural norms and language, as well as lack of absorptive capacity/local capabilities are at stake.

**Figure 2. Average time to the first citation received across territory pairs**

**Figure 2.a. 1991-2000**

	Destination territories													
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Africa	4.0	5.7	5.5	6.4	4.9	5.9	6.3	6.2	7.0	5.5	4.9	6.6	5.9	6.1
CEE	5.4	4.3	5.1	6.5	4.7	5.5	6.1	5.4	6.0	4.8	4.8	5.9	5.6	5.8
China	3.4	3.6	2.9	3.6	3.2	3.0	3.6	3.3	3.5	3.1	3.2	3.2	3.3	3.5
Germany	7.5	7.7	7.9	6.6	7.5	7.4	8.0	7.9	8.1	7.5	7.1	7.8	7.7	7.6
India	3.1	3.2	3.4	3.5	2.4	3.3	3.5	2.9	3.2	3.3	3.1	2.9	3.0	3.3
Japan	7.7	7.7	7.3	7.4	7.3	5.4	8.2	7.6	7.7	6.5	6.9	7.1	7.4	7.5
LAC	5.0	5.6	5.4	5.6	5.0	5.4	3.9	5.5	5.8	5.3	4.9	5.4	5.5	5.4
Northern America	5.3	5.9	5.9	6.3	5.2	5.7	6.5	4.8	6.5	5.5	5.2	6.1	5.7	6.0
Oceania	6.7	6.9	6.7	7.0	6.1	6.5	7.4	6.9	5.0	6.6	6.0	6.8	6.7	6.8
Rep. Korea	4.1	4.2	4.3	4.3	4.0	3.8	4.6	4.0	4.4	3.3	4.0	4.0	4.2	4.1
SCSE Asia	3.9	4.3	4.2	4.2	3.8	3.8	4.5	4.1	4.2	3.9	2.8	4.0	4.0	4.1
United States	6.8	7.1	7.0	7.1	6.5	6.6	7.3	6.8	6.9	6.6	6.7	6.3	6.6	6.9
Western Asia	5.5	5.5	5.7	5.5	5.0	5.3	5.8	5.4	5.6	5.3	5.2	5.2	3.8	5.4
Western Europe	6.7	7.1	7.1	7.3	6.6	6.9	7.4	7.1	7.3	6.7	6.5	7.3	7.0	6.6

**Figure 2.b. 2001-2010**

Origin territories	Destination territories													
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Africa	5.7	8.3	7.9	8.2	7.5	7.6	9.4	7.6	8.8	7.1	7.8	7.6	7.5	8.1
CEE	7.1	5.8	6.9	6.8	6.4	6.8	7.6	6.8	7.4	6.4	7.1	6.4	7.2	6.9
China	5.6	5.4	3.9	4.9	4.8	4.4	5.7	4.7	5.3	4.2	5.2	4.4	5.4	5.0
Germany	9.8	9.9	9.7	7.4	9.2	9.1	10.4	9.5	9.9	9.0	9.3	8.8	9.7	9.4
India	5.9	5.8	5.4	5.2	4.1	5.2	6.0	5.0	5.8	5.1	5.8	4.5	5.6	5.4
Japan	10.6	10.2	9.0	8.8	9.5	6.1	10.9	9.5	10.0	8.0	9.6	8.2	9.8	9.6
LAC	7.8	7.8	7.6	7.3	7.1	7.3	5.7	7.4	7.8	7.3	7.7	6.6	8.3	7.4
Northern America	7.6	8.3	7.6	7.9	7.2	7.4	8.9	6.0	8.7	7.0	7.6	7.0	7.9	8.0
Oceania	9.4	9.7	8.9	8.9	8.7	8.5	10.0	8.9	6.6	8.6	9.1	8.2	9.2	9.0
Rep. Korea	6.6	6.1	5.8	5.6	5.6	5.1	6.8	5.4	6.0	4.3	6.0	5.4	6.3	5.9
SCSE Asia	6.1	6.5	5.9	6.0	5.6	5.6	6.8	5.8	6.3	5.5	4.5	5.4	6.4	6.2
United States	9.1	9.3	8.4	8.5	8.2	8.1	10.0	8.3	9.0	7.9	8.8	6.7	8.9	8.8
Western Asia	6.7	7.8	6.9	6.8	6.7	6.6	8.1	6.9	7.5	6.6	7.3	6.0	5.1	7.1
Western Europe	8.9	9.2	8.7	8.6	8.3	8.5	9.8	8.6	9.1	8.2	8.7	8.0	9.1	8.0

**Figure 2.c. 2011-2020**

Origin territories	Destination territories													
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Africa	1.5	2.1	2.2	2.8	4.0	7.4	0.7	2.0	5.3	6.5	7.4	2.1	3.2	2.7
CEE	1.5	1.5	1.9	1.6	2.4	7.0	2.5	2.6	3.4	5.6	2.0	2.2	2.2	2.4
China	4.1	2.0	0.3	2.1	1.4	2.2	2.6	0.8	1.4	2.7	1.2	1.7	1.2	2.0
Germany	2.4	4.2	4.4	1.3	3.5	6.2	3.5	3.5	3.3	6.9	3.2	3.3	4.3	2.9
India	2.4	2.9	2.1	2.2	0.7	4.7	2.4	2.3	2.6	3.6	1.5	1.2	2.2	2.5
Japan	7.5	7.7	6.6	6.8	5.6	1.1	9.2	6.2	6.0	8.2	6.1	5.6	6.8	5.8
LAC	2.9	2.8	3.2	2.5	2.8	4.6	1.9	2.7	4.0	4.0	3.6	2.4	5.0	2.7
Northern America	6.1	3.5	1.4	2.6	3.0	4.7	3.1	1.2	2.6	3.7	1.9	2.3	3.2	3.5
Oceania	1.5	4.4	2.1	3.2	3.3	7.3	5.2	3.2	2.3	6.4	2.9	3.4	3.8	3.1
Rep. Korea	4.3	4.8	3.4	2.4	2.6	4.0	5.0	3.0	2.5	0.8	0.5	3.1	5.1	4.8
SCSE Asia	6.5	2.3	1.0	1.7	1.6	1.9	2.0	2.4	2.9	3.5	0.8	1.6	3.1	2.3
United States	4.9	4.2	3.0	3.8	2.6	5.7	5.4	2.9	4.0	5.2	3.4	1.8	2.9	4.1
Western Asia	2.1	4.1	2.5	3.4	2.4	3.8	4.6	1.4	2.9	4.1	2.8	2.1	1.0	2.7
Western Europe	3.8	4.6	3.9	2.8	3.2	5.5	5.4	3.3	4.7	7.6	4.4	3.0	4.4	2.1

## Technological trajectories as IPC combinations in patents

Next, in this subsection, we examine the idea of *reuse* of technological knowledge, as explained in section 3 (technological trajectories as IPC combinations in patents). For this exercise, we use the PATSTAT database to collect all patents filed at the EPO in the period 1985-2024. Using the method described there, we identified 25,513 technological trajectories that originated from 1985 to 2005 and developed until 2024.

We analyze cross-border transmission of technological knowledge by looking at the location of the inventors of each patented invention belonging to the 25,513 technological trajectories that we identified. We mark ‘sender’ countries/territories, i.e., countries/territories in which the technological trajectories originate, and ‘receiver’ countries/territories, i.e., countries/territories reached by the technological trajectories.

Table 3 lists the sender and receiver countries/territories, along with the corresponding number of trajectories originating in each sender country/territory and reaching each receiver country/territory. As we can observe, the United States plays the role of top-sender (being the country where more than 40% of the technological trajectories originated), followed by Western Europe and Japan. The United States, Western Europe, and Japan are also the top-3 receiver

countries/territories. Almost all the technologies in our sample reached the United States, as well as Western Europe.

**Table 3. The top-10 sender and receiver countries of the technological trajectories.**

(1) Sender country	(2) N of trajectories	(3) Share*	(4) Receiver country	(5) N of trajectories	(6) Share*
United States	11,372	44.98%	United States	24,387	96.45%
Western Europe	7,596	30.04%	Western Europe	24,141	95.48%
Japan	5,229	20.68%	Japan	21,886	86.56%
Germany	4,848	19.17%	Germany	21,867	86.49%
Northern America	540	2.14%	Northern America	11,192	44.27%
Oceania	504	1.99%	Rep. Korea	9,785	38.70%
Western Asia	278	1.10%	China	8,484	33.55%
CEE	198	0.78%	Oceania	6,664	26.36%
Rep. Korea	175	0.69%	Western Asia	6,156	24.35%
China	90	0.36%	CEE	4,514	17.85%
LAC	51	0.20%	India	2,665	10.54%
Africa	48	0.19%	SCSE Asia	2,628	10.39%
SCSE Asia	38	0.15%	LAC	1,967	7.78%
India	25	0.10%	Africa	1,071	4.24%

NOTE: Column 2 counts the number of distinct trajectories originating in the sender country. Column 4 counts the number of trajectories that, during their development, show at least one patent in the receiving country. \*The share is calculated as the total number of trajectories that originate/reach a country, as reported in Column 2/Column 4, divided by the number of distinct trajectories in our study sample, 25,284. The sum of the shares in columns 3 and 4 exceeds 100%, as the same trajectory can originate from or reach multiple countries.

To provide a visual representation of the international technological knowledge flows, we continue with a series of heatmaps, where darkest colors indicate more intense flows of technological knowledge and lighter tones indicate less intense flows between pairs of countries. The diagonal of each heatmap illustrates the proportion of technological trajectories that, at one point in their development, return to the country that originated the trajectory.

Figure 3 illustrates the overall flows of technological knowledge across countries. Each cell  $[i,j]$  represents the share of technological trajectories originating in country/territory  $i$  and arriving in country/territory  $j$ , where the share is calculated over the total number of trajectories originating in country/territory  $i$ . For instance, we observe that 98.69% of the technological trajectories that originated in the United States are reused within the country. Japan is a receiving country for about 84% of the technological trajectories originating in the United States, meaning that 84% of the technological trajectories originating in the United States reach Japan in our observation period.<sup>3</sup> We also observe that the largest part of the

<sup>3</sup>The cumulative sum by row of the shares is not 100% since multiple countries can reuse the same technology. Each cell can take values from 0 to 100%. A value of zero indicates that the technological trajectory originating in country  $i$  never reached country  $j$ . A value of 100% indicates that all the technological trajectories originating in country  $i$  reached country  $j$ .

technological trajectories is highly reused in the country/territory where they originated, as denoted by the high values appearing on the diagonal of the matrix. Germany, Japan, the United States, and Western Europe are the countries/territory with the highest reuse shares. Germany reuses 93.81% of the technological trajectories originated within the country, but is also open to reusing technological trajectories originating from abroad. Japan reuses 91.67% of the technological trajectories originated within the country; however, it also registers a high inflow of foreign technological trajectories, such as those originated in the United States. Interestingly, bilateral exchanges exist between countries like China and the Republic of Korea, indicating that geographical and technological affinity matter. First, both countries are relatively close to each other – in geographical terms. Regarding technological affinity, the reuse flows relate to nanotechnologies and electric data processing, which are core activities for companies like Samsung, LG, and Huawei. During our observation period, other territories in the Global South show a marginal position in terms of the flows of technological knowledge across countries. For example, Africa appears to have scarce activity, as indicated by the prevalence of lighter tone cells, which denotes its low capabilities to reuse foreign technological knowledge. Interestingly, all the technological trajectories that originate in Africa reach Western Europe (100.00%), and a large part of them reach the United States (95.83%), Japan (91.67%), and Germany (81.25%).

