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Sources of knowledge flow between developed and developing nations

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The present paper is based on a chapter prepared for the forthcoming *Handbook on Trade in Knowledge* edited by Jayashree Watal from the World Trade Organization.

Abstract

This paper provides a long-term view on the sources of knowledge flow between developed and developing nations. It relies on patent data to explore three potential sources: R&D collaboration, technology sourcing, and technology transfer. All three sources provide a very consistent message. First, knowledge flows with East Asia, particularly China, are occurring more frequently. Second, knowledge flows are increasingly concentrateded in information and communication technologies. Third, the United States & Canada had traditionally larger patenting activity with Asia than Europe, but the share of activity between Europe and Asia has been increasing in recent years. Fourth, larger patenting activity between the United States & Canada and Asia implies that the U.S./Canada region is more likely to benefit from reverse knowledge flows as China progresses towards becoming a technological leader.

Keywords: international technology sourcing; R&D offshoring; R&D collaboration; technology transfer; patent

Introduction

R&D globalization is a defining feature of modern innovation systems and a major driver of productivity growth (Eaton & Kortum 1996; Thomson & de Rassenfosse 2016). Innovating firms set up R&D labs abroad or cooperate with foreign partners in order to tap into an ever more globally dispersed knowledge frontier and to reduce R&D costs (Harhoff et al. 2014).

From the viewpoint of host countries, policy makers are keen to attract foreign R&D. The knowledge that flows from foreign R&D may be appropriated by local firms and raise their productivity level. If appropriation takes place without local firms contributing to the cost of the research, one talks of “knowledge spillovers”. Appropriation can also occur in the context of a transaction on the market for technology (Arora et al. 2004).

The existence of cross-border knowledge flows has been well documented in the academic literature. Most of the literature tracks knowledge flows by means of patent citations, where citations are measured between a citing and a cited country, industry or firm (see, e.g., Jaffe & Trajtenberg, 1999; Maruseth & Verspagen, 2002; Peri, 2005). The vast majority of studies focus on developed economies—literature on developing economies is scarcer (see, e.g., Svensson 2007). For developing countries, attracting foreign knowledge from more developed regions is both crucial and challenging. It is crucial because knowledge flows from the technology frontier are a key source of learning (Griffith, Redding, & Van Reenen, 2004; Seliger, 2016). It is challenging because developing countries lack the knowledge base and infrastructure to fully benefit from them. From the viewpoint of a developed country, conducting R&D activities in or together with developing countries is also both challenging and crucial. The challenges mainly lie in inadequate intellectual property righty and in political and economic uncertainties. However, developing countries act as important suppliers of specific technologies and they are important partners for the division of labor (Branstetter et al. 2014; Zhao 2006). In addition, they have large populations making them the largest markets worldwide and offering an infinite amount of workforce.

This paper contributes to the literature on cross-border knowledge flows in two ways. First, it puts the spotlight on flows between developed and developing economies. Second, it focuses on some potential sources of knowledge flows rather than on documenting their existence. We explore three potential sources: R&D collaboration, technology sourcing, and technology transfer. [1] We quantify these sources by means of patent data. In contrast to prior studies that focus on patents filed at selected patent offices in the United States or Europe, our analysis considers 52 patent offices in the world.

R&D collaboration is measured by looking at patents that are co-invented or co-applied by parties in two different countries. Technology sourcing is measured by patents that are applied by a party in one country but invented in another country. Finally, knowledge transfer is measured using information on the transfers of ownership (i.e. sales) of patents. For collaborative U.S. patents, Kerr and Kerr (2018) found that collaborative patents are more observed when a U.S. public company is entering new foreign regions, especially when intellectual property rights are weak.

[1] Other sources of knowledge transfer exist, such as the mobility of R&D personnel (e.g., Lenzi 2010). Our analysis is silent on this and other sources.

We find that there has been a large shift towards R&D collaboration and technology sourcing with Asian countries (especially China) in the last two decades. Asia is today the only significant area for R&D collaboration and technology sourcing for Western economies. We also find that R&D collaboration and technology sourcing mainly take place in the information and communication technology sector and especially in computer technology. Regarding patent transfers, we document an important increase in the last decade, although overall levels remain low. East Asia is the largest recipient region among developing countries. Patent transfers from developing to developed economies also exist, although the volumes are more modest, reaching about a third of the volumes of the opposite direction.

Method and Data

In contrast to studies that seek to assess the *effect* of knowledge flows on the sending or receiving country, this paper focuses on the *sources* of knowledge flows. It is well-documented that interpersonal and interfirm collaboration raise knowledge flows between the parties involved (Agrawal et al. 2006; Gomes-Casseres et al. 2006; Singh 2005). We discuss the three potential sources in turn.

Measuring R&D collaboration with patent data

Cross-border R&D collaboration occurs when firms from different countries work together on an invention or when inventors from different countries work together. These aspects can be measured by looking at applicant-applicant and inventor-inventor pairs of the patent documents, respectively (see Guellec & de la Potterie, 2001; Picci, 2010; Picci & Savorelli, 2018). In the context of the present study, one applicant (inventor) must come from a developed country and the other applicant (inventor) from a developing country.

Consider for example the case of patent application number FR2965057A1 filed on September 22nd, 2010. This patent is co-applied by two organizations, namely the Soils and Fertilizers Research Institute (Vietnam) and the Institut de Recherche pour le Développement (France). This patent is most likely the result of R&D collaboration between these two institutes.

Note that the term "collaboration" is more appropriate for inventor-inventor pairs than for applicant-applicant pairs. The fact that a patent is co-applied does not necessarily imply that applicants are on equal footing. The patent could be fully developed by a subsidiary and co-applied by the subsidiary and the headquarter. Our data do not include ownership information and we are thus unable to assess whether patents arise from collaboration between two related entities. As we will see, however, insights obtained from applicant-applicant pairs are very similar to insights obtained from inventor-inventor pairs.[2]

Most research in the field relies on the count of patents filed at major patent offices, such as the European Patent Office (EPO) or the United States Patent and Trademark Office (USPTO). However, the patenting activity at these offices may not necessarily be representative of the overall situation across the globe.

[2] We cannot fully exclude the possibility that co-applications and co-inventions can also comprise R&D contracts where only one party contributed significantly to the invention (see Bergek & Bruzelius, 2010).

By contrast, the present analysis exploits the worldwide count of priority filings put forward by de Rassenfosse *et al.* (2013). This patent count identifies all priority patent applications filed worldwide and assigns them to the country of residence of the applicant and/or inventor. A priority patent application is the first patent application that is filed to protect an invention, anywhere in the world. The implementation of this count is quite challenging because of missing data on the inventors' and applicants' countries of residence. The authors have proposed a technical solution for recovering missing information on countries of residence that involves exploiting patent family information. Briefly, the technical solution involves looking for information on the countries of residence of applicants and inventors in the subsequent patent applications that belong to the same family.[3] Subsequent filings are typically made in other jurisdictions (i.e., at other patent offices) than the priority filing but this needs not be the case. The 'worldwide count of priority filings' considers 52 patent offices and seeks to impute potential missing country information (for more details, see Appendix A.2).

Measuring technology sourcing with patent data

We measure technology sourcing by considering patents for which applicants and inventors are located in different countries. In our context, one country needs to be a developed country and the other needs to be a developing country. Such patents can indicate R&D offshoring or external R&D contracting. In case of R&D offshoring, the inventor works for a foreign subsidiary, whereas the patent is filed by the mother company. In case of R&D contracting, a firm contracts out research to a R&D supplier.

Consider for example patent application number DE102011014441A1 filed on March 18th 2011. The sole applicant is the Germany-based automotive company Daimler AG and the inventors are all located in Pune, India. The Daimler group has a R&D center in Pune, and the patent application is therefore the result of R&D offshoring.

The literature usually identifies three main motives for technology sourcing. First, the technology-seeking motive relates to firms tapping into frontier knowledge that is not available in their home country. Second, the market-seeking motive relates to firms seeking to enter new markets and involves adapting home technology to local specificities. Third, the cost-reduction motive relates to performing R&D tasks in a country with cheaper labor (Chung & Alcácer 2002; Dunning & Lundan 2008). The data at hand do not allow us to distinguish between the various motives but we note that one or more of these motives may be at play.

