UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Inclusive and Sustainable Industrial Development Working Paper Series
WP 11 | 2019

MEASURING THE CREATION AND ADOPTION OF NEW TECHNOLOGIES USING TRADE AND PATENT DATA

DEPARTMENT OF POLICY, RESEARCH AND STATISTICS

WORKING PAPER 11/2019

Measuring the creation and adoption of new technologies using trade and patent data

Neil Foster-McGregor
UNU-MERIT

Önder Nomaler
UNU-MERIT and Eindhoven University of Technology

Bart Verspagen
UNU-MERIT

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Vienna, 2019

Acknowledgments

We are grateful for comments from Alejandro Lavopa and the team at UNIDO on earlier drafts of this paper.

This is a Background Paper for the UNIDO Industrial Development Report 2020: Industrializing in the Digital Age

Table of Contents

List of Figures

List of Tables

Abstract

Emerging technologies are shaping the new industrial landscape, potentially creating opportunities for developing countries to industrialize through increased productivity. However, the risk that they may be excluded from the benefits of these technologies through reshoring and through the erosion of their competitive advantage is also very real. In this paper we identify trade (i.e. imports and exports) and inventions (patents) in 4IR technologies as a means to ascertain the development, production and use of such technologies globally. The paper provides information on those countries that are leading the technology race, those that are keeping up, and those that are lagging far behind. We use detailed patent data to identify the technology leaders in the Fourth Industrial Revolution, and trade data to identify the producers and users of these technologies. The paper subsequently relates the use of such technologies to indicators of countries' level of industrial development.

Keywords: Fourth Industrial Revolution, industrialization, patents, imports, exports

JEL Classification: O14, O33

1 Introduction

It is commonly thought that a set of emerging technologies is shaping the new industrial landscape. One key feature of these technologies typically associated with the so-called Fourth Industrial Revolution (4IR), is the growing interconnection and complementarity between digital and physical production systems. These technologies include robotics, additive manufacturing, artificial intelligence, the Internet of Things and big data. While much of this discussion has concentrated on the effects of the 4IR in the developed world, in particular related to the benefits of increased productivity and to the costs in terms of labour demand (especially for low-skilled workers), the increased use of these technologies also creates opportunities and poses risks for countries in the developing world. On the one hand, the increased use of these technologies globally generates risks for developing countries by eroding their competitive advantage associated with low cost, low-skilled labour. Indeed, there is some evidence to suggest that the share of occupations that are at risk of significant automation may actually be higher in developing countries than in developed countries (World Bank, 2016). These negative impacts of 4IR technologies are particularly relevant in the context of global value chains, with firms in developed countries potentially able to reshore activities that were previously offshored to developing countries. On the other hand, these technologies may allow countries in the developing world to take advantage of potential export opportunities in manufacturing activities. This would be the case, for example, if firms invested in these technologies to improve productivity, in turn becoming more competitive and able to succeed in export markets.

In this paper, we explore trade (i.e. imports and exports) and inventions (patents) in 4IR technologies as a means of identifying the development, production and use of such technologies globally. The aim of the paper is to provide information about those countries leading the technology race, those that are not leading but still following, and those that are lagging behind. To achieve this, the paper uses detailed patent data to identify the technology leaders in the Fourth Industrial Revolution, and trade data to identify trade in these technologies, before summarizing country level trends in their exports and imports. Particular attention is paid to variables such as Balassa type indices of both imports and exports to identify the set of countries that have a 'revealed comparative advantage' in the production and use of these technologies. In later analysis, the paper further relates the use of these technologies to indicators of the level of industrial development.

The remainder of the paper is organized as follows: Section 2 discusses issues of data and how the production and adoption of these technologies is identified in the trade and patent data; Section 3 provides a descriptive analysis of patenting in 4IR technologies at both the global and country level, as well as information on patenting activities by organization; Section 4 provides a similar descriptive analysis but uses data on exports and imports to provide an indication of the users and producers of these new technologies; Section 5 considers the future possibilities for developing countries to specialize in 4IR technologies; and Section 6 summarizes and concludes.

2 Data

2.1 Trade data

To identify the sources and diffusion of 4IR technologies, we make use of the UN COMTRADE dataset – as collated through CEPII's BACI database.[1] In particular, we look to identify specific products that are associated with these technologies. We are interested in five specific 4IR technologies, namely: (i) industrial robots; (ii) additive manufacturing (or 3D printing); (iii) computer-aided design and computer aided manufacturing (CAD/CAM) techniques; (iv) big data and cloud computing; and (v) artificial intelligence and machine learning. Here we describe in further detail how these technologies are identified in the trade data.

For a number of reasons, it is very difficult to identify big data and cloud computing and artificial intelligence and machine learning in the trade data. First, the most important part of this technology is software, which is very difficult to find in the trade classification (i.e. the Harmonized System classification). Second, to the extent that these technologies depend on hardware, it usually involves generic hardware (e.g. fast computers, large storage), and these systems are multi-purpose. Thus, even if we can distinguish this type of hardware in the trade data, we cannot distinguish its specific use for these technologies. Third, and lastly, to the extent that these technologies are embodied in manufacturing capital goods (e.g. a "smart" sewing machine), the trade classification system does not distinguish between "normal" and "smart" versions of these products. We therefore do not attempt to identify these technologies in the trade data, but instead leave a discussion about these technologies to the complementary analysis using patent data. We therefore focus on the remaining three technologies.