Compared to Figure 1 in the preceding subsection (and despite the differences in methodological approach and data used), several aspects could be highlighted. In both cases, the main diagonal presents large values. Again, in both cases, the United States and, to a lesser extent, Western Europe are significant receivers of technological knowledge from everywhere else, with Africa being a lower receiver in both cases. On the contrary, while Germany and Japan are big re-users of technological trajectories (Figure 3), this is more nuanced for the case of citations (Figure 1).

Table 4 presents the content of the technological flow across countries/territories, reporting the most frequent IPC code under which patents associated with the technological trajectories are classified. That is to say, each cell [i,j] represents the most frequent IPC code appearing in the technological trajectories originating in country/territory *i* and arriving in country/territory *j*. For instance, the technological trajectories originating in Africa that reach the United States and Japan relate to the IPC code H01M that covers battery technologies and fuel cells. Africa suffers from limited grid access, and other countries might then reuse technological knowledge related to off-grid solutions that originated there. In the case of the exchanges between Africa and Germany, the prevalent technological trajectories that originated in Africa and reached Germany relate to the IPC code C07D, which is core to pharmaceuticals and agrochemicals. The reuse flows between the two territories may be the result of frequent collaborations on local diseases, such as malaria, or agrochemical research.

More broadly, Table 4 highlights some specialization paths. We observe that countries act as ‘sender’ for a few technologies, which are at the core of their specialization, while they are ‘receiver’ for a broad range of technologies. For example, the technological trajectories originating in the United States and used by other countries are associated with two distinct IPC codes, i.e., preparing chemical compounds for therapeutic treatment (IPC code A61P) and mobile and wireless broadband communications technologies (IPC code H04W). As ‘receiver,’ the United States is reached by eight distinct IPC codes that range from nanotechnology (IPC code B82Y) to organic chemistry (C07D).

**Figure 3. Flows of technological knowledge across countries.**

		Share of trajectories reaching destination														
		Destination territories														
Origin territories		Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe	
	Africa		18.8	31.3	37.5	81.3	10.4	91.7	8.3	50.0	31.3	45.8	22.9	95.8	22.9	100.0
CEE		7.1	29.8	36.4	87.9	11.6	81.3	10.1	43.9	37.4	34.8	12.6	97.0	33.3	97.0	
China		2.2	14.4	46.7	87.8	5.6	88.9	10.0	41.1	30.0	53.3	7.8	95.6	23.3	98.9	
Germany		3.3	17.2	31.1	93.8	8.8	87.5	6.3	39.2	22.7	35.6	7.2	94.9	18.8	96.4	
India		4.0	20.0	32.0	80.0	36.0	76.0	8.0	36.0	20.0	40.0	12.0	92.0	12.0	76.0	
Japan		3.2	16.6	38.2	85.3	9.9	95.4	6.3	42.2	22.4	46.9	11.0	94.2	20.3	93.7	
LAC		2.0	13.7	19.6	84.3	7.8	82.4	17.6	60.8	49.0	37.3	7.8	98.0	29.4	96.1	
Northern America		7.2	23.9	35.0	84.6	18.0	82.0	11.7	58.0	30.2	39.8	12.2	97.8	31.7	96.7	
Oceania		3.8	18.5	31.0	73.6	9.5	76.0	11.1	44.2	42.7	34.5	13.5	90.9	23.4	87.1	
Rep. Korea		6.3	29.1	63.4	78.9	17.1	86.3	11.4	43.4	37.1	74.3	21.1	96.0	38.3	93.1	
SCSE Asia		5.3	18.4	47.4	78.9	18.4	84.2	15.8	65.8	55.3	42.1	23.7	97.4	42.1	94.7	
United States		5.0	18.8	32.5	84.5	11.2	84.4	8.6	47.3	28.5	37.3	11.5	98.7	28.2	95.4	
Western Asia		7.9	29.1	39.9	84.5	23.4	78.1	17.3	57.9	40.6	46.8	15.8	97.5	56.5	93.9	
Western Europe		4.6	17.6	36.3	89.0	10.7	86.2	8.4	47.6	25.6	39.6	10.0	96.4	23.3	97.8	

NOTE: Each cell $[i,j]$  represents the share of trajectories originating in country  $i$  and arriving in country  $j$  at least once during their development. The share is calculated over all the trajectories originating in country  $i$ .

**Table 4. The most frequent IPC code involved in the technological flow sender-receiver country pair.**

	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Africa	H01M	H04L	H04L	C07D	H04L	H01M	A47B	H01M	H04L	H04L	H04L	H01M	H04L	H01M
CEE	A01N	A61P	A61P	A61P	H04L	A61P	A61P	A61P	A61P	A61P	A61P	A61P	A61P	A61P
China	B65D	H01J	G06F	G06F	A61L	G06F	A01H	G06F	A23D	G06F	G06F	G06F	G06F	G06F
Germany	A61P	A61P	H04W	C07D	A61P	H04W	A61P	H04W	A61P	H04W	H04W	C07D	A61P	C07D
India	A01P	A01P	A01P	A01P	A01P	A01P	A01P	A01P	A01P	A01P	A01P	A01P	A61P	A01P
Japan	H04W	H04W	H04W	H04W	H04W	H04W	H04W	H04W	H04W	H04W	H04W	H04W	H04W	H04W
LAC	A01H	B82Y	B82Y	A01N	B82Y	B32B	A01H	A01N	A01N	B82Y	A01H	A01N	A01N	A01N
Northern America	H04L	A61P	H04W	A61P	H04W	A61P	A61P	A61P	A61P	H04W	H04L	A61P	A61P	A61P
Oceania	A61P	C07K	G06F	A61K	C07K	G06F	C07K	A61P	B41J	G06F	A61K	A61P	A61K	A61P
Rep. Korea	B82Y	B82Y	B82Y	B82Y	B82Y	B82Y	B82Y	B82Y	B82Y	B82Y	B82Y	B82Y	B82Y	B82Y
SCSE Asia	C12Q	G06F	G06F	G06F	G06F	G06F	A01N	G06F	G06F	G06F	B81C	G06F	G06F	G06F
United States	A61P	A61P	H04W	H04W	A61P	H04W	A61P	H04W	A61P	H04W	H04W	A61P	A61P	A61P
Western Asia	A61P	A61P	H04W	A61P	A61P	A61P	A61P	A61P	A61P	H04W	B33Y	A61P	A61P	A61P
Western Europe	A61P	A61P	H04W	H04W	A61P	H04W	A61P	H04W	A61P	H04W	H04W	H04W	A61P	H04W

NOTE: Each cell $[i,j]$  reports the most frequent IPC class among those identifying the trajectories that connect country  $i$  and  $j$

The geography of technological knowledge diffusion might have evolved over time, and countries might become more open or close in how they source their technological knowledge. To explore this time dimension, we construct a series of heatmaps where, in line with Figure 3, we depict the flows of technological

trajectories across countries/territories, distinguishing i) the phases of the technological trajectories, ii) the years when each technology originates.

In considering the phases of the technological trajectories (i), we split each trajectory into three moments. Each cell in Figure 4 reports the share of technological trajectories originating in country/territory i and arriving in country/territory j in the first 5 years after their origin. Figure 5 reports the share of technological trajectories originating in country/territory i and arriving in country/territory j during the time period from the 6<sup>th</sup> to the 10<sup>th</sup> year after the trajectory origin, and finally Figure 6 reports the share of technological trajectories originating in country/territory i and arriving in country/territory j during the time period from the 11<sup>th</sup> to the 20<sup>th</sup> year after the trajectory origin.

**Figure 4. Flows of technological knowledge across countries in the first 5 years of the development of each technological trajectory.**

Share of trajectories reaching destination after 5 years

	Destination territories													
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Origin territories	Africa	2.1	2.1	48.9	0.0	34.0	2.1	19.1	10.6	6.4	4.3	70.2	4.3	66.0
CEE	2.2	8.3	5.6	42.2	0.6	32.8	1.7	8.9	10.0	1.7	1.7	68.9	7.2	65.0
China	1.2	2.4	8.4	42.2	0.0	51.8	3.6	10.8	9.6	9.6	0.0	69.9	4.8	53.0
Germany	0.5	2.8	8.7	63.1	0.6	46.7	0.7	13.2	4.7	10.1	0.6	67.7	3.3	63.2
India	0.0	4.2	4.2	50.0	4.2	41.7	4.2	8.3	4.2	8.3	0.0	87.5	0.0	45.8
Japan	0.4	2.0	3.8	45.5	0.5	69.5	0.5	8.2	4.6	8.6	1.1	68.9	3.1	57.5
LAC	0.0	4.8	2.4	42.9	0.0	23.8	2.4	14.3	9.5	7.1	0.0	59.5	11.9	66.7
Northern America	0.6	6.5	5.7	41.7	0.6	41.1	1.6	25.8	6.1	8.5	2.0	81.5	6.5	66.1
Oceania	1.3	4.4	4.0	44.4	1.5	43.3	0.4	11.9	21.4	5.3	0.9	70.9	6.4	62.3
Rep. Korea	1.3	3.2	9.1	33.1	2.6	55.8	1.3	13.6	9.7	40.9	3.2	65.6	9.7	59.1
SCSE Asia	0.0	0.0	8.6	51.4	0.0	60.0	2.9	20.0	14.3	11.4	5.7	80.0	2.9	62.9
United States	0.8	2.8	4.6	40.7	0.8	43.5	0.7	12.6	6.6	6.6	1.1	83.1	5.5	58.7
Western Asia	1.2	6.6	3.1	36.6	4.7	40.9	0.8	10.9	10.9	8.9	0.8	83.3	23.0	63.4
Western Europe	0.9	2.7	11.6	50.6	0.6	47.8	1.0	17.1	5.1	13.5	0.9	74.5	3.8	71.0

**Figure 5. Flows of technological knowledge across countries in 6 to 10 years of the development of each technological trajectory.**

Share of trajectories reaching destination 6-10 years

	Destination territories													
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Origin territories	Africa	8.9	4.4	44.4	4.4	71.1	0.0	17.8	6.7	11.1	2.2	82.2	11.1	77.8
CEE	2.2	9.3	10.9	52.5	1.1	52.5	2.2	18.0	17.5	10.9	1.6	81.4	12.6	73.8
China	0.0	7.0	9.3	48.8	1.2	66.3	2.3	16.3	8.1	18.6	1.2	73.3	5.8	64.0
Germany	0.9	4.2	13.1	60.0	1.7	58.2	1.4	11.2	6.9	8.2	1.6	68.5	6.1	66.4
India	0.0	13.0	4.3	52.2	13.0	56.5	4.3	17.4	8.7	21.7	4.3	60.9	8.7	60.9
Japan	1.0	4.5	15.7	55.6	2.2	75.6	1.3	19.5	7.5	20.7	2.8	73.8	6.3	65.8
LAC	2.0	4.0	8.0	44.0	2.0	48.0	4.0	10.0	24.0	8.0	0.0	94.0	6.0	76.0
Northern America	3.2	8.9	12.7	52.5	7.8	55.9	2.8	28.4	14.5	16.7	4.2	81.9	11.3	70.0
Oceania	0.2	7.2	13.5	49.2	1.4	53.0	4.3	18.8	19.3	14.5	4.3	74.7	11.8	66.3
Rep. Korea	3.0	10.2	27.1	42.2	5.4	57.2	6.0	17.5	13.9	38.6	8.4	74.1	15.7	63.3
SCSE Asia	0.0	5.7	17.1	22.9	5.7	28.6	5.7	14.3	22.9	11.4	11.4	80.0	14.3	74.3
United States	1.4	5.9	11.3	51.1	2.7	55.7	2.5	18.3	11.0	12.0	2.9	83.5	10.7	69.5
Western Asia	3.9	8.6	13.3	56.5	7.1	51.4	4.3	25.5	20.8	14.5	4.3	85.9	22.0	73.7
Western Europe	1.4	4.6	17.5	52.0	2.0	57.6	2.1	15.2	8.5	10.7	2.5	72.8	7.5	68.6