The count again relies on priority filings with imputed applicant and inventor country information. We exclude patents that were also co-applied (i.e., patent applications that have been filed by applicants from both the developing and developed countries). This restriction ensures that we exclude patents arising from technology collaboration and, therefore, that we identify more accurately cases of technology sourcing.

Measuring technology transfer with patent data

We measure technology transfer using detailed information on the transfers of ownership, i.e., the sale of rights. We rely on the register of the European Patent Office (EPO) for patent

[3] A family of patents is a set of patents that are related to each other through common priority patent applications. The original data in de Rassenfosse *et al.* (2013) has recently been updated and improved thanks to an EPFL-ETH Zurich project funded by the Swiss National Science Foundation.

applications, and on the register of the German Patent Office (DPMA) for *granted* European (EP) patents. Indeed, once a European patent application has been granted by the EPO, it is transformed into a bundle of national patents. This implies that, before grant, a transfer of patent ownership should be registered at the EPO, while after grant, the transfer has to be registered in national offices of countries in which the patent has been validated.[4] Germany is the country with the largest proportion of validated EP patents (95% in 2003). It is therefore the most complete source for post-grant changes of ownership of European patents (Harhoff et al. 2009).

It should be mentioned that registering a transfer of patent ownership is mandatory neither at the EPO, nor at the DPMA. There are nevertheless strong incentives for patent purchasers to register patent acquisitions, as the lack of registration may have severe consequences. Indeed, in many European countries, the non-registration of patent transfers considerably hinders the enforcement of patent rights in case of litigation (see Ciaramella et al. 2017 for a more detailed discussion). In comparison with the amounts at stake before courts, the costs of registering a transfer of ownership are negligible.[5]

Note that the countries of patent protection (in our setting, European countries), and of patent ownership are distinct. For example, it is possible for a European patent to be owned by a U.S. firm and transferred to a Chinese firm. Thus, we will be able to provide a global view of patent transfers even using EP patents alone.

Consider for example patent application number EP1905886A1 filed on April 2nd, 2008. This patent was developed by the Germany-based company AMTEC Wäschereimaschinen GmbH. It was then transferred on July 7th, 2010 to Supreme Machinery Manufacturing Co. LTD, based in Thailand.

Empirical large-scale research investigating the transfers of patent ownership is recent. It started with Serrano (2010), which provides insights on the sale of U.S. patents. Several studies have contributed to this emerging stream of literature, most of them focusing on the market for U.S. patents (e.g. Galasso et al. 2013, De Marco et al. 2017). Literature on European patents is scarcer (see Bösenberg & Egger 2017, Ciaramella et al. 2017 for notable exceptions).

Descriptive Statistics

R&D collaboration

Figure 1 provides an overview of the proportion of patents co-applied between core European applicants and applicants from developing countries, by region (panel A) and by technology field (panel B).[6] The number of co-applied patents grew from 16 in 1980 to 1501 in 2010, leading to a compound annual growth rate (CAGR) of 16.3 percent. To put that figure in perspective, collaboration between core European applicants and U.S. applicants increased from about 500 patents in 1980 to more than 5000 patents in 2010 and experienced a CAGR

[4] It should be noted that it is still possible to register the transaction at the EPO during the nine-month period following the grant of the patent.

[5] The cost of registering a transfer of ownership at the EPO is EUR 100. There is no cost for registering a transfer of patent ownership at the DPMA since 2002.

[6] Section A.1 in the Appendix explains how we allocate countries to groups of developed and developing countries. Section A.3 discusses the allocation of patents to technological fields.

of 8 percent. Thus, from a European perspective, collaboration with developing countries amounts to about one third of the extent of collaboration with the United States. However, the growth rate has been more than twice as high.

Regarding the regional breakdown, most of the growth in collaboration is driven by firms located in East Asia, notably China. Collaboration with Russia and other former Soviet Union countries is low and oscillates around 100 patents since the 2000s. Finally, collaboration with Africa, Central and South America has slightly increased in total numbers, although it remains at low levels. As a proportion, patents arising from collaboration with non-Asian countries is shrinking fast—it represents a mere 17 percent in recent years. Asia has now become the dominant collaborating partner among all developing regions.

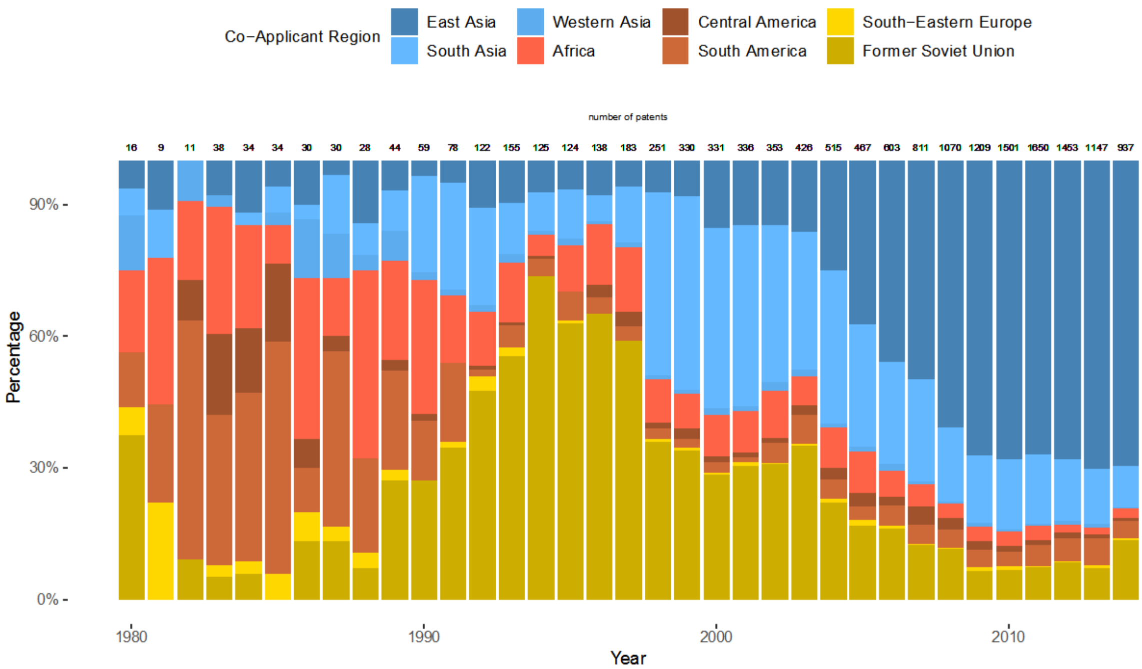
A strikingly similar pattern is obtained when looking at patents co-applied between U.S. and Canadian applicants and applicants from developing countries (not shown), at least for recent years. The CAGR is higher than for Europe, reaching 24 percent, and the breakdown in the 2010–2014 period is the following: East Asia (57%); South Asia (33%); Western Asia (<1%); Africa (1%); Central America (1.3%); South America (2.2%); South-Eastern Europe (<1%); former Soviet Union (5.3%). However, contrary to Europe, the United States & Canada had their main focus on Asian partners already since the 1990s. In addition, although the number of priority filings is smaller for the United States & Canada compared to Europe (67,412 vs. 113,952 in 2010), these countries have a much larger number of co-applications with developing countries (3,829 vs. 1,501). Thus, from a U.S./Canadian perspective, collaboration with developing countries is almost as important as collaboration with Europe.

Panel B of Figure 1 breaks down the collaboration between core European applicants and applicants from developing countries by technology field. The color scheme allocates single technological fields into five technology sectors (see Schmoch, 2008): Information and communication technologies (ICT) and electrical engineering (blue); instruments (yellow); chemistry and pharmaceuticals (red); mechanical engineering (green); and other fields (orange). Collaboration in ICT accounts for the majority of collaboration with developing countries in recent years (65.6% in 2010). Historically, collaboration occurred mainly in pharmaceuticals & chemistry (58.1% in 1990) but this sector has been marginalized, in relative terms, with the rise of communication and computer technologies. Similar findings emerge for the United States & Canada (not reported). However, the rise in the proportion of ICT started earlier (United States & Canada: 29% in 2000, Europe: 10.7% in 2000).