**Figure 6. Flows of technological knowledge across countries in 11 to 20 years of the development of each technological trajectory.**

Share of trajectories reaching destination 11-20 years

	Destination territories														
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe	
Origin territories	Africa	4.3	21.3	36.2	72.3	8.5	78.7	6.4	34.0	23.4	40.4	19.1	91.5	17.0	83.0
CEE	3.2	21.8	31.9	70.7	11.2	73.9	8.0	33.5	28.2	33.0	10.6	87.8	26.1	88.3	
China	2.2	7.9	40.4	71.9	4.5	79.8	4.5	30.3	20.2	44.9	6.7	94.4	14.6	86.5	
Germany	2.3	13.3	24.0	78.4	7.9	76.6	4.9	26.0	16.8	27.2	6.1	85.0	14.5	85.9	
India	4.3	13.0	26.1	69.6	30.4	60.9	0.0	26.1	13.0	30.4	8.7	87.0	8.7	73.9	
Japan	2.1	13.7	30.1	67.4	9.0	85.7	5.2	28.6	16.5	36.6	9.1	82.9	16.4	80.4	
LAC	0.0	8.0	16.0	68.0	6.0	76.0	16.0	58.0	40.0	30.0	8.0	92.0	20.0	94.0	
Northern America	4.0	16.0	31.3	66.5	13.7	71.7	8.3	38.3	21.0	31.9	8.7	88.1	24.6	81.9	
Oceania	3.2	14.9	28.5	67.4	9.2	71.3	9.4	37.0	27.1	31.0	12.2	86.4	20.5	83.7	
Rep. Korea	2.5	25.3	58.0	55.6	13.6	71.6	7.4	30.2	25.3	58.0	14.8	86.4	32.1	84.0	
SCSE Asia	5.4	13.5	40.5	59.5	13.5	75.7	8.1	51.4	24.3	29.7	10.8	86.5	37.8	73.0	
United States	3.5	14.1	27.7	67.8	9.5	74.5	6.6	34.9	20.6	30.5	9.2	91.0	21.3	83.4	
Western Asia	4.0	22.9	37.9	69.2	14.6	68.8	15.0	47.0	30.0	40.7	14.2	90.1	39.5	80.2	
Western Europe	3.0	14.3	27.8	72.0	10.1	74.9	6.7	32.2	20.4	29.4	8.4	87.4	18.8	86.6	

Comparing the three figures (Figure 4, Figure 5, and Figure 6), we observe that the United States and Western Europe are early users, i.e., they reuse a high share of foreign technological knowledge since the early years of its development. This latter trend is evident in Figure 6, where we can observe that the two columns referring to the United States and Western Europe, respectively, are darkest, indicating a high share of reuses. For technological trajectories in the early phases of their development, i.e., in the first 5 years, China is absorbing technological knowledge from other Asian areas (Republic of Korea, and SCSE Asia), and it is open to countries/territories such as Germany, and Western Europe, while only fewer than 5% of American technological trajectories reach China. Over time, China has shown an increasing receptiveness towards American technologies, with 27.74% of the trajectories originating in the United States reaching China during the last 10 years of their development. Those figures most likely denote China's ability to strengthen its absorptive capacities and infrastructure, making it possible to reuse foreign technologies. Regardless of the development phase of the technological trajectories, Africa remains behind, and it appears challenging for the country to absorb foreign technological knowledge.

There may be cohort effects, and technological trajectories may have different diffusion paths across countries, depending on the period in which they originated. To explore this aspect, we split our sample into two sub-samples, considering a first group of trajectories that originated between 1985 and 1995, and a second group between 1996 and 2005. Figure 7 and Figure 8 show that the trajectories originating in the first temporal window mainly reach Germany, Japan, the United States, and Western Europe during their development, whereas more recent trajectories show a more equal distribution of countries reached. Some countries show themselves to be more receptive to the trajectories originating in neighboring countries. For example, about 42% of the technologies that originated in China between 1985 and 1995 are reused by the

Republic of Korea (Figure 7), and that percentage grows to about 70% for the most recent Chinese technological trajectories (Figure 8).

**Figure 7. Flows of technological knowledge across countries, for those trajectories that originated in the timeframe 1985-1995.**

Share of trajectories reaching destination 1985-1995

Origin territories	Destination territories													
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Africa	25.0	25.0	25.0	82.1	7.1	92.9	10.7	50.0	28.6	46.4	21.4	96.4	10.7	100.0
CEE	7.3	27.6	26.0	87.8	6.5	83.7	7.3	37.4	38.2	30.1	9.8	96.7	26.0	100.0
China	1.9	11.1	35.2	94.4	1.9	88.9	9.3	35.2	33.3	42.6	7.4	98.1	18.5	98.1
Germany	3.8	15.8	18.2	94.6	6.6	86.7	6.6	33.8	24.3	25.2	6.7	96.1	17.8	96.6
India	0.0	30.0	0.0	100.0	30.0	70.0	0.0	40.0	40.0	30.0	0.0	100.0	20.0	90.0
Japan	3.7	15.2	23.9	86.5	7.5	94.7	6.5	36.8	24.1	35.2	9.7	96.4	19.9	94.7
LAC	2.9	8.8	8.8	88.2	2.9	91.2	17.6	55.9	50.0	26.5	8.8	100.0	11.8	97.1
Northern America	8.4	22.6	25.3	88.9	14.2	81.9	11.1	58.4	29.2	30.7	10.5	99.1	26.5	96.4
Oceania	5.2	23.0	23.4	87.4	8.2	85.5	14.1	50.2	45.7	33.8	13.4	96.7	24.5	95.2
Rep. Korea	0.0	25.0	35.7	75.0	3.6	85.7	3.6	39.3	32.1	46.4	3.6	100.0	32.1	96.4
SCSE Asia	0.0	10.0	30.0	80.0	20.0	100.0	30.0	70.0	30.0	20.0	10.0	100.0	40.0	90.0
United States	5.6	18.6	23.9	86.8	9.0	85.1	8.5	44.4	29.2	31.1	10.6	99.2	27.1	96.1
Western Asia	8.5	27.1	29.5	92.2	17.8	84.5	19.4	67.4	43.4	41.9	14.0	99.2	56.6	96.1
Western Europe	5.4	17.0	21.6	90.3	8.7	86.0	9.1	40.4	28.5	26.9	9.5	97.7	23.5	98.1

**Figure 8. Flows of technological knowledge across countries, for those trajectories that originated in the timeframe 1996-2005.**

Share of trajectories reaching destination 1996-2005

Origin territories	Destination territories													
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Africa	10.5	36.8	57.9	78.9	15.8	89.5	5.3	47.4	36.8	47.4	26.3	94.7	42.1	100.0
CEE	5.2	37.9	53.4	89.7	20.7	72.4	17.2	48.3	25.9	46.6	15.5	96.6	43.1	89.7
China	3.1	18.8	62.5	78.1	12.5	87.5	12.5	46.9	28.1	68.8	9.4	93.8	28.1	100.0
Germany	2.4	20.9	59.7	92.5	13.4	89.4	5.9	51.8	19.5	58.0	8.5	92.5	20.9	96.0
India	6.7	13.3	53.3	66.7	40.0	80.0	13.3	33.3	6.7	46.7	20.0	86.7	6.7	66.7
Japan	2.0	18.0	62.3	82.6	13.9	96.7	5.9	51.3	19.1	66.0	13.1	90.7	21.2	91.7
LAC	0.0	23.5	41.2	76.5	17.6	64.7	17.6	70.6	47.1	58.8	5.9	94.1	64.7	94.1
Northern America	5.1	24.6	52.0	76.6	25.7	81.7	13.7	58.3	31.4	57.1	13.7	94.9	41.7	96.6
Oceania	1.8	12.8	38.3	56.4	11.0	65.2	7.0	37.0	38.8	34.4	12.8	83.7	21.6	77.1
Rep. Korea	7.5	30.1	69.2	80.1	19.9	86.3	13.0	44.5	38.4	80.1	24.7	95.9	39.7	93.2
SCSE Asia	7.4	22.2	55.6	77.8	18.5	77.8	11.1	63.0	66.7	51.9	29.6	96.3	40.7	96.3
United States	3.5	19.5	52.1	79.0	16.7	81.8	9.0	53.5	26.3	52.0	13.4	97.2	31.0	93.2
Western Asia	7.3	32.8	48.2	77.4	29.9	70.1	16.1	50.4	39.4	48.2	17.5	95.6	56.2	91.2
Western Europe	2.9	18.8	65.9	86.5	15.0	86.8	7.0	62.1	19.7	64.9	11.1	94.1	22.6	97.4

Technological trajectories may have different diffusion paths across countries/territories, depending on the quality of the technological knowledge on which they rely. Using forward citations as a proxy for the quality of the technological knowledge (Hall et al., 2005), we split trajectories into two subgroups, distinguishing between trajectories for which the patent/s originating the trajectory has/have been highly cited, or else has/have received a low number of citations. Highly/low-cited patents are those receiving a number of citations above/below the median number of citations.<sup>4</sup> Comparing Figure 9 and Figure 10, it seems that the flow of technological knowledge across countries is partially

<sup>4</sup> Forward citations received by the originating patent are calculated using a time window of 20 years after its application year. In case multiple patents are at the origin of the trajectory, we consider their average number of citations.

affected by the quality of the originating patents. There are a few interesting paths. For instance, when looking at the case of Africa, and interpreting jointly the two figures, we observe that the lower quality trajectories are more likely than higher quality ones to return to the country at a certain point in their development (21.21% versus 13.33%). For other more developed countries/territories like the United States or Western Europe, quality does not affect the likelihood of a technology returning to the country of origin. In both cases, almost all technologies – at a certain point in their development – return to the country of origin.