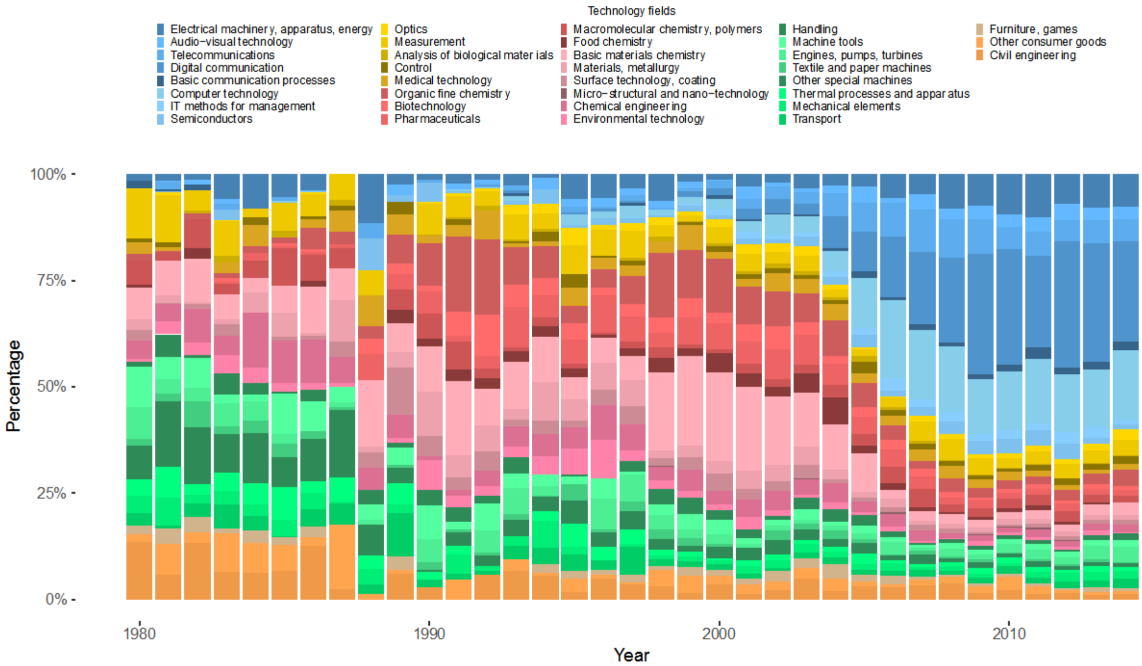
Figure 2 provides an overview of the proportion of patents co-invented between inventors from developed countries and inventors from developing countries, by region. Panel A focuses on core European inventors and Panel B focuses on U.S. and Canadian inventors. Cross-border inventor collaboration looks very similar to cross-border firm collaboration over time. The similar pattern between cross-border firm collaboration and cross-border inventor collaboration should not come as a surprise. Indeed, a patent co-applied by firms in two countries very often involves inventors from these two countries.

Figure 1. R&D Collaboration (Applicant Criterion), by Region and Technology

Panel A. Patents Co-Applied Between Core Europe and Developing Countries, by Region in (%)



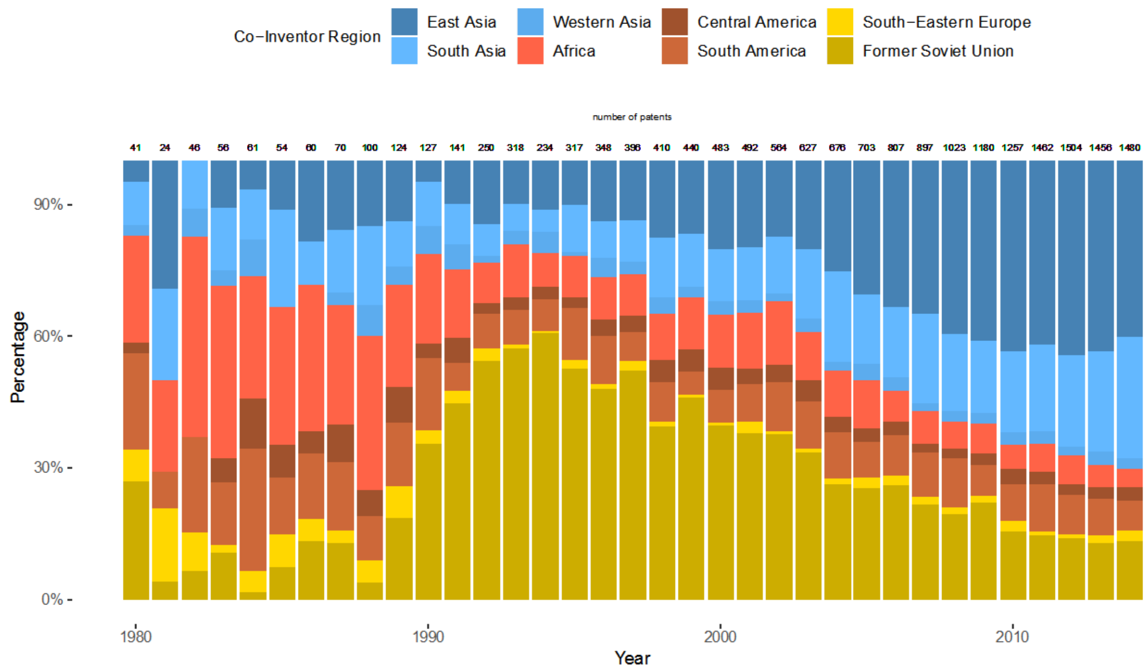
Panel B. Patents Co-Applied Between Core Europe and Developing Countries, by technology field in (%)



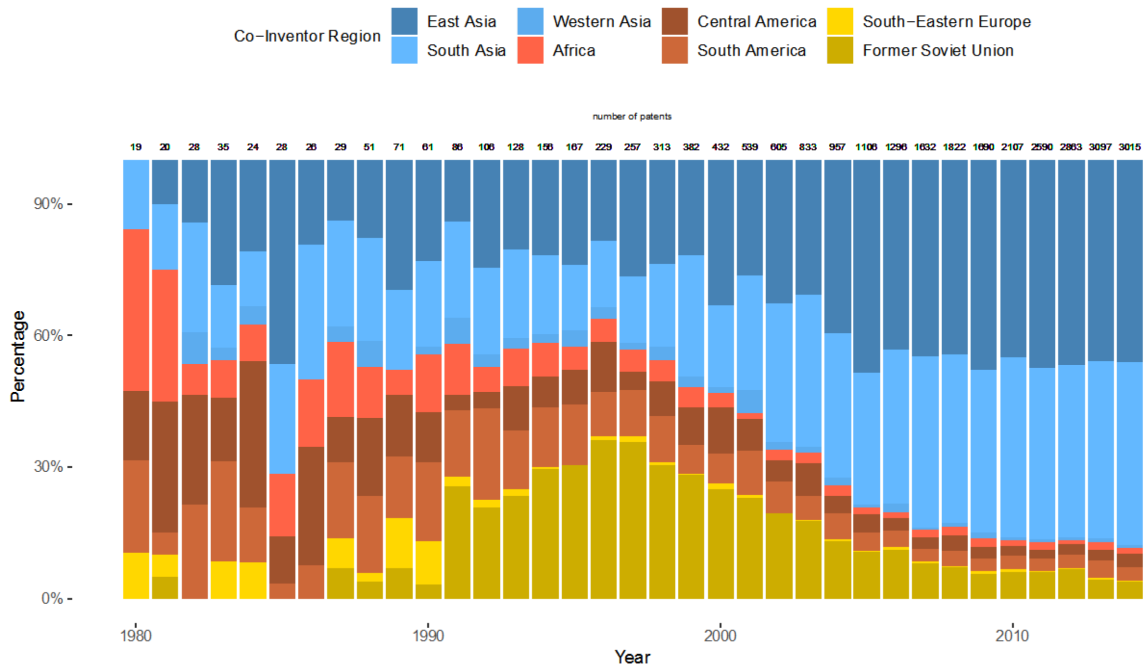
Note: The figures above each bar indicate the total number of patents that were co-applied with developing countries.

Figure 2. R&D Collaboration (Inventor Criterion), by Region

Panel A. Patents Co-Invented Between Core Europe and Developing Countries, by Region in (%)



Panel B. Patents Co-Invented Between the United States & Canada and Developing Countries, by Region in (%)



Note: The figures above each bar indicate the total number of patents that were co-invented with developing countries.

Comparing Panel A with Panel B, it seems that European inventors as a whole have a collaboration network that is more geographically dispersed than North-American inventors—the latter focus on Asia to a greater extent. However, similar to co-applications, the share of patents co-invented with Asia among total co-invented patents has increased strongly also in Europe. Looking at technology fields (not reported) suggests a pattern that is very similar to Panel B of Figure 1. The greater reliance on Asia for North-America translates into a greater share of patents co-invented in information and communication technologies.

Technology sourcing

The present section looks at patents sourced internationally. Figure 3 shows patent filings from applicants in Core Europe (Panel A) and the United States & Canada (Panel B) that are developed by inventors located in developing countries. The overall pattern is again very similar to the findings in Figure 1 and Figure 2. However, South Asia seems to be a bit more important for technology sourcing activities of Northern American applicants compared to East Asia, at least in recent years (the share of "sourced" patents is 57% for South Asia, compared to 30% for East Asia in 2014). Figure A.1 Panel A in the Appendix provides a complementary view. It shows a Sankey diagram of technology sourcing between developed regions and developing regions for the year 2014.[7] We can see that the United States & Canada account for the majority of technology sourcing from developing countries.

The numbers of patents sourced by the United States & Canada dropped significantly during the 2008 global financial crisis.[8] Comparing the numbers of patents in Panel B of Figure 3 with those in Panel B of Figure 2 reveals that technology sourcing was more sensitive to the crisis than R&D collaboration. Firms in the United States & Canada had dramatically reduced their technology sourcing activities during the crisis. One possible explanation is that collaboration projects establish medium to long-term relationships that are more resilient to changing financial conditions. The number of patents filed by U.S. and Canadian applicants with inventors in developing countries again increased strongly after the crisis period had ended.

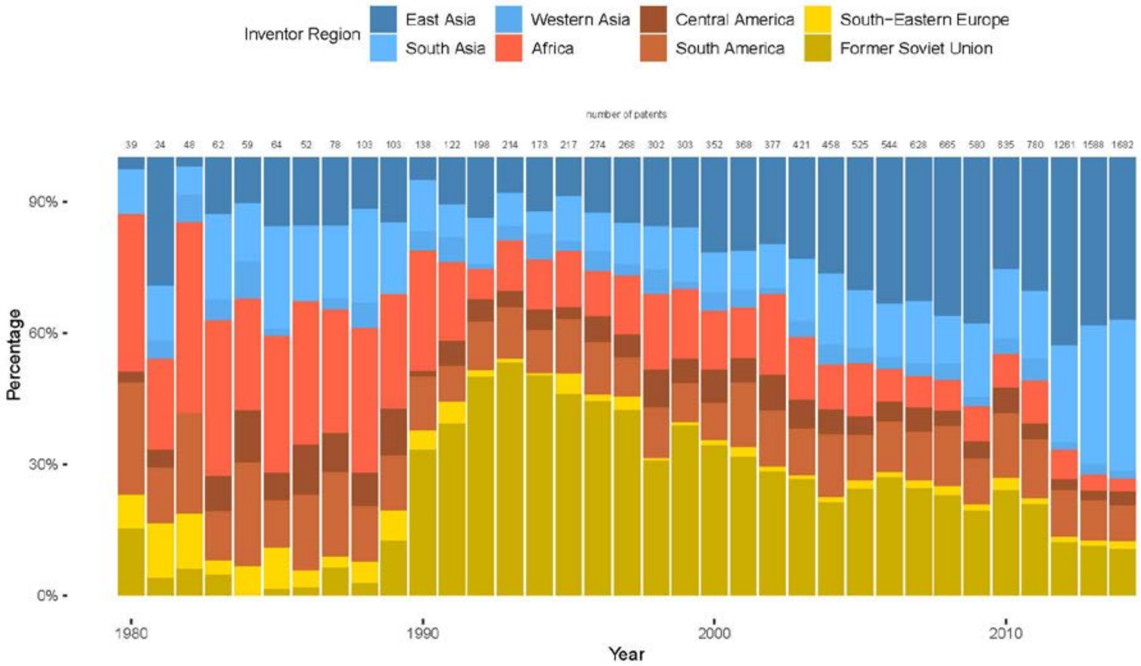
As already discussed in the "Method and Data" section, we exclude co-applied patent filings in order to measure technology sourcing more accurately. Nevertheless, it is instructive to compare "pure" technology sourcing (excluding co-applications) with technology sourcing including co-applications (which is suggestive of R&D collaboration). The former has become less common for East Asia relative to the latter. This suggests that firms from developed economies increasingly rely on R&D collaboration in East Asia in order to tap into local knowledge. In China, for example, finding local collaboration partners helps mitigate political and bureaucratic risks (Gassmann & Han 2004). It is also sometimes a prerequisite imposed by the government to gain access to the Chinese market. In contrast, R&D offshoring to South Asia might still offer a large potential for saving costs.

[7] Sankey diagrams are a specific type of flow diagram, in which the width of the arrows is shown proportionally to the flow quantity.

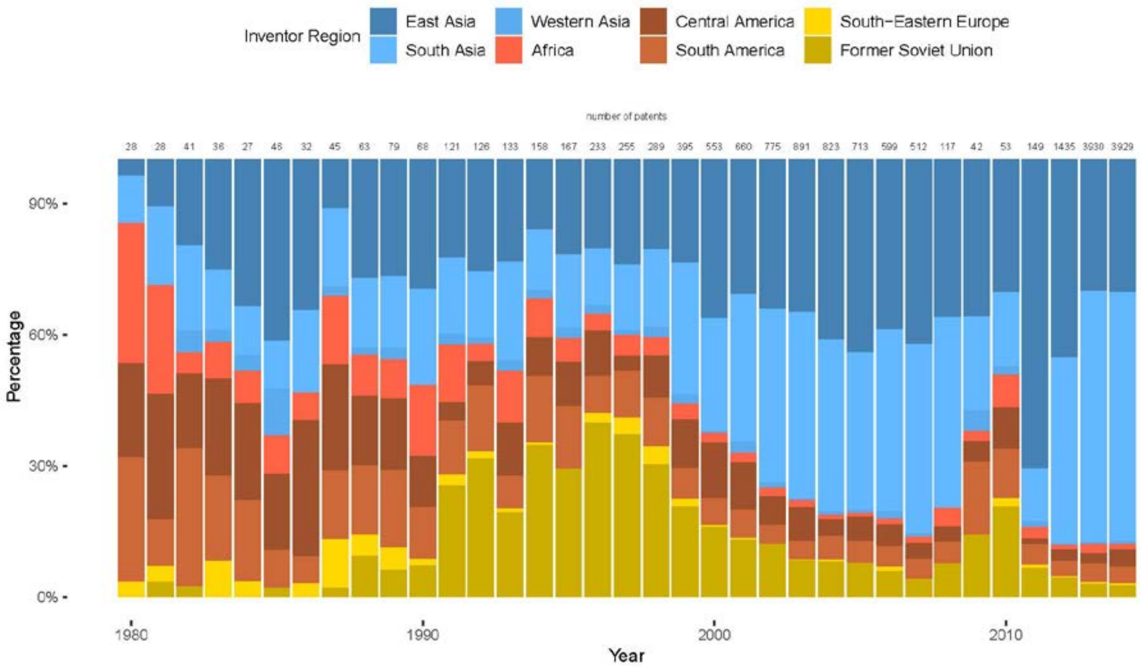
[8] Not only the number of patents with U.S. applicants and inventors abroad decreased in 2008–2009, but also the number of total patent filings.