**Figure 9. Flows of technological knowledge across countries for the sub-sample of trajectories originating from highly cited patents.**

Share of trajectories reaching destination Highly Cited

Origin territories	Destination territories														
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe	
Africa	13.3	6.7	20.0	93.3	6.7	93.3	0.0	46.7	13.3	40.0	26.7	86.7	6.7	100.0	
CEE	7.4	35.2	27.8	96.3	11.1	88.9	9.3	48.1	31.5	31.5	13.0	96.3	33.3	98.1	
China	0.0	9.4	50.0	93.8	6.3	90.6	18.8	37.5	21.9	46.9	15.6	93.8	28.1	100.0	
Germany	4.0	18.3	23.7	94.4	9.2	86.6	7.5	36.1	25.6	31.6	7.6	94.7	20.1	96.7	
India	0.0	0.0	0.0	100.0	100.0	100.0	0.0	50.0	50.0	50.0	0.0	100.0	0.0	100.0	
Japan	3.4	16.3	40.8	86.9	9.5	96.1	6.0	43.6	20.6	49.4	10.5	94.5	19.5	94.1	
LAC	4.5	13.6	22.7	90.9	9.1	90.9	31.8	72.7	72.7	40.9	13.6	100.0	50.0	100.0	
Northern America	8.0	20.9	25.7	86.1	14.4	84.0	8.6	54.5	25.1	32.1	8.6	97.3	24.1	95.7	
Oceania	7.0	24.3	34.8	88.7	13.0	91.3	17.4	47.8	50.4	42.6	15.7	94.8	28.7	95.7	
Rep. Korea	1.8	17.5	52.6	77.2	7.0	87.7	3.5	47.4	29.8	71.9	15.8	96.5	22.8	93.0	
SCSE Asia	0.0	11.1	44.4	88.9	11.1	88.9	22.2	77.8	33.3	33.3	11.1	100.0	66.7	100.0	
United States	6.3	20.5	28.7	87.8	11.3	86.2	8.8	47.1	30.0	35.7	13.1	99.0	27.6	96.1	
Western Asia	6.3	20.6	31.7	84.1	15.9	82.5	15.9	74.6	34.9	46.0	11.1	98.4	54.0	95.2	
Western Europe	5.2	18.9	28.2	89.0	10.9	85.1	9.1	43.1	27.1	32.8	10.7	95.4	24.5	98.2	

**Figure 10. Flows of technological knowledge across countries for the sub-sample of trajectories originating low cited patents.**

Share of trajectories reaching destination Low Cited

Origin territories	Destination territories														
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe	
Africa	21.2	42.4	45.5	75.8	12.1	90.9	12.1	51.5	39.4	48.5	21.2	100.0	30.3	100.0	
CEE	6.9	27.8	39.6	84.7	11.8	78.5	10.4	42.4	39.6	36.1	12.5	97.2	33.3	96.5	
China	3.4	17.2	44.8	84.5	5.2	87.9	5.2	43.1	34.5	56.9	3.4	96.6	20.7	98.3	
Germany	2.9	16.6	36.0	93.5	8.5	88.1	5.6	41.2	20.7	38.2	7.0	95.1	17.9	96.2	
India	4.3	21.7	34.8	78.3	30.4	73.9	8.7	34.8	17.4	39.1	13.0	91.3	13.0	73.9	
Japan	2.8	17.1	34.3	82.8	10.5	94.3	6.7	40.2	25.0	43.1	11.8	93.8	21.3	93.1	
LAC	0.0	13.8	17.2	79.3	6.9	75.9	6.9	51.7	31.0	34.5	3.4	96.6	13.8	93.1	
Northern America	6.8	25.5	39.9	83.9	19.8	81.0	13.3	59.8	32.9	43.9	14.2	98.0	35.7	97.2	
Oceania	2.8	16.7	29.8	69.2	8.5	71.5	9.3	43.2	40.4	32.1	12.9	89.7	21.9	84.6	
Rep. Korea	8.5	34.7	68.6	79.7	22.0	85.6	15.3	41.5	40.7	75.4	23.7	95.8	45.8	93.2	
SCSE Asia	6.9	20.7	48.3	75.9	20.7	82.8	13.8	62.1	62.1	44.8	27.6	96.6	34.5	93.1	
United States	4.2	17.7	34.7	82.6	11.1	83.3	8.5	47.4	27.7	38.3	10.5	98.5	28.5	95.0	
Western Asia	8.4	31.6	42.3	84.7	25.6	76.7	17.7	53.0	42.3	47.0	17.2	97.2	57.2	93.5	
Western Europe	4.1	16.7	41.3	89.0	10.6	86.9	8.0	50.5	24.7	43.8	9.5	97.0	22.6	97.6	

Having mapped the geographical diffusion of the technological trajectories, we consider now the time required for the technological knowledge to be reused. Specifically,

Figure 11 reports the minimum time needed for the technological trajectories originating in country/territory  $i$  to be reused in country/territory  $j$ , on average. Countries like the United States, Germany, and Japan, or territories like Western

Europe, appear to be faster than the remaining ones in reusing technologies originated elsewhere. For instance, technological trajectories originated in India take, on average, 3 years and 2 months to be reused in the United States. Looking at the American market, we can observe that it is particularly reactive when receiving technologies from Western Asia (3 years and 9 months), North America (4 years and 2 months), and Western Europe (4 years and 4 months).

Figure 11 shows a few outliers, like 19 years for trajectories originating in SCSE Asia to reach Africa. However, a closer look at the absolute number of trajectories involved in the transfer (Figure 12) reveals that the flow refers to only two trajectories in that case. More broadly, Figure 12 shows the number of trajectories originating in country/territory i and entering country/territory j. As expected, the most developed countries are also the most active users of technologies. The United States, for example, is a top reuser of technologies; through the United States, we observe the largest flow of technologies, regardless of their origin.

**Figure 11. Average time to the arrival of a trajectory in the destination territory.**

		Average time first reuse													
		Destination territories													
		Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Origin territories	Africa	6.3	11.6	13.6	6.2	12.4	6.7	11.0	9.3	10.1	12.9	12.5	4.9	9.7	5.5
	CEE	9.1	10.0	12.2	7.6	13.5	8.0	12.4	10.6	10.0	13.0	11.8	5.0	10.7	5.4
	China	6.0	10.9	12.3	7.4	14.6	6.4	9.1	10.1	10.1	11.7	13.7	5.3	10.5	6.5
	Germany	11.5	11.9	11.1	5.4	13.3	6.7	12.3	9.7	10.8	10.8	13.0	5.0	11.3	5.4
	India	15.0	8.0	12.9	5.4	11.1	6.3	7.0	10.2	10.4	9.6	11.7	3.2	10.3	5.9
	Japan	11.9	12.2	11.4	6.8	13.4	5.0	13.0	9.8	10.8	10.3	12.5	4.9	11.3	5.9
	LAC	9.0	7.3	10.8	7.5	15.5	8.6	11.7	11.2	10.2	11.9	13.8	5.3	9.9	5.6
	Northern America	11.0	10.0	11.5	7.1	11.7	7.1	12.4	7.8	9.8	10.7	11.0	4.2	11.1	5.4
	Oceania	10.7	10.7	12.0	6.5	13.3	6.7	12.2	10.0	7.1	11.6	12.3	4.9	10.4	5.4
	Rep. Korea	10.3	11.3	10.7	7.7	11.3	5.8	10.6	9.7	10.2	7.5	10.9	4.8	9.8	6.0
	SCSE Asia	19.0	14.6	12.7	7.2	12.7	6.1	9.5	11.2	9.5	11.4	10.9	4.3	12.4	5.1
	United States	11.3	11.4	11.9	7.1	12.9	6.9	12.3	9.9	10.2	11.3	12.4	3.9	10.6	5.8
	Western Asia	9.6	10.4	11.8	7.4	10.9	7.1	13.2	10.2	9.0	10.9	12.9	3.8	8.2	5.5
	Western Europe	10.7	11.7	10.4	6.3	13.3	6.6	12.2	9.4	10.8	10.0	12.5	4.4	11.2	4.8

**Figure 12. Number of trajectories that arrives at the destination territories from the origin territories.**

		First reuse													
		Destination territories													
		Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Origin territories	Africa	9	15	18	39	5	44	4	24	15	22	11	46	11	48
	CEE	14	59	72	174	23	161	20	87	74	69	25	192	66	192
	China	2	13	42	79	5	80	9	37	27	48	7	86	21	89
	Germany	162	836	1506	4548	426	4244	307	1899	1099	1724	349	4602	910	4672
	India	1	5	8	20	9	19	2	9	5	10	3	23	3	19
	Japan	165	870	1995	4458	518	4987	329	2207	1171	2450	577	4928	1059	4900
	LAC	1	7	10	43	4	42	9	31	25	19	4	50	15	49
	Northern America	39	129	189	457	97	443	63	313	163	215	66	528	171	522
	Oceania	19	93	156	371	48	383	56	223	215	174	68	458	118	439
	Rep. Korea	11	51	111	138	30	151	20	76	65	130	37	168	67	163
	SCSE Asia	2	7	18	30	7	32	6	25	21	16	9	37	16	36
	United States	567	2133	3692	9608	1275	9593	978	5377	3245	4243	1304	11223	3202	10845
	Western Asia	22	81	111	235	65	217	48	161	113	130	44	271	157	261
	Western Europe	346	1334	2757	6760	815	6548	638	3619	1945	3006	759	7325	1770	7431

## Reliance on global science

The next set of heatmaps illustrates where the science produced in a country/territory flows to support other countries' technologies. In other words, we map the cross-country flows between science and technology.

Figure 13 shows country/territory  $i$ 's papers cited by country/territory  $j$ 's patents. Specifically, considering only papers cited by at least one patent<sup>5</sup>, each cell  $[i,j]$  represents the proportion of papers written by authors affiliated with institutions in country/territory  $i$  and cited by patents invented by inventors located in country/territory  $j$ . For instance, we observe that 34.62% of the papers cited by at least one patent written by US authors are cited by patents with a Western European inventor. Importantly, we observe, again, that geography matters (Jaffe et al., 1993): the highest values lie on the diagonal of the matrix to indicate that the largest share of science produced in a country fuels national technologies. Countries that, despite relying largely on their own science, show openness to worldwide science are the United States and Western Europe.

**Figure 13. Flows between countries generating science and countries applying that science to produce technologies.**

		Science to technology													
		Destination territories													
Origin territories		Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
	Africa	3.1	2.8	5.0	16.2	2.0	10.9	2.1	4.1	2.6	3.0	1.1	38.3	3.1	41.0
	CEE	0.3	10.3	4.2	18.6	1.4	13.2	1.2	3.4	2.0	2.8	0.8	36.7	2.7	35.1
	China	0.2	2.6	14.7	14.4	1.9	13.5	0.9	3.1	1.6	5.7	1.2	31.5	2.7	30.5
	Germany	0.3	2.9	4.2	37.0	1.2	12.5	1.0	3.6	2.2	2.9	0.9	36.4	2.6	35.9
	India	0.6	3.0	6.0	17.7	8.2	12.8	1.6	3.1	1.9	3.5	1.2	33.7	2.8	31.9
	Japan	0.2	2.0	3.7	14.3	1.1	39.7	0.9	3.1	2.0	3.3	0.8	35.1	2.0	27.5
	LAC	0.4	2.9	4.6	15.9	1.8	10.3	8.6	3.7	2.1	2.7	0.8	34.7	2.8	37.3
	Northern America	0.3	2.4	4.5	16.5	1.3	12.2	1.3	13.4	2.8	2.8	0.9	44.9	3.2	35.8
	Oceania	0.4	2.6	4.7	16.8	1.4	11.6	1.5	4.4	13.2	2.7	1.3	40.7	3.0	36.4
	Rep. Korea	0.2	2.6	7.7	13.9	1.5	15.8	0.8	2.9	1.3	18.2	1.2	31.5	2.6	28.5
	SCSE Asia	0.3	2.9	7.5	15.2	2.5	12.5	1.5	3.4	2.1	4.4	5.4	33.7	3.1	34.4
	United States	0.3	2.5	4.5	17.0	1.4	13.8	1.4	4.8	2.7	3.1	1.0	56.4	3.2	34.6
	Western Asia	0.4	2.8	4.9	15.9	1.6	10.6	1.4	4.0	2.0	2.9	1.0	38.5	17.7	34.0
	Western Europe	0.4	2.8	4.2	18.1	1.4	12.1	1.4	4.1	2.6	2.7	1.0	39.8	2.8	47.3

Figure 13 highlights interesting paths. For instance, nearly half (40.98%) of the total African papers cited by a patent are cited by Western Europe patents. To better understand the content of the science-to-technology flow, we identify the technologies that are fueled by science.