Figure 3. Technology Sourcing from Developing Countries

Panel A. Patents Applied by Core Europe and Invented in Developing Countries, by Region in (%)



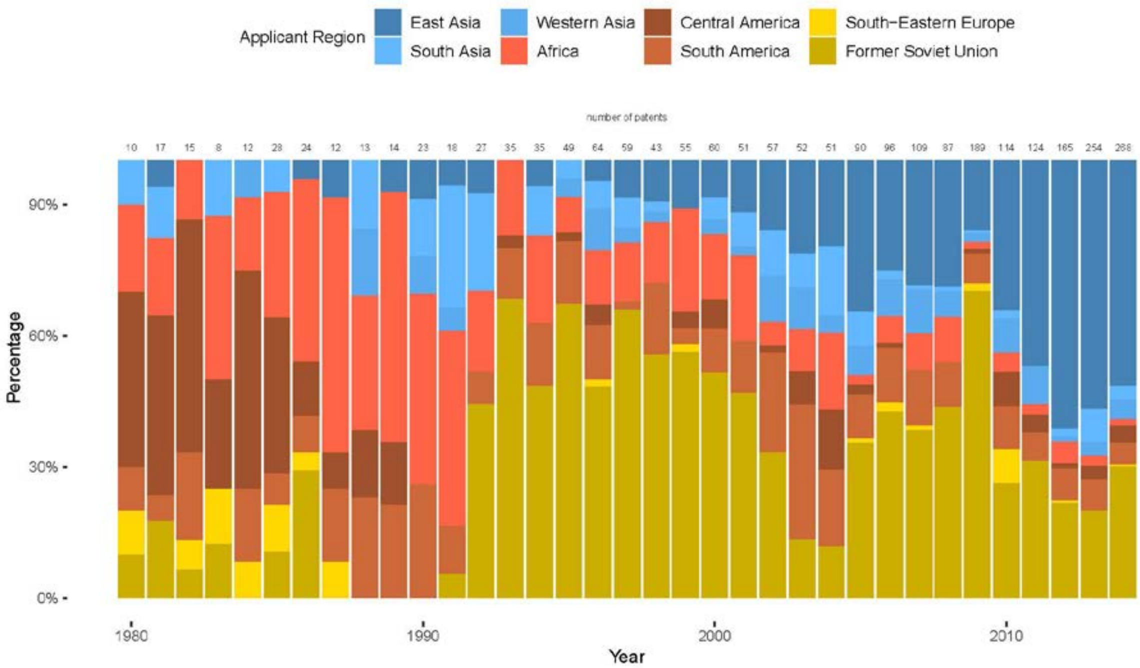
Panel B. Patents Applied by the United States & Canada and Invented in Developing Countries, by Region in (%)



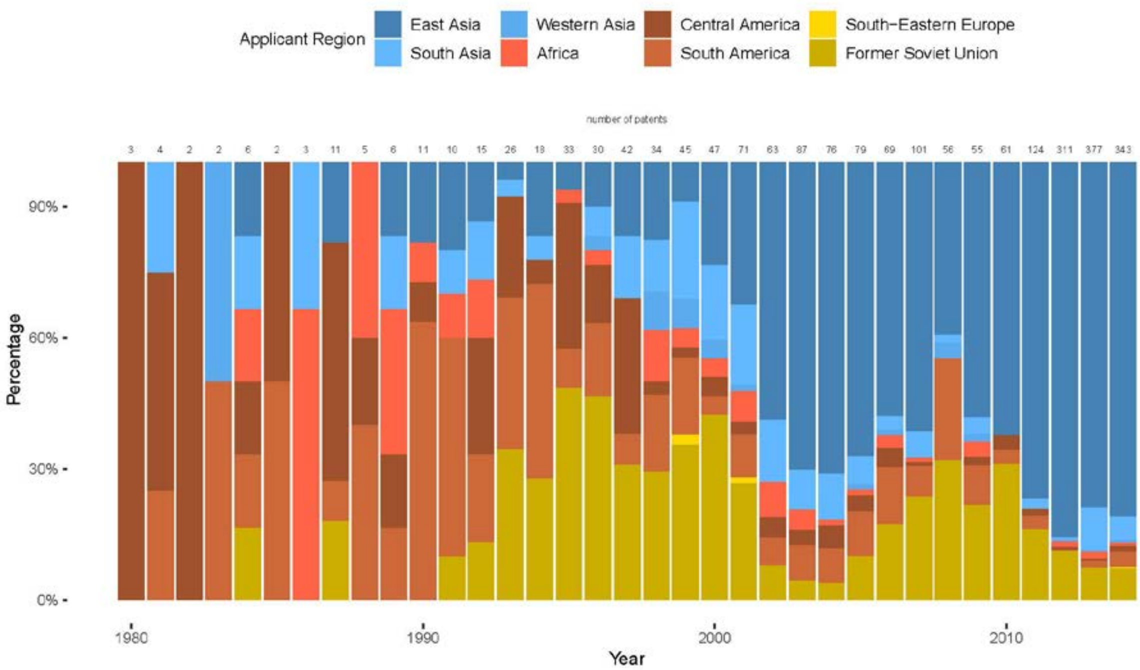
Note: The figures above each bar indicate the total number of patents that were “sourced” from developing countries.

Figure 4. Technology Sourcing from Developed Countries

Panel A. Patents Invented in Core Europe and Applied by Developing Countries, by Region in (%)



Panel B. Patents Invented in the United States & Canada and Applied by Developing Countries, by Region in (%)



Note: The figures above each bar indicate the total number of patents that were "sourced" from developed countries.

Figure 4 shows technology sourcing by developing countries from developed countries. It presents the number of patents applied by developing countries and invented in developed countries (again excluding co-applied patents). The figures show a dominance of East Asian countries. Regarding the United States & Canada as host countries, the dominance is particularly visible. East Asia is the most active region in terms of sourcing technologies from developed countries, and it mainly does so in the United States. Interestingly, South Asian applicants are not very active when it comes to technology sourcing. Regarding technology sourcing from Europe, former Soviet Union countries still play a role. South America, which had a couple of patents with U.S. and Canadian inventors in the past, has been marginalized, in relative terms. Figure A.1 Panel B in the Appendix shows a Sankey diagram of technology sourcing of developing regions from developed regions for the year 2014. It further illustrates the dominance of the link between East Asia and the United States & Canada in terms of technology sourcing.

Figure 4 illustrates that East Asian companies increasingly source technologies in countries that are at the forefront of science and R&D. The reverse might not be true, at least in the past: Western companies might source technologies from developing countries for different reasons, for example in order to reduce R&D costs. However, the fact that developed economies source technologies mainly from East Asia and South Asia, and especially in ICT and electrical engineering, suggests that Asian regions have developed a comparative advantage in terms of the availability of skills and the technological sophistication over other developing regions. Asian regions have certainly learned some of the knowledge brought in by Western firms (Li et al. 2012). The fact that only East Asia, especially China, sources technologies at a larger scale reflects the sheer size of the country. It may also be a consequence of Chinese strategy of building up own R&D capabilities by drawing on knowledge from abroad (see also Hou & Mohnen, 2013; Nepelski & De Prato, 2015).

Technology transfer

In this section, we focus on the transfers of ownership, i.e., the sales of rights of European patents. Panel A of Figure 5 shows the transfers of European patents from original owners located in Core Europe, to new owners located in developing countries. Panel B of Figure 5 follows the same logic. It displays the transfers of European patents from original owners located in the United States & Canada to developing countries.

In terms of overall volumes, patents transferred from Europe to developing countries have increased over the last decade. However, the overall activity is rather marginal. The year during which the largest number of patents were transferred from Core European to developing countries is 2013, during which 68 patents changed ownership to developing countries. Transfers arising from the United States & Canada represent a similar volume to transfers arising from Core Europe.

In terms of recipient regions, Panel A of Figure 5 shows that African countries were the most important destination region for patent transfers originating from Core Europe in the late 1990s, attracting around 40% of transfers.[9] The pattern changed in the early 2000s, with the drastic increase of the proportion of East Asian countries as recipients of patents transferred to developing countries. In 2014, 83% of these transfers were made to a new owner located in an East Asian country.

[9] The absolute volumes are nevertheless very low.

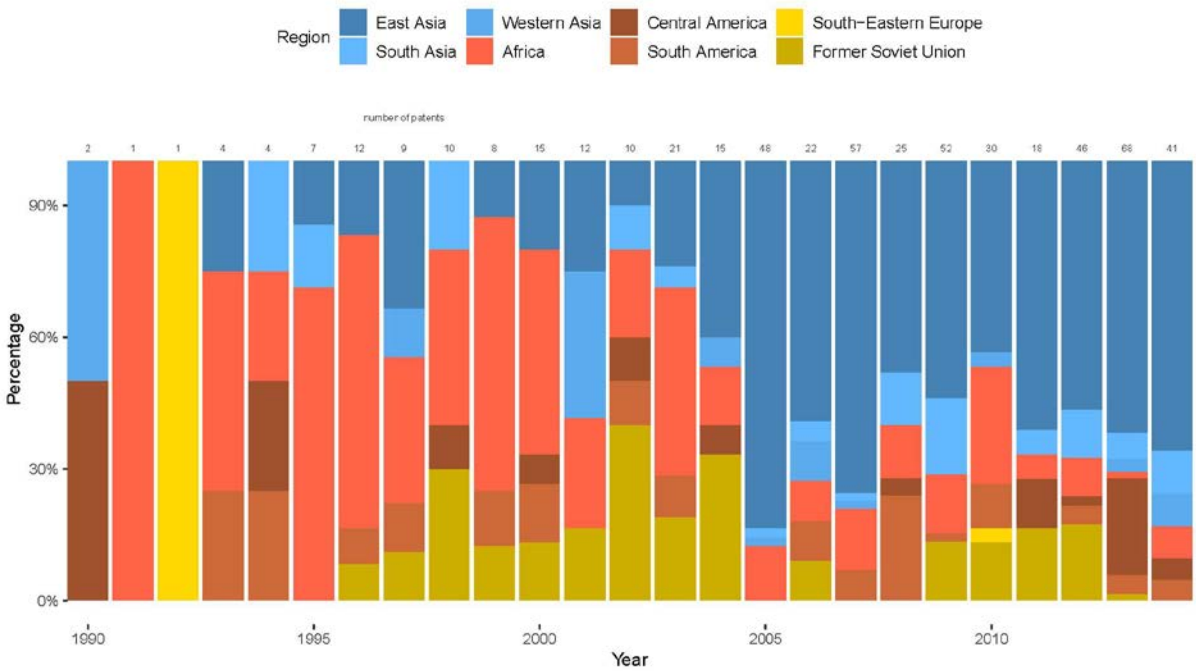
Panel B of Figure 5 shows the shares of developing countries regions as recipients of patent transfers originating from the United States & Canada, by year. Similarly to transfers originating from Core Europe countries, the share of East Asian countries as recipients of transfers originating from the United States & Canada has increased over the last two decades. Central American countries are also an important destination in the recent years for patent transfers originating from the United States & Canada.

Figure 6 focuses on developing countries as sources of patent transfers. Panel A presents the shares of developing regions as origin countries for patent transfers to Core Europe countries. Africa was the dominant origin region in the pre-2000 period, although this result should be interpreted with caution as the absolute numbers are very low. In more recent years, the shares are balanced, and there is no absolute dominance of a particular region. East Asia, Central America, Africa and the Former Soviet Union are the most important origin regions. Taking the average absolute volumes in the entire period, the number of patents transferred from developing countries to Core Europe is twice as small as the number of patents transferred from Core Europe to developing countries.

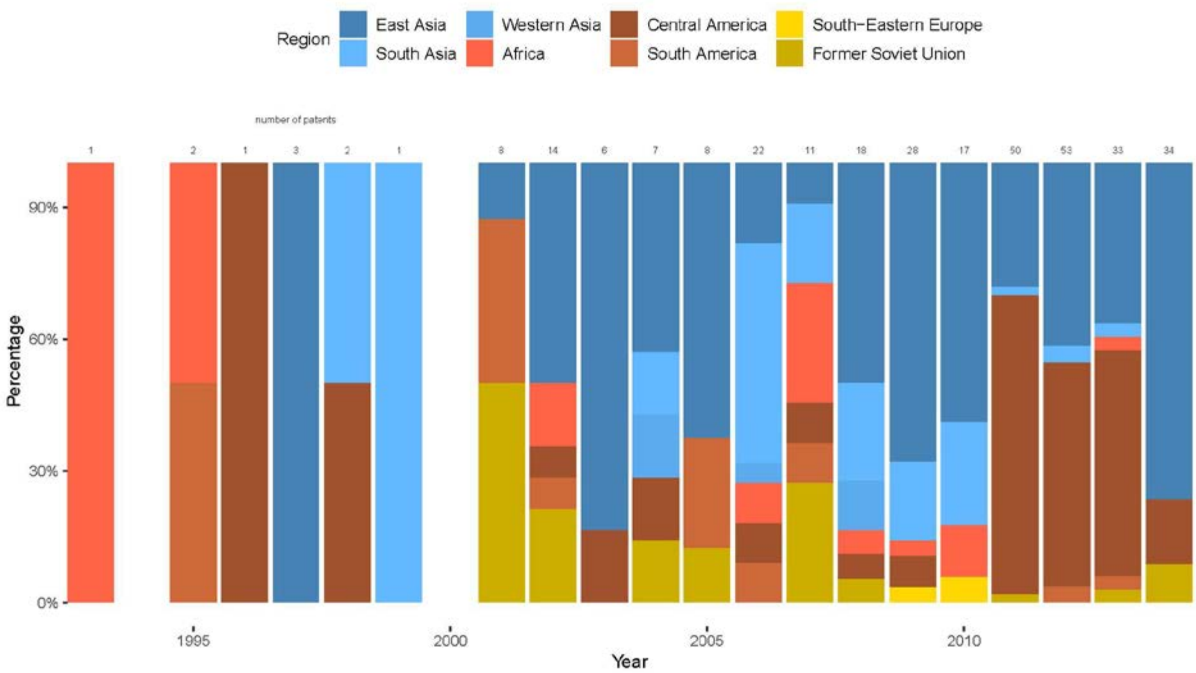
Panel B of Figure 6 displays the shares of developing regions as origin countries for patent transfers to the United States & Canada. Asian countries account for the bulk of the activity, although former Soviet Union countries are also well represented. In terms of absolute volumes, transfers from developing countries to the United States & Canada are more than three times less important than transfers to developing countries from U.S. and Canadian owners in most of the recent years.

Figure 5. Technology Transfers to Developing Countries

Panel A. Patents Transferred from Core Europe to Developing Countries, by Region in (%)



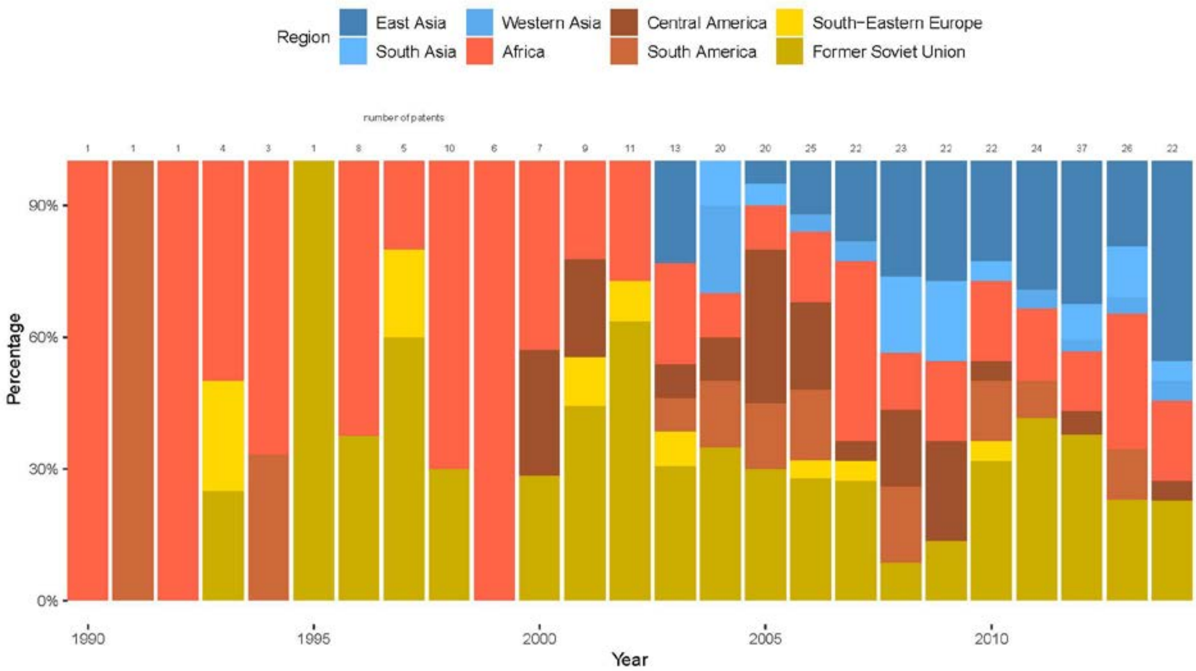
Panel B. Patents Transferred from United States & Canada to Developing Countries, by Region in (%)