Table 5 reports the most frequent IPC codes to which the technologies in country/territory  $j$ , citing papers published in country/territory  $i$ , are classified. We can observe that, for instance, the US technologies cite African papers that belong to a specific area of biotechnology within genetic engineering (IPC C12N15), indicating that most of the African papers to which the US technologies refer are those related to genetic interventions applied in the treatment of local diseases (like malaria).

<sup>5</sup> Restricting our analysis to the papers cited by at least one patent allows us to focus on science that is close to technological applications.

**Table 5. The most frequent IPC code to which the technologies in country j, citing papers published in country i, are classified.**

	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
Africa	A61K31	A61K31	A61K31	A61K31	A61K31	C12N15	A61K31	A61K31	C12N15	A61K31	C12N15	C12N15	A61K31	A61K31
CEE	A61K31	A61K31	A61K31	C12N15	A61K31	C12N15	A61K31	A61K31	C12N15	C12N15	A61K31	A61K31	A61K31	A61K31
China	A61K31	A61K31	A61K31	A61K31	A61K31	C12N15	A61K31	A61K31	A61K31	H04N19	C12N15	A61K31	A61K31	A61K31
Germany	A61K31	A61K31	A61K31	A61K31	A61K31	C12N15	C12N15	A61K31	C12N15	C12N15	C12N15	A61K31	A61K31	A61K31
India	A61K31	A61K31	A61K31	A61K31	A61K31	A61K31	A61K31	A61K31	C12N15	A61K31	A61K31	A61K31	A61K31	A61K31
Japan	A61K31	A61K31	A61K31	A61K31	A61K31	C12N15	C12N15	A61K31	C12N15	A61K31	C12N15	A61K31	A61K31	A61K31
LAC	A61K31	A61K31	A61K31	A61K31	A61K31	C12N15	A61K31	A61K31	A61K31	A61K31	A61K31	A61K31	A61K31	A61K31
Northern America	A61K31	A61K31	A61K31	A61K31	A61K31	C12N15	C12N15	A61K31	C12N15	A61K31	C12N15	A61K31	A61K31	A61K31
Oceania	C07K14	A61K31	A61K31	A61K31	A61K31	C12N15	C12N15	C12N15	C12N15	A61K31	C12N15	A61K31	A61K31	A61K31
Rep. Korea	A61K31	A61K31	A61K31	A61K31	A61K31	C12N15	A61K31	C12N15	A61K31	A61K31	C12N15	A61K31	A61K31	A61K31
SCSE Asia	A61K31	A61K31	A61K31	A61K31	A61K31	C12N15	A61K31	A61K31	A61K31	A61K31	C12N15	A61K31	A61K31	A61K31
United States	A61K31	A61K31	A61K31	A61K31	A61K31	C12N15	A61K31	A61K31	C12N15	A61K31	C12N15	A61K31	A61K31	A61K31
Western Asia	A61K31	A61K31	A61K31	A61K31	A61K31	C12N15	A61K31	A61K31	A61K31	A61K31	C12N15	A61K31	A61K31	A61K31
Western Europe	A61K31	A61K31	A61K31	A61K31	A61K31	C12N15	A61K31	A61K31	C12N15	A61K31	C12N15	A61K31	A61K31	A61K31

Regardless of the origin of the scientific flow – national or international – the technologies that rely the most on science are those related to pharmaceutical chemistry (IPC code A61K31), and biotechnology and genetic engineering (IPC code C12N15), which appear as the most frequent in Table 5.

To investigate if the patterns of cross-country flows between science and technology change over time, we consider the publication years of the papers cited by patents and replicate Figure 13 by time window. Overall, we consider four time windows: 1985-1995, 1996-2005, 2006-2015, and 2016-2022, respectively.

Comparing Figure 14, Figure 15, Figure 16, and Figure 17, we observe stable paths, with only minor variations over time. The United States and Western Europe have shown their openness to international science since the earliest years. China has become increasingly receptive over time. For instance, looking at the relationship between the United States and China, only 2% of the oldest U.S. papers (published in the time window 1985-1995) have been cited by Chinese patents, while the percentage significantly increases (8.82%) for the most recent papers (published in the time window 2016-2022). China has opened up to international science faster than any other country. As in the case of the reuse of foreign technologies, over time, Chinese investment in strengthening its absorptive capacity resources made the Chinese market able to integrate foreign knowledge into the national system.

**Figure 14. Flows between countries generating science and countries applying that science to produce technologies when the paper cited is published in the time window 1985-1995.**

		Science to technology													
		Destination territories													
Origin territories		Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
	Africa	3.8	2.3	2.8	15.6	1.7	14.9	2.1	4.5	3.7	2.2	0.6	45.7	3.4	38.7
	CEE	0.5	7.8	2.2	18.0	1.3	18.1	1.4	4.1	2.6	1.9	0.6	44.0	2.8	33.6
	China	0.4	2.1	5.8	14.4	1.5	23.9	1.2	3.4	1.9	2.6	1.2	40.5	1.6	28.2
	Germany	0.5	2.6	2.1	36.0	1.0	16.7	1.2	4.0	2.6	2.1	0.6	43.2	2.5	34.4
	India	0.6	1.9	2.9	16.6	7.2	19.1	1.9	3.2	2.2	1.9	0.8	40.5	1.9	29.3
	Japan	0.2	1.7	2.1	14.2	0.8	42.5	0.8	3.4	2.1	2.3	0.6	39.3	1.9	27.3
	LAC	0.5	2.4	2.2	15.0	1.4	13.2	9.1	3.6	2.4	1.4	0.9	40.4	2.2	36.0
	Northern America	0.4	2.4	2.2	16.0	1.0	14.9	1.4	14.4	3.7	2.0	0.7	51.6	3.0	34.0
	Oceania	0.6	2.1	2.3	15.3	1.2	14.1	1.7	5.4	15.5	1.9	1.0	49.0	2.9	35.0
	Rep. Korea	0.1	2.1	2.5	16.0	1.0	26.2	0.7	2.4	0.6	7.8	1.2	41.5	1.5	29.8
	SCSE Asia	0.5	2.1	3.9	14.2	1.8	17.0	2.5	4.2	3.3	3.0	3.9	47.2	3.2	31.9
	United States	0.4	2.2	2.5	16.7	1.2	17.1	1.5	5.8	3.3	2.4	0.9	62.9	3.4	33.7
	Western Asia	0.4	2.1	1.8	15.8	1.0	13.7	1.6	5.3	2.5	1.6	0.7	47.2	20.4	32.2
	Western Europe	0.5	2.4	2.2	17.8	1.2	15.5	1.5	4.8	3.2	1.9	0.7	47.4	2.9	45.5

**Figure 15. Flows between countries generating science and countries applying that science to produce technologies when the paper cited is published in the time window 1996-2005.**

		Science to technology 1996-2005													
		Destination territories													
Origin territories		Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
	Africa	3.4	2.7	4.1	17.1	2.2	12.4	2.9	5.1	3.2	3.2	1.2	39.6	3.4	43.3
	CEE	0.3	9.4	3.4	19.4	1.5	15.3	1.4	4.1	2.5	2.9	0.9	38.6	3.0	35.7
	China	0.2	2.3	10.6	15.0	1.8	18.3	1.2	3.7	2.0	5.7	1.4	35.3	2.9	30.7
	Germany	0.4	2.9	3.5	36.4	1.2	14.4	1.3	4.4	3.0	3.3	1.1	40.0	3.1	37.3
	India	0.8	2.5	4.3	18.2	8.9	14.8	1.9	3.8	2.4	3.3	1.4	36.3	3.0	33.0
	Japan	0.2	2.0	3.6	14.8	1.2	39.7	1.2	3.5	2.5	3.8	0.9	36.5	2.3	28.3
	LAC	0.5	2.6	3.4	16.7	1.6	11.8	9.9	4.0	2.7	2.8	0.8	37.8	2.8	36.2
	Northern America	0.3	2.2	4.0	17.1	1.4	13.7	1.6	13.6	3.2	3.0	1.1	47.1	3.3	37.3
	Oceania	0.4	2.5	3.4	17.6	1.5	12.9	1.9	5.1	15.4	2.9	1.5	43.3	3.3	37.1
	Rep. Korea	0.2	2.3	5.7	13.8	1.7	20.3	1.2	3.5	1.6	16.9	1.3	35.4	2.7	28.5
	SCSE Asia	0.2	2.3	5.4	15.7	2.5	15.3	2.2	4.2	2.8	4.3	5.3	37.3	3.4	35.2
	United States	0.3	2.5	4.3	18.3	1.5	15.0	1.6	5.5	3.3	3.7	1.1	56.9	3.6	36.1
	Western Asia	0.5	2.8	3.6	16.1	1.6	12.0	1.7	4.8	2.9	2.8	1.1	42.3	19.6	34.9
	Western Europe	0.4	2.8	3.6	19.3	1.4	13.4	1.7	4.8	3.2	3.1	1.1	42.1	3.1	47.4

**Figure 16. Flows between countries generating science and countries applying that science to produce technologies when the paper cited is published in the time window 2006-2015.**

		Science to technology 2006-2015													
		Destination territories													
Origin territories		Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
	Africa	3.3	3.1	6.0	15.4	1.9	8.6	1.8	3.6	2.0	3.1	1.4	36.8	3.0	42.2
	CEE	0.2	12.1	5.3	18.1	1.6	10.0	1.1	3.0	1.8	3.2	0.9	34.0	2.7	36.2
	China	0.3	2.7	15.3	14.1	1.9	12.3	0.9	3.1	1.6	5.6	1.2	31.4	2.8	30.8
	Germany	0.2	3.1	5.6	37.1	1.3	9.4	0.9	3.0	1.7	3.3	1.0	32.4	2.6	36.5
	India	0.4	3.8	7.3	16.9	8.0	10.3	1.6	3.0	1.8	4.5	1.4	32.3	3.1	32.7
	Japan	0.2	2.3	5.6	13.2	1.3	37.8	0.7	2.6	1.6	4.1	1.1	29.8	2.1	27.0
	LAC	0.4	3.2	5.5	15.2	2.1	9.3	8.8	3.6	2.1	3.0	0.8	32.3	3.1	38.3
	Northern America	0.3	2.5	6.1	16.1	1.4	9.3	1.1	13.7	2.4	3.2	1.1	40.6	3.3	36.3
	Oceania	0.3	2.9	6.3	16.8	1.5	9.7	1.4	3.7	11.6	2.9	1.6	36.7	3.0	37.4
	Rep. Korea	0.2	2.8	8.7	14.1	1.4	13.7	0.7	2.8	1.4	18.7	1.3	30.3	2.6	28.5
	SCSE Asia	0.3	3.1	7.9	14.9	2.4	11.5	1.3	3.2	1.8	4.5	6.3	32.9	3.3	34.3
	United States	0.3	2.7	6.5	16.1	1.5	9.8	1.1	3.9	2.0	3.5	1.2	52.5	3.1	34.7
	Western Asia	0.4	3.1	6.4	15.5	1.8	8.6	1.2	3.1	1.4	3.4	0.9	34.6	16.7	34.5
	Western Europe	0.3	3.0	5.7	17.3	1.5	9.1	1.2	3.4	1.9	3.0	1.1	34.9	2.7	49.1

**Figure 17. Flows between countries generating science and countries applying that science to produce technologies when the paper cited is published in the time window 2016-2022.**

Science to technology 2016-2022

	Destination territories														
	Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe	
Origin territories	Africa	1.7	2.8	9.6	17.7	2.3	8.4	0.8	3.0	1.9	4.1	1.3	24.3	2.7	35.9
CEE	0.1	14.9	8.3	17.9	1.5	8.2	0.9	2.2	1.1	3.4	0.7	24.0	2.4	34.3	
China	0.1	2.7	20.3	14.5	2.3	8.7	0.4	2.3	1.0	6.8	0.8	24.7	2.2	30.2	
Germany	0.2	3.0	7.3	39.6	1.5	6.2	0.6	2.4	0.8	2.5	0.7	23.4	1.8	33.8	
India	0.2	2.9	10.2	18.6	10.8	7.5	1.1	2.6	1.0	3.9	0.8	22.2	3.2	30.2	
Japan	0.1	2.5	7.7	12.6	1.1	39.4	0.4	2.0	1.1	4.1	0.8	20.7	1.5	23.1	
LAC	0.1	3.9	7.3	17.8	1.8	6.5	4.9	3.1	0.7	2.8	0.6	26.5	2.9	39.1	
Northern America	0.0	3.0	9.3	17.0	1.9	7.7	0.5	12.3	1.1	3.8	0.6	31.2	2.6	32.7	
Oceania	0.3	3.1	8.9	17.5	2.0	8.0	0.8	3.2	9.7	3.5	1.0	28.7	2.0	33.9	
Rep. Korea	0.2	2.8	11.3	12.9	1.8	9.3	0.3	1.9	0.7	23.4	0.9	22.1	2.1	27.8	
SCSE Asia	0.1	3.3	11.4	15.7	3.1	9.6	0.7	2.6	1.5	5.0	3.9	23.6	2.2	34.8	
United States	0.1	2.2	8.8	15.4	1.8	7.5	0.6	2.7	1.0	3.8	0.7	45.0	2.3	31.2	
Western Asia	0.3	2.8	9.9	15.6	2.0	7.1	0.8	2.8	0.8	3.8	1.1	24.9	14.7	33.5	
Western Europe	0.2	3.1	7.9	17.3	1.7	6.8	0.7	2.5	1.1	3.1	0.8	25.9	2.1	48.1	

How long does it take for science to be absorbed by technologies? Figure 18 illustrates the average time elapsing between the publication of a paper in country/territory  $i$  and its citation by a patent in country/territory  $j$ . Each cell  $[i,j]$  indicates the time it takes for papers authored by researchers affiliated with institutions in country/territory  $i$  to be cited by patents developed by inventors in country/territory  $j$ . Interestingly, Chinese papers are cited in a relatively short time by patents filed in other countries. If a foreign patent cites a Chinese paper, it happens within a maximum of 8 years from the paper's publication. On the contrary, papers published in the United States take longer to be absorbed by patents, with a minimum average time of 9 years and 4 months for Japanese patents, and a maximum average time of more than 13 years for African patents. A possible explanation for these time differences is the different nature of the publication content, with U.S. publications having more basic science content and Chinese ones having more applied content. However, when we look at the absolute number of documents entering those statistics (see Figure 19), i.e., the number of papers produced in one country, and supporting other countries' technologies, the United States appears as the most prolific country.

**Figure 18. Average time taken by scientific papers written in the origin territories and to be cited by patents in the destination territories.**

		Average time to cite science													
		Destination territories													
Origin territories		Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
	Africa	9.4	11.2	9.3	9.3	11.4	9.0	11.6	11.8	11.8	10.3	9.3	10.6	11.2	9.6
	CEE	12.3	8.5	9.7	9.4	10.7	9.3	11.1	11.2	10.7	9.9	10.2	10.4	11.2	9.6
	China	8.6	7.5	6.3	6.8	7.6	6.6	8.4	7.9	8.0	6.4	7.6	7.6	8.1	7.0
	Germany	11.9	11.1	10.3	8.6	11.7	9.2	11.4	11.1	11.2	10.1	10.8	10.5	11.1	9.8
	India	11.7	9.3	8.5	8.7	8.4	8.8	10.9	10.3	10.4	8.8	9.2	9.9	9.9	9.1
	Japan	13.2	12.4	11.4	10.1	13.2	7.0	12.4	11.8	11.7	10.6	11.1	10.4	12.0	10.4
	LAC	10.9	9.1	8.4	8.1	9.7	8.2	8.7	9.8	10.0	8.8	9.7	9.6	9.5	8.7
	Northern America	12.2	11.8	10.2	9.8	11.9	8.9	13.5	9.2	12.0	10.3	10.8	10.5	11.2	10.0
	Oceania	11.3	10.8	9.6	9.4	11.0	8.7	11.3	11.3	8.2	9.8	10.2	10.2	11.4	9.8
	Rep. Korea	8.1	8.4	7.5	7.4	8.5	6.7	9.1	8.3	8.4	5.5	8.2	7.9	8.7	7.6
	SCSE Asia	10.6	8.1	7.3	7.6	8.4	7.3	9.8	8.6	8.6	7.4	5.9	8.7	9.0	7.8
	United States	13.6	13.1	11.4	10.6	13.0	9.4	13.4	12.5	12.7	11.3	12.4	10.3	12.4	10.9
	Western Asia	9.6	10.1	9.3	9.3	10.2	8.7	12.3	11.0	10.7	9.7	10.7	9.9	8.4	9.4
	Western Europe	12.1	11.4	10.6	9.6	11.8	9.0	12.0	11.7	11.7	10.4	11.2	10.5	11.5	9.3

NOTE: When multiple patents cite the same paper, we consider the publication year of the patent that cites first.

**Figure 19. Number of scientific papers written in the origin territories and cited by patents in the destination territories.**

		Number of articles cited by patents													
		Destination territories													
Origin territories		Africa	CEE	China	Germany	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia	Western Europe
	Africa	418	377	670	2158	262	1459	276	546	346	403	153	5111	411	5463
	CEE	112	4209	1702	7577	583	5375	470	1383	809	1132	330	14967	1115	14307
	China	212	2308	13004	12709	1709	11891	778	2731	1415	5029	1049	27794	2353	26939
	Germany	411	3588	5151	45907	1524	15550	1262	4419	2715	3599	1130	45108	3280	44473
	India	119	641	1286	3798	1756	2750	347	675	400	761	255	7239	599	6862
	Japan	297	2567	4815	18467	1422	51292	1140	3955	2595	4264	1060	45302	2606	35552
	LAC	97	656	1014	3554	400	2289	1916	820	475	602	176	7735	634	8317
	Northern America	171	1421	2683	9734	779	7173	769	7891	1675	1678	559	26513	1871	21108
	Oceania	142	1037	1860	6693	578	4633	607	1773	5280	1077	534	16214	1186	14495
	Rep. Korea	61	760	2275	4094	440	4649	238	865	395	5338	363	9253	753	8377
	SCSE Asia	67	642	1672	3407	564	2812	344	766	472	984	1220	7570	700	7724
	United States	1866	14992	27249	103607	8555	84213	8339	29334	16442	18931	6190	343195	19687	210618
	Western Asia	114	718	1276	4133	412	2753	374	1043	512	752	252	10017	4605	8830
	Western Europe	1483	10956	16762	71999	5531	48003	5499	16340	10142	10819	3776	158003	11237	188115

## Patent families and international knowledge diffusion

For the analysis of international patent families as indicators of knowledge diffusion, we consider all DOCDB patent families comprising patent filings to more than one patent office (4,197,521 families in total) and priority years 1985-2022, as available in PATSTAT Autumn 2024.<sup>6</sup> In contrast with the previous indicators,

<sup>6</sup> The dataset used for this section comprises all the 4,197,521 international DOCDB families and all their patent applications with earliest filing year 1985-2022 and appln\_kind equal to A included in PATSTAT Autumn 2024. Patent applications with other kind codes are excluded to focus on national/regional phase entries for PCT and to avoid duplications. Based on this, we do not include patent applications with kind code W (PCT applications at the international phase) or patent applications with kind code T (code used in some national offices of EPC member states to indicate that an EPO granted patent has been translated and validated in the country). This

in this section we refer to patent offices, rather than countries or territories, but use a similar terminology (e.g. territories, understood as jurisdictions in this case). For instance, we pool together Western Europe, Germany and CEE into a single category: Europe. We create a single broader region for Europe mostly to be able to classify filings to the European Patent Office (EPO) in it, as it includes countries from Western, Eastern and Central Europe.<sup>7</sup>

Table 6 presents the top bilateral links within families, considering different priority and destination patent offices over four periods of priority years spanning almost forty years (1985-1995, 1996-2005, 2006-2015, 2016-2022). The top priority-destination pair is Europe-Europe in the early periods, followed by different combinations of links between Europe, United States and Japan. China starts to appear among the top for origin and destination offices within international families in the second period, first as destination of families with priority in Japan, Europe and United States, until the mid-2000s, after the entry of China in the WTO and signature of TRIPS, when China starts to appear as priority office at the top with USPTO as the destination office. This is consistent with Chinese companies being among the top patent applicants in many jurisdictions, including United States, in recent years.

It is worth noting that the number of families increases in the first three periods for most of these pairs, but decreases abruptly for some of the top pairs/corridors between the second and third period. This decrease reflects the publication delay that characterizes patents, the time needed for patent families to be formed and the additional time required for patent documents from all offices involved to appear in patent databases, and the possibility of missing data for some countries.

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dataset is a small portion of the total number of DOCDB patent families with priority years 1985-2022 in PATSTAT Autumn 2024, which is equal to 36,933,401 and mostly includes national DOCDB families (those whose members remain domestic, i.e. all members are applications to the same patent office).

<sup>7</sup> In addition we classify regional office EAPO in Europe, ARIPO and OAPI in Africa and GCC in Western Asia.

**Table 6. The top-10 bilateral links within international patent families, 1985-2022**

1985-1995			1996-2005		
Priority	Destination	International families	Priority	Destination	International families
Europe	Europe	279,976	Europe	Europe	335,438
Europe	United States	157,321	Europe	United States	253,504
Europe	Japan	141,313	Japan	United States	252,736
United States	Europe	127,476	United States	Europe	178,612
Japan	United States	120,809	Europe	Japan	146,268
United States	Japan	105,229	United States	Japan	122,885
United States	Northern America	90,202	Japan	Europe	118,226
Japan	Europe	80,202	Japan	China	117,187
Europe	Northern America	63,906	Europe	Oceania	115,136
Europe	Oceania	62,052	Europe	China	99,697
2006-2015			2016-2022		
Priority	Destination	International families	Priority	Destination	International families
Europe	Europe	325,742	Japan	United States	195,682
Japan	United States	309,177	Europe	United States	193,777
Europe	United States	285,993	Europe	Europe	192,656
Japan	China	210,666	Japan	China	161,142
Europe	China	186,527	China	United States	160,697
United States	Europe	165,895	Europe	China	155,806
United States	China	145,562	Rep. Korea	United States	112,998
Rep. Korea	United States	142,380	United States	Europe	112,093
China	United States	136,730	United States	China	108,701

Figure 20 shows four heatmaps (almost four decades, 1985-2022) with international patent family links by destination. Each cell  $[i,j]$  counts the number of international patent families with priority office  $i$  and destination office  $j$ , divided by the total number of international patent families with priority office  $i$ . In other words, it shows the breakdown by destination of all international patent families having priority in a given territory. The diagonal is blank for single countries (e.g. India, Japan, Rep. Korea, United States) and for regions dominated by single countries (Northern America with Canada) because by construction the analysis focuses on cross-border links, excluding pairs where the priority and the destination office are the same.