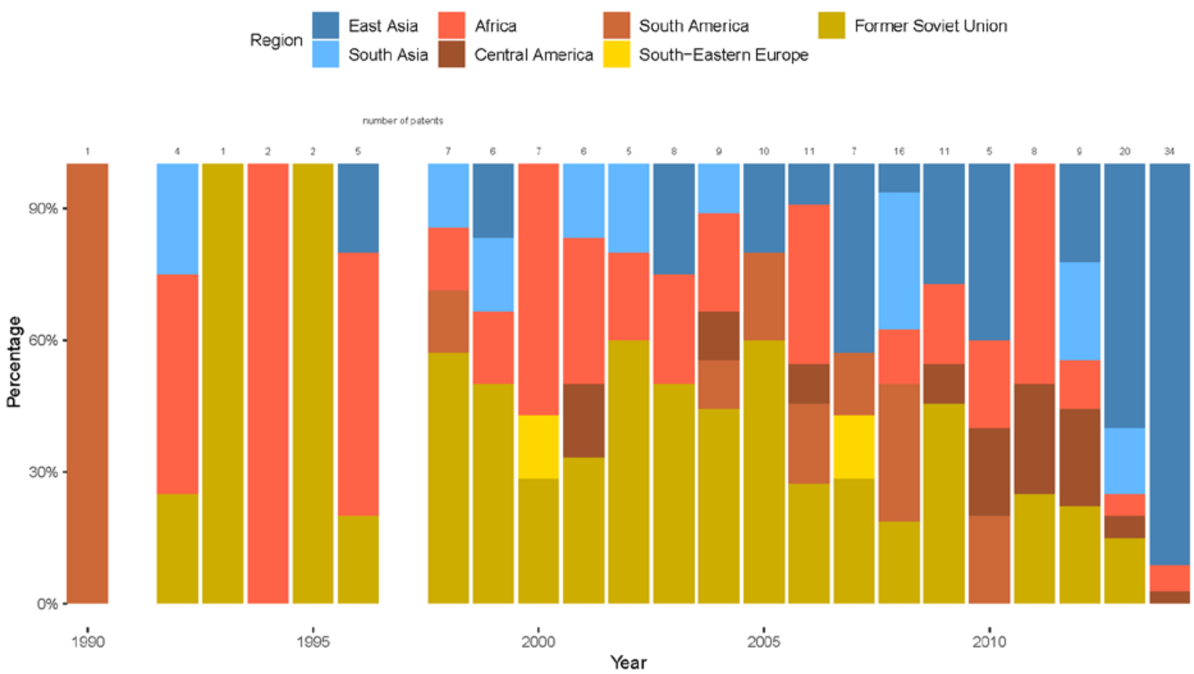
Note: The figures above each bar indicate the total number of patents that were transferred to developing countries. Empty bars indicate that the number is zero in the respective year.

Figure 6. Technology Transfers from Developing Countries

Panel A. Patents Transferred from Developing Countries to Core Europe, by Region in (%)



Panel B. Patents Transferred from Developing Countries to United States & Canada, by Region in (%)



Note: The figures above each bar indicate the total number of patents that were transferred to developed countries. Empty bars indicate that the number is zero in the respective year.

Concluding Remarks

This paper studied the sources of cross-border knowledge flows through the lens of patent data. The various patent counts presented can be interpreted as proxies for R&D collaboration (co-applications and co-inventions), technology sourcing (applicant and inventor from different countries) and technology transfer (patent transferred across countries).

A few caveats must be borne in mind when interpreting these results. First, the analysis is subject to the well-known limitation of patent data (Griliches 1998). Not all inventions are patented, not all patented inventions are useful and patents widely vary in quality. Second, effective knowledge transfer involves more than co-developing or transferring patents (e.g.,Liu 2017). Third, the majority of transfers occur within developed economies, and some of the trends we document may be a consequence of the rising GDP of developing economies. Finally, lack of data on the ownership structure of firms prevents us from providing a more fine-grained analysis (for instance, by differentiating technology sourcing into R&D offshoring or R&D contracting).

Notwithstanding these limitations, a consistent message emerges across the three indicators. The main finding is that R&D activities and patent transfers have been concentrating in recent years. First, on the regional level, East Asia, and to a smaller extent South Asia, have risen as the developing regions that attract almost all of the patenting activities from developed regions. Regarding patent transfers, East Asia has become over the last decade the largest recipient region among developing countries, for transfers coming both from the United States and from Europe. In terms of volumes, transfers going to developing countries are almost three times as large as transfers originating in developing economies. East Asia, Central America and Former Soviet Union are the major origin regions for this last type of transfers in the recent years. Second, on the technological level, ICT has become the dominant sector.

In addition, although the developments are quite similar in Europe and the United States & Canada, we see some striking differences. First, the United States & Canada traditionally have larger patent activities with Asia, whereas it is a relatively new phenomenon for Europe. Second, the United States & Canada have started to focus on ICT for a longer period of time than Europe. Finally, Central American countries remain an important destination for patent transfers originating from U.S. and Canadian owners (although numbers are admittedly small).

Two additional findings are worth discussing. First, technology sourcing seems to be more sensitive to the economic conditions than R&D collaboration. Firms in the United States & Canada dramatically reduced their technology sourcing activities during the global financial crisis.

Second, we observe more and more "reverse" knowledge flows, whereby firms in developed regions source technologies from developing economies. Here again China is leading the charge. We can expect that Asian countries that attract foreign patent activities are benefiting from knowledge flows from the more developed countries, thereby raising their own technological base. China is already at the stage at which it sources technologies from developed countries to a large extent. Given that East Asia will continue to progress towards becoming a technological leader, U.S. and Canadian firms seem to be in a better position than European firms to benefit from the rising sophistication of East Asia. They have a larger and better-established network of patent applicants and inventors in this region and are thus better placed to benefit from potential "reverse" knowledge flows.

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Appendix

A.1 Allocation of developed and developing countries to regions

The allocation of developed and developing countries to regions is based on the country classification in the World Economic Situation and Prospects report (United Nations, 2018) and per capita nominal GDP figures from the World Economic Outlook Database (International Monetary Fund, 2018). The former classifies all countries of the world into developed economies, economies of transition and developing economies mainly reflecting the basic economic conditions of the whole region. Geographical regions for developing economies are North Africa, Central Africa, East Africa, Southern Africa, West Africa, East Asia, South Asia, Western Asia, the Caribbean, Mexico and Central America, and South America. Economies of transition comprise countries in South-Eastern Europe and from the former Soviet Union (including Russia). For simplicity, we treated transition countries as developing economies.

The country classification is in some respects problematic as some regions of developing countries also comprise high-income countries (for example, Israel in Western Asia and South Korea and Singapore in East Asia). Therefore, we adapted the country classification and excluded countries from developing regions if they have a per capita nominal GDP that lies above the world average in 2017. In our analysis, we grouped all African regions into “Africa” as the co-patenting shares are tiny for smaller regions. We also build one group for “Central America” including the Caribbean and Mexico and other countries in Central America.

For the developed economies, we use two groups of countries: “Core Europe” and “United States & Canada”. Core Europe comprises all European Union member states (28) as well as Iceland, Norway and Switzerland. Other developed countries (Australia, New Zealand, Japan) are not considered in the paper.

The patent filings are assigned to countries (and to regions) based on the applicants’ and inventors’ country codes in PATSTAT (European Patent Office, 2016). As the country codes are missing for many priority filings, we impute them using the method described in Appendix A.2.

The following table shows the groups of countries we used to allocate patent filings to different world regions.