Reading by rows, of all international patent families with a priority office in Africa, 19.9% are extended to another patent office in Africa. The darker cells in all four periods correspond to patent families with Europe, Japan and United States as destination territories, but China takes over as a frequent destination office over the years, with Japan decreasing its relevance. In addition, it is worth noting that Europe is showing a decreasing trend as destination, with some exceptions, while US is growing.

**Figure 20. International patent family links by destination**

**Figure 20a. 1985-1995**

		Destination territories											
		Africa	China	Europe	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia
Priority territories	Africa	19.9	7.7	61.7	1.5	18.4	13.8	24.5	38.3	6.1	2.6	30.6	6.1
	China	2.5	6.6	54.2	0.5	42.3	6.4	14.0	27.0	8.6	2.5	52.4	1.4
	Europe	7.5	8.8	88.2	1.0	44.5	8.6	20.1	19.6	10.1	2.0	49.6	3.4
	India	8.5	14.6	59.8	0.0	15.9	7.3	17.1	20.7	6.1	7.3	40.2	4.9
	Japan	0.5	10.8	54.0	0.1	0.0	1.2	9.7	5.0	26.3	2.1	81.4	0.2
	LAC	6.2	9.6	62.2	0.7	25.7	32.1	23.2	20.5	5.8	1.8	45.9	2.2
	Northern America	3.8	5.8	38.2	1.1	20.0	5.8	0.0	20.7	4.2	1.0	80.5	1.2
	Oceania	17.1	14.7	52.6	2.8	26.8	10.6	28.4	45.7	9.1	5.2	46.4	2.4
	Rep. Korea	0.3	28.0	39.9	0.8	73.2	2.0	3.1	3.5	0.0	1.8	73.0	0.5
	SCSE Asia	18.3	33.3	63.3	3.3	31.7	15.0	25.0	28.3	13.3	11.7	56.7	5.0
	United States	5.9	12.4	74.1	0.7	61.2	14.3	52.5	31.2	17.2	4.0	0.0	4.8
	Western Asia	15.2	6.2	67.4	0.4	31.8	7.1	21.4	29.5	7.2	1.2	63.1	0.8

**Figure 20.b. 1996-2005**

		Destination territories											
		Africa	China	Europe	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia
Priority territories	Africa	11.8	22.4	56.5	0.0	18.6	20.5	23.0	54.0	9.9	4.3	36.6	8.1
	China	0.4	3.6	14.7	0.0	18.9	1.2	2.1	9.1	4.8	0.7	84.9	0.2
	Europe	5.0	23.4	78.8	0.1	34.3	11.9	17.3	27.0	11.9	2.0	59.5	3.0
	India	27.2	24.3	50.3	0.0	21.3	26.6	24.3	40.2	12.4	7.1	75.1	5.3
	Japan	0.3	39.7	40.1	0.0	0.0	1.3	3.9	3.9	25.0	2.3	85.7	0.2
	LAC	7.9	21.1	48.8	0.2	18.5	46.9	21.1	30.9	10.0	2.9	60.3	2.1
	Northern America	1.8	10.2	28.9	0.0	11.8	6.3	0.0	24.2	3.9	0.6	85.8	1.1
	Oceania	16.9	24.8	55.6	0.1	30.4	11.7	33.4	34.5	10.3	4.8	68.5	3.8
	Rep. Korea	0.4	49.2	27.5	0.1	44.3	2.1	2.1	6.7	0.0	0.9	84.1	0.3
	SCSE Asia	2.9	36.2	35.2	0.2	27.9	4.2	6.3	24.2	12.2	12.4	70.3	1.5
	United States	3.3	34.8	69.0	0.1	47.5	15.5	33.7	35.8	19.1	4.1	0.0	3.2
	Western Asia	6.0	15.8	57.2	0.1	24.1	9.5	22.4	57.5	10.0	1.2	70.0	0.6

**Figure 20.c. 2006-2015**

		Destination territories											
		Africa	China	Europe	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia
Priority territories	Africa	21.8	30.7	51.5	3.0	21.8	18.8	20.8	28.7	12.9	6.9	58.4	4.0
	China	0.6	22.0	23.9	0.4	14.7	2.8	1.9	2.3	7.2	1.4	85.2	0.2
	Europe	3.2	43.2	75.4	1.0	24.1	13.9	14.1	8.4	13.3	2.8	66.2	2.2
	India	6.8	23.3	41.4	0.0	12.6	10.4	8.0	10.8	8.2	5.8	86.8	3.3
	Japan	0.2	56.4	31.6	0.4	0.0	2.3	1.7	1.7	19.0	1.8	82.8	0.1
	LAC	6.8	25.3	45.4	1.3	15.0	50.3	19.7	11.2	8.7	3.4	73.3	2.2
	Northern America	1.8	15.6	27.2	1.0	7.6	9.0	0.0	9.9	4.6	1.0	94.4	1.0
	Oceania	6.8	21.0	36.8	0.6	12.1	8.9	17.1	40.5	4.5	3.6	71.3	1.2
	Rep. Korea	0.2	44.4	26.8	0.2	20.9	1.3	1.0	1.4	0.0	0.8	89.5	0.2
	SCSE Asia	3.1	54.1	38.1	1.9	23.6	8.5	6.9	16.0	15.0	16.0	71.7	1.6
	United States	1.5	62.5	71.2	0.8	32.0	14.9	22.7	11.6	18.9	3.3	0.0	2.2
	Western Asia	2.7	19.8	68.7	1.6	13.1	9.9	12.7	9.5	10.1	5.6	74.0	0.6

**Figure 20.d. 2016-2022**

		Destination territories											
		Africa	China	Europe	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia
Priority territories	Africa	9.5	27.0	69.8	0.0	17.5	12.7	19.0	25.4	4.8	0.0	57.1	0.0
	China	1.9	17.1	34.0	0.0	16.8	2.0	2.2	4.0	8.7	1.6	77.1	0.2
	Europe	1.7	52.4	64.9	0.0	19.2	8.5	11.3	7.1	12.7	1.4	65.2	2.3
	India	9.3	29.3	57.3	0.0	14.7	22.7	16.0	20.0	10.7	8.0	77.3	4.0
	Japan	0.0	65.2	29.1	0.0	0.0	1.1	1.0	1.1	14.5	1.4	79.1	0.1
	LAC	4.3	26.1	41.8	0.0	10.1	44.1	19.2	13.0	5.3	1.5	70.9	2.4
	Northern America	1.5	13.4	27.5	0.0	7.2	10.6	0.0	14.3	5.0	1.3	94.0	1.7
	Oceania	2.2	25.8	39.6	0.0	8.7	8.1	19.6	10.9	6.0	3.5	71.7	2.8
	Rep. Korea	0.1	61.4	31.4	0.0	16.5	0.7	0.9	1.6	0.0	0.8	88.8	0.1
	SCSE Asia	1.6	46.9	26.3	0.0	20.2	4.6	3.8	11.0	12.7	10.5	74.4	1.0
	United States	0.6	67.6	69.7	0.0	18.8	7.8	15.5	7.8	12.7	1.4	0.0	2.5
	Western Asia	1.7	21.7	74.6	0.0	12.3	6.5	9.6	9.2	9.9	3.7	64.5	1.0

Figure 21 shows the perspective of the destination offices, by showing the origins (priorities) of the international patent families that reach them. Reading by columns, of all international patent families extended to Africa, only 0.1% originate in Africa. Europe and United States are the regions where most international patent families originates in the early years considered (1985-1995): 66.3% of families reaching Africa had a priority in Europe, 28.2% in the United States. This has changed over the years with the emergence of large patent applicants from China for instance, as reflected in the last heatmap, for the period 2016-2022, where we can see that of all international patent families extended to Africa, 38.1% were first filed in China, 47.7% in Europe and only 9.5% in the United States. Even though, as mentioned earlier, the breakdown for the most recent periods can be affected by data truncation issues as some patent families may still be developing, they reflect changes worth analyzing further.

**Figure 21. International patent family links by origin**

**Figure 21.a. 1985-1995**

		Destination territories											
		Africa	China	Europe	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia
Priority territories	Africa	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
	China	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
	Europe	66.3	40.5	56.2	65.2	54.9	49.7	37.5	48.8	31.5	37.3	53.5	54.7
	India	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Japan	2.0	23.2	16.1	4.4	0.0	3.3	8.4	5.9	38.6	19.1	41.1	1.6
	LAC	0.2	0.1	0.1	0.1	0.1	0.6	0.1	0.2	0.1	0.1	0.2	0.1
	Northern America	0.6	0.5	0.4	1.2	0.4	0.6	0.0	0.9	0.2	0.3	1.6	0.4
	Oceania	1.3	0.6	0.3	1.5	0.3	0.5	0.4	0.9	0.2	0.8	0.4	0.3
	Rep. Korea	0.1	4.0	0.8	1.5	2.8	0.4	0.2	0.3	0.0	1.1	2.5	0.2
	SCSE Asia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	United States	28.2	30.7	25.6	25.7	40.9	44.5	52.9	42.1	29.1	40.9	0.0	42.4
	Western Asia	1.2	0.3	0.4	0.2	0.3	0.4	0.4	0.7	0.2	0.2	0.6	0.1

**Figure 21.b. 1996-2005**

		Destination territories											
		Africa	China	Europe	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia
Priority territories	Africa	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	China	0.4	0.3	0.7	0.0	1.9	0.4	0.4	1.2	0.8	0.7	4.3	0.3
	Europe	63.8	28.6	50.1	57.0	46.7	50.5	41.0	48.7	28.5	30.5	41.3	56.5
	India	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Japan	2.6	33.6	17.7	7.7	0.0	3.8	6.4	4.9	41.5	25.0	41.2	2.7
	LAC	0.6	0.2	0.2	0.6	0.2	1.2	0.3	0.3	0.1	0.3	0.3	0.2
	Northern America	0.5	0.3	0.4	0.3	0.3	0.6	0.0	0.9	0.2	0.2	1.3	0.4
	Oceania	4.8	0.7	0.8	1.4	0.9	1.1	1.8	1.4	0.5	1.7	1.1	1.6
	Rep. Korea	0.8	10.3	3.0	4.9	10.3	1.5	0.9	2.1	0.0	2.5	10.0	0.9
	SCSE Asia	0.1	0.1	0.1	0.2	0.1	0.1	0.0	0.1	0.1	0.6	0.2	0.1
	United States	25.4	25.8	26.7	27.6	39.2	40.3	48.6	39.2	27.9	38.3	0.0	37.0
	Western Asia	0.8	0.2	0.4	0.3	0.4	0.4	0.6	1.1	0.3	0.2	0.5	0.1

**Figure 21.c. 2006-2015**

		Destination territories											
		Africa	China	Europe	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia
Priority territories	Africa	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	China	5.0	5.4	5.5	6.7	9.9	3.9	2.4	4.7	6.3	7.6	15.4	2.2
	Europe	68.3	28.6	46.7	48.9	43.8	52.9	48.2	46.3	31.0	38.9	32.2	59.5
	India	0.4	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.2	0.1	0.2
	Japan	4.1	32.3	16.9	16.7	0.0	7.7	5.0	8.2	38.2	21.8	34.8	2.9
	LAC	1.5	0.2	0.3	0.6	0.3	1.9	0.7	0.6	0.2	0.5	0.4	0.6
	Northern America	0.4	0.1	0.2	0.5	0.1	0.3	0.0	0.6	0.1	0.1	0.5	0.3
	Oceania	0.7	0.1	0.1	0.1	0.1	0.2	0.3	1.1	0.1	0.3	0.2	0.2
	Rep. Korea	1.3	10.8	6.1	3.2	14.0	1.9	1.2	2.9	0.0	4.0	16.0	1.7
	SCSE Asia	0.3	0.2	0.1	0.4	0.2	0.1	0.1	0.4	0.2	1.0	0.2	0.2
	United States	17.5	22.3	23.8	22.2	31.3	30.5	41.7	34.7	23.8	25.0	0.0	32.1
	Western Asia	0.4	0.1	0.3	0.6	0.2	0.3	0.3	0.4	0.2	0.6	0.3	0.1

**Figure 21.d. 2016-2022**

		Destination territories											
		Africa	China	Europe	India	Japan	LAC	Northern America	Oceania	Rep. Korea	SCSE Asia	United States	Western Asia
Priority territories	Africa	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	China	38.1	6.6	14.4	0.0	24.3	8.8	6.9	17.3	16.1	23.6	24.0	3.6
	Europe	47.7	28.7	39.1	66.7	39.4	53.2	49.3	44.1	33.4	28.5	28.9	57.3
	India	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Japan	1.1	29.7	14.6	0.0	0.0	5.9	3.7	5.9	31.7	23.3	29.2	2.7
	LAC	1.1	0.1	0.2	0.0	0.2	2.6	0.8	0.7	0.1	0.3	0.3	0.6
	Northern America	0.3	0.0	0.1	0.0	0.1	0.4	0.0	0.6	0.1	0.2	0.3	0.3
	Oceania	0.1	0.0	0.1	0.0	0.0	0.1	0.2	0.2	0.0	0.2	0.1	0.2
	Rep. Korea	1.3	14.4	8.1	16.7	14.6	1.9	1.7	4.1	0.0	6.9	16.8	1.5
	SCSE Asia	0.2	0.1	0.1	0.0	0.2	0.1	0.1	0.3	0.1	0.9	0.1	0.1
	United States	9.5	20.1	22.8	16.7	20.9	26.4	36.8	26.1	18.1	15.2	0.0	33.5
	Western Asia	0.6	0.1	0.5	0.0	0.3	0.5	0.5	0.7	0.3	0.9	0.3	0.3

## 5. Conclusion

This paper has examined how technological knowledge diffuses internationally by integrating theory, measurement, and evidence. Section 2 outlined the historical and conceptual foundations of diffusion, stressing the roles of trade, foreign direct investment, migration, and science–technology linkages, among others. Section 3 highlighted methodological challenges, including how different proxies capture complementary dimensions of the same process. Section 4 then provided empirical evidence based on global patents. Results on patent citations reveal the directional flows of knowledge, showing persistent dominance by advanced economies but also rising contributions from emerging countries. Analyses of patent extensions through international families demonstrate how inventions circulate across markets, with some technologies spreading widely and rapidly while others remain nationally concentrated. These patterns are

complemented by results on technological trajectories and global science diffusion, which reveal how specific domains evolve and how scientific inputs shape the geography of innovation.

Overall, this paper shows that some countries act as senders of technologies, while others receive them. Our mapping shows that countries such as the United States, Western Europe, and Japan are highly active in both sending and receiving technologies. At the same time, the Global South tends to remain inactive due to its limited capabilities, which make it challenging for technological development as well as the absorption of foreign technologies. Analysing the reuse flows of technologies across countries, most of them are reused in the countries where they originated. However, there are also relevant inter-country exchanges such as the one between the United States and Western Europe, or Japan. Some differences appear when looking at the temporal dimension. The United States and Western Europe are early users, while countries like China are open to reusing mature technologies. More recent technologies show a more equal distribution of their reuses across countries than older technologies, for which reuses were concentrated mainly in Germany, Japan, the United States, and Western Europe.

The analysis of global science diffusion shows that scientific knowledge is increasingly embedded in inventive activity worldwide, with patent references to scientific publications growing steadily over time. This reinforces the idea that science serves as a global input into innovation, shaping technological opportunities across borders. At the same time, results on international patent family extensions demonstrate that firms actively decide where to protect their inventions, signaling strategic choices about which markets are likely to absorb or further develop given technologies. Together, these findings suggest that diffusion through science and diffusion through market-oriented patenting strategies are complementary yet distinct mechanisms that help explain the global geography of innovation.

To understand the technological development, it is important to map how science flows across countries to fuel technologies. The largest share of science produced in a country fuels national technologies, however, countries such as the United States and Western Europe show openness to worldwide science. Despite a weak position, the Global South's science plays an important role as an input for other countries' technologies, particularly in subjects related to genetic interventions for treating local diseases. Interestingly, China is progressively opening up to transnational science, and it is the country that has opened up faster than any other country.

The combined evidence from trajectories, science, citations, and patent extensions points to the importance of considering multiple channels of diffusion simultaneously. Each indicator captures a different facet of how technologies spread: trajectories map long-run evolutionary paths, science highlights the role of foundational knowledge, citations trace the building blocks of invention, and extensions reveal the global reach of market protection strategies. By analyzing

them together, we obtain a more comprehensive picture of international technology diffusion—one that highlights both the concentration of innovation in advanced economies and the growing contributions of emerging countries, while also underlining the persistent exclusion of large parts of the Global South.

Taken together, the evidence paints a nuanced picture of how technology travels across borders. Citations highlight where knowledge originates and who builds upon it, while family extensions show how rights are strategically projected into foreign markets. Trajectories capture the longer-term evolution of technological fields, and scientific references reveal the growing weight of global science as an input into invention. Considering all of these together makes clear that no single measure suffices; triangulation is essential for understanding diffusion in its full complexity. Substantively, the results point to three broader conclusions. First, global innovation remains highly asymmetric: advanced economies still concentrate most knowledge flows, yet emerging economies, especially China, are increasingly central players. Second, the diffusion of science is reshaping the geography of innovation, particularly in fast-moving fields where scientific inputs are critical. Third, the benefits of diffusion are far from universal: many regions of the Global South remain excluded, suggesting that openness alone will not close global divides without deliberate investments in local absorptive capacity. For policymakers, this underscores the need to combine openness to trade, mobility, and scientific exchange with long-term strategies to build domestic capabilities. For scholars, the results encourage new work on the causal mechanisms of diffusion, especially the interplay between citations, patenting strategies, and scientific knowledge. Only by integrating these perspectives can we fully grasp the changing geography of technology and its implications for growth, competitiveness, and inequality.

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## Appendices

### Appendix A: List of country codes and world region names

ISO2	World Region	ISO2	World Region	ISO2	World Region	ISO2	World Region	ISO2	World Region
AD	Western Europe	CZ	CEE	KE	Africa	PH	SCSE Asia	TT	LAC
AE	Western Asia	DD	Western Europe	KG	SCSE Asia	PK	SCSE Asia	TV	Oceania
AF	SCSE Asia	DE	Germany	KH	SCSE Asia	PL	CEE	TZ	Africa
AG	LAC	DJ	Africa	KI	Oceania	PT	Western Europe	UA	CEE
AL	CEE	DK	Western Europe	KM	Africa	PW	Oceania	UG	Africa
AM	Western Asia	DM	LAC	KN	LAC	PY	LAC	US	United States
AO	Africa	DO	LAC	KP	SCSE Asia	QA	Western Asia	UY	LAC
AR	LAC	DZ	Africa	KR	Rep. Korea	RO	CEE	UZ	SCSE Asia
AT	Western Europe	EC	LAC	KW	Western Asia	RS	CEE	VC	LAC
AU	Oceania	EE	CEE	KZ	SCSE Asia	RU	CEE	VE	LAC
AZ	Western Asia	EG	Africa	LA	SCSE Asia	RW	Africa	VN	SCSE Asia
BA	CEE	ER	Africa	LB	Western Asia	SA	Western Asia	VU	Oceania
BB	LAC	ES	Western Europe	LC	LAC	SB	Oceania	WS	Oceania
BD	SCSE Asia	ET	Africa	LI	Western Europe	SC	Africa	YE	Western Asia
BE	Western Europe	FI	Western Europe	LK	SCSE Asia	SD	Africa	YU	CEE
BF	Africa	FJ	Oceania	LR	Africa	SE	Western Europe	ZA	Africa
BG	CEE	FR	Western Europe	LS	Africa	SG	SCSE Asia	ZM	Africa
BH	Western Asia	GA	Africa	LT	CEE	SI	CEE	ZW	Africa
BI	Africa	GB	Western Europe	LU	Western Europe	SK	CEE	HK	China
BJ	Africa	GD	LAC	LV	CEE	SL	Africa	TW	China
BN	SCSE Asia	GE	Western Asia	LY	Africa	SM	Western Europe	KO	Rep. Korea
BO	LAC	GH	Africa	MA	Africa	SN	Africa	NC	Oceania
BR	LAC	GM	Africa	MC	Western Europe	SO	Africa	AI	LAC
BS	LAC	GN	Africa	MD	CEE	SR	LAC	UM	United States
BT	SCSE Asia	GQ	Africa	ME	CEE	ST	Africa	VG	LAC
BW	Africa	GR	Western Europe	MG	Africa	SU	CEE	PR	United States
BY	CEE	GT	LAC	MH	Oceania	SV	LAC	BM	LAC
BZ	LAC	GY	LAC	MK	CEE	SY	Western Asia	GI	Western Europe
CA	Northern America	HN	LAC	ML	Africa	SZ	Africa	MO	China
CD	Africa	HR	CEE	MM	SCSE Asia	TD	Africa	BU	SCSE Asia
CF	Africa	HT	LAC	MN	SCSE Asia	TG	Africa	AN	LAC
CG	Africa	HU	CEE	MR	Africa	TH	SCSE Asia	MS	LAC
CH	Western Europe	ID	SCSE Asia	MT	Western Europe	TJ	SCSE Asia	NA	Africa
CI	Africa	IE	Western Europe	MU	Africa	TM	SCSE Asia	KY	LAC
CL	LAC	IL	Western Asia	NL	Western Europe	TN	Africa	TK	Oceania
CM	Africa	IN	India	NO	Western Europe	TO	Oceania	RE	Africa
CN	China	IQ	Western Asia	NP	SCSE Asia	TR	Western Asia	VA	Western Europe
CO	LAC	IR	SCSE Asia	NR	Oceania	TH	SCSE Asia	GP	LAC
CR	LAC	IS	Western Europe	NZ	Oceania	TJ	SCSE Asia	FO	Western Europe
CS	CEE	IT	Western Europe	OM	Western Asia	TM	SCSE Asia	VI	United States
CU	LAC	JM	LAC	PA	LAC	TN	Africa	IM	Western Europe
CV	Africa	JO	Western Asia	PE	LAC	TO	Oceania	MP	United States
CY	Western Asia	JP	Japan	PG	Oceania	TR	Western Asia		

Note: CEE stands for Central and Eastern Europe, LAC stands for Latin America and the Caribbean.

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