Table A-1. Groups of countries used in the paper

Developed Countries	Developing Countries			
Core Europe	***South-Eastern Europe***	Egypt	Zimbabwe	Cuba
Austria	Albania	Eritrea	***East Asia***	Dominican Rep.
Belgium	Bosnia and Herzegovina	Ethiopia	China	El Salvador
Bulgaria	Montenegro	Gabon	Fiji	Guatemala
Croatia	Serbia	Gambia	Indonesia	Guyana
Cyprus	Macedonia	Ghana	Kiribati	Haiti
Czech Republic	***Former Soviet Union***	Guinea	Lao People’s Dem. Rep.	Honduras
Denmark	Armenia	Guinea-Bissau	Malaysia	Jamaica
Estonia	Azerbaijan	Kenya	Mongolia	Mexico
Finland	Belarus	Lesotho	Myanmar	Nicaragua
France	Georgia	Liberia	Papua New Guinea	Suriname
Germany	Kazakhstan	Libya	Philippines	***South America***
Greece	Kyrgyzstan	Madagascar	Samoa	Bolivia
Hungary	Republic of Moldova	Malawi	Solomon Islands	Brazil
Iceland	Russian Federation	Mali	Thailand	Colombia
Ireland	Tajikistan	Mauritania	Timor-Leste	Ecuador
Italy	Turkmenistan	Mauritius	Vanuatu	Paraguay
Latvia	Ukraine	Morocco	Vietnam	Peru
Lithuania	Uzbekistan	Mozambique	**South Asia**	Venezuela
Luxembourg	***Africa***	Namibia	Afghanistan	
Malta	Algeria	Niger	Bangladesh	
Netherlands	Angola	Nigeria	Bhutan	
Norway	Benin	Rwanda	India	
Poland	Botswana	Sao Tome and Principe	Iran	
Portugal	Burkina Faso	Senegal	Nepal	
Romania	Burundi	Sierra Leone	Pakistan	
Slovakia	Cabo Verde	Somalia	Sri Lanka	
Slovenia	Cameroon	South Africa	***Western Asia***	
Spain	Central African Rep.	Sudan	Iraq	
Sweden	Chad	Swaziland	Jordan	
Switzerland	Comoros	Togo	Syrian Arab Rep	
United Kingdom	Congo	Tunisia	Turkey	
United States and Canada	Côte d’Ivoire	Uganda	Yemen	
USA	Dem. Rep. of the Congo	United Rep. of Tanzania	***Central America***	
Canada	Djibouti	Zambia	Belize	

A.2 Information on inventors' and applicants' countries of residence in priority filings

Patent statistics are based on so-called priority filings. Priority filings are the first filings within a patent family that might comprise multiple filings in different jurisdictions. We impute missing inventor (applicant) country codes using the method described in de Rassenfosse *et al.* (2013). Basically, their algorithm looks for equivalents and subsequent filings in the same family (preferring filings that are closer in time to the first filing) and uses the country codes from these filings if the priority filings' inventor (applicant) country code is missing. Subsequent filings are typically made at other patent offices. The algorithm browses 52 patent offices in order to impute missing information. To be more precise, it first selects all priority filings of a given patent office in a given year, so the first information source is the priority filing itself. For each filing that has missing information on the inventor's (applicant's) country of residence, it looks into six additional sources of information. The sources are browsed subsequently in order to retrieve missing information. The algorithm stops looking into those sources, once it has found the country information in one of them. Source 1 is the priority document itself, whereas sources 2 and 3 exploit family linkages. Sources 4 to 6 look into country information of applicants, thereby assuming that the applicant's country is most likely to be identical with the inventor's country. Source 7 uses the country of the priority office for the country of residence of the inventor (applicant) if all other sources do not provide information. The following list provides more detailed information on the sources. If the interest lies in the applicant's country of residence rather than the inventor's country of residence, the sources are browsed in the same way starting with the applicant's country of residence in the priority document (as indicated in parentheses for each source).

- Source 1: Uses the inventor's (applicant's) country of residence from the priority document itself.
- Source 2: If no information on the inventor's (applicant's) country of residence is available from the priority document, the earliest direct equivalent is browsed. A direct equivalent is a second filing claiming the priority application in source 1 as sole priority.
- Source 3: If no information on the inventor's (applicant's) country of residence is available in the direct equivalents, the other second filings of the same family are browsed. The second filings considered in this source claim more than the priority document.
- Source 4: If no information on the inventor's (applicant's) country of residence is available in the other subsequent filings, the applicant's (inventor's) country of residence from the priority document is used.
- Source 5: If no information on the applicant's (inventor's) country of residence is available from the priority document, the earliest direct equivalent is browsed for this information.
- Source 6: If no information on the applicant's (inventor's) country of residence is available in the direct equivalents, the other second filings of the same family are browsed.
- Source 7: If the information is still missing, the country of the priority office is used for the inventor's (applicant's) country of residence.

In our context, we are interested in priority filings including more than one applicant (inventor) country or one applicant and one inventor being located in different countries. Of course, priority filings can have mixed applicant (inventor) teams with applicants (inventors) coming from more than one region of developing countries. These filings are then counted separately for each region. These cases are rare, but we checked the results using fractional counting (by assigning a weight to each developing country taking into account the relative size of the inventor team for each country). The results are very similar to the results reported in the main part of the paper.

A.3 Allocation of technology fields to patent filings

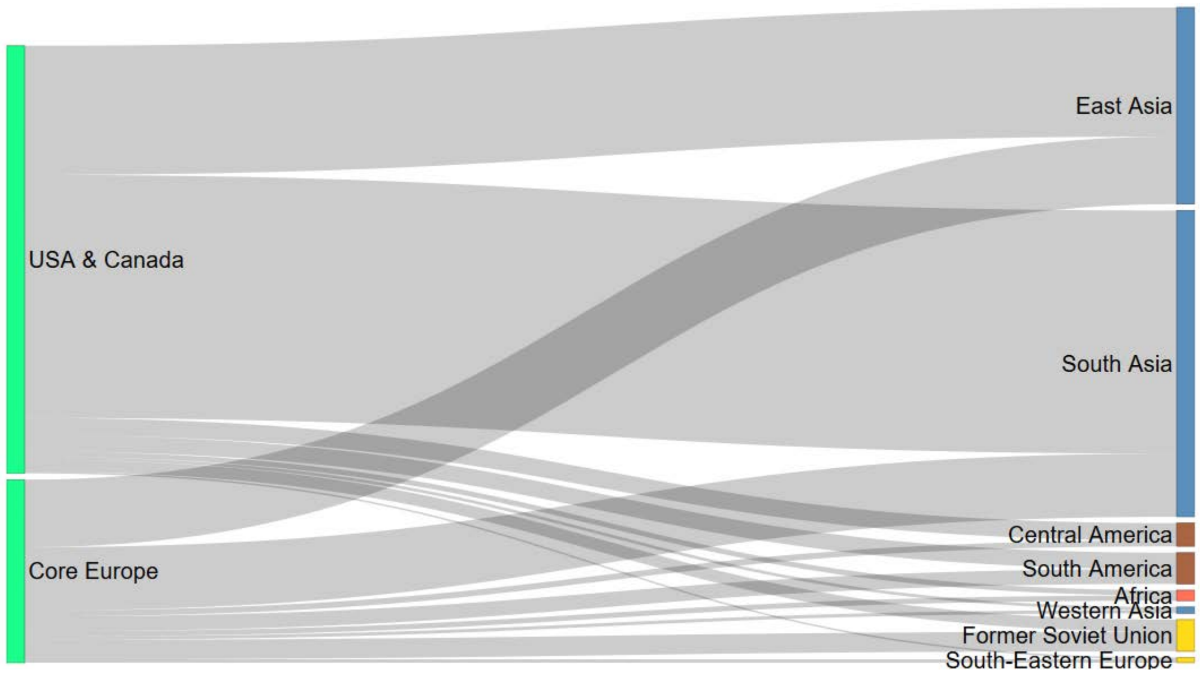
The International Patent Classification (IPC) that is used to categorize patents according to their technological content provides a good starting point for an analysis by technologies. However, the IPC is highly technical with hundreds of subclasses and groups. Therefore, we use more aggregated technology fields that have been assigned to IPC codes of patent filings based on the “Concept of a Technology Classification for Country Comparisons” (Schmoch, 2008).

As patent filings usually have several IPC codes that correspond to several technologies, we use the weights from PATSTAT. It considers the degree to which a patent belongs to a certain technology field based on its IPC codes. To give an example, patent filing WO2018126352A1 is assigned to IPC Codes C09K9/00, G01K11/16 and H01B13/00. The technology classification uses only the first four digits. Here, C09K corresponds to “Basic materials chemistry”, G01K to “Measurement” and H01B to “Electrical machinery, apparatus, energy”. This means that the respective filing counts one third for “Basic materials chemistry”, one third for “Measurement”, and one third for “Electrical machinery, apparatus, energy”. The filings’ weights that are calculated in this way can be found in PATSTAT. In our analysis, we sum them up by technology field (and year, region).

A.4 Sankey diagrams

Figure A1. Links between the United States & Canada / Core Europe and Developing Countries

Panel A. Patents Applied by the United States & Canada / Core Europe and Invented in Developing Countries, by Region, priority year 2014



Panel B. Patents Applied by Developing Countries and Invented in the United States & Canada / Core Europe, by Region, priority year 2014