We find the term industrial robots once in the HS classification, namely as HS 847950 "Industrial robots, not elsewhere specified or included". The corresponding 4-digit classification (HS 8479) is "Machines and mechanical appliances having individual functions, not specified or included elsewhere in this Chapter". Turning to additive manufacturing (or 3D printing), Abeliansky et al. (2015) define it in the HS classification as a single group: HS 847780. It is defined as "Other

[1] Data from the COMTRADE dataset is used in the case of Botswana, South Africa, Lesotho and Swaziland to divide the data for the South African Customs Union in BACI, as well as in the case of Belgium and Luxembourg for similar reasons. To make this division, we use shares of the respective country in the total for the particular aggregate from UN COMTRADE and apply these shares to the data from BACI to divide the aggregates.

machinery” in the four-digit product class (HS 8477) “Machinery for working rubber or plastics or for the manufacture of products from these materials, not specified or included elsewhere in this Chapter”. This four-digit product group contains several other six-digit classes: 847710 (“Injection-moulding machines”); 847720 (“Extruders”); 847730 (“Blow moulding machines”); 847740 (“Vacuum moulding machines and other thermoforming machines”); 847751 (“Other machinery for moulding or otherwise forming: For moulding or retreading pneumatic tyres or for moulding or otherwise forming inner tubes”); 847759 (“Other machinery for moulding or otherwise forming:-- Other”); and 847790 (“Parts”). In the analysis that follows, we combine these different six-digit codes as our indicator of additive manufacturing. Finally, for computer-aided design and computer aided manufacturing (CAD/CAM) techniques, we find several groups in the HS classification in the 84th chapter (“Nuclear reactors, boilers, machinery and mechanical appliances parts thereof”) that refer to numerically controlled machines or machine tools. These are: 845811 (“Horizontal lathes: Numerically controlled”); 845819 (“Other lathes: Numerically controlled”); 845921 (“Other drilling machines: Numerically controlled”); 845931 (“Other boring-milling machines: Numerically controlled”); 845951 (“Milling machines, knee-type: Numerically controlled”); 845961 (“Other milling machines: Numerically controlled”); 846011 (“Flat-surface grinding machines, in which the positioning in any one axis can be set up to an accuracy of at least 0.01 mm: Numerically controlled”); 846021 (“Other grinding machines, in which the positioning in any one axis can be set up to an accuracy of at least 0.01 mm: Numerically controlled”); 846031 (“Sharpening (tool or cutter grinding) machines: Numerically controlled”); 846221 (“Bending, folding, straightening or flattening machines (including presses): Numerically controlled”); 846231 (“Shearing machines (including presses), other than combined punching and shearing machines: Numerically controlled”); 846241 (“Punching or notching machines (including presses), including combined punching and shearing machines: Numerically controlled”). Once again, we combine these different six-digit HS codes to capture CAD/CAM technologies.

One word of warning before we turn to the data: given the imperfect overlap between these technologies and the HS codes, it is inevitable that we will also be capturing earlier vintages of technology (e.g. third industrial revolution technologies) in these classifications. Despite this, the data should provide an insight into the use of advanced technologies in these domains and into the means of identifying countries with the capabilities to use these technologies (and therefore potentially benefit from them).

2.2 Patent data

To get an idea of which countries are important inventors of 4IR patents, we use the PATSTAT database.[2] This database covers (almost) all global patent jurisdictions. This means that it provides a fairly complete overview of global patenting activity, but also that it likely covers an individual invention multiple times, i.e. when a firm patents the same invention with multiple patent offices. To avoid double counting, we adopt the patent family as the main unit in our patent counts. A patent family is a set of patents in different jurisdictions (offices or designated states in international offices) that cover the same invention.

To identify patent families that refer to 4IR technologies, we focus on the same four fields that are used for the trade data, i.e. CAD-CAM, robots, machine leaning (ML) and 3D printing (or additive manufacturing). In line with the overall focus of the Industrial Development Report, we also limit patents to (smart) manufacturing, i.e. the use of the four technology fields in the manufacturing process.

To arrive at this general definition of relevant technologies, we adopt the categories used by Derwent by applying the Derwent Innovation Index (DII by Clarivate Analytics), which is a complete and highly processed patent database (well-known for its high quality) that is endowed with a sophisticated search engine. The DII has a proprietary patent classification system (Derwent Manual Codes). It is built on a particular interpretation of the standard classification schemes as assigned by the patent offices (i.e. CPC or IPC), and on intelligent text-mining algorithms and expert judgement.[3]

We focus on code T06: Process and machine control. There are about half a million patent families to which this code is assigned, of which the greater part is not related to 4IR manufacturing technologies. In weeding out the patents that are irrelevant for our purpose, we first excluded a number of Derwent subject areas that are obviously unrelated to manufacturing (such as agriculture, general internal medicine or music) as well patents that were co-classified with a number of Derwent class codes that are not related to manufacturing (such as W05 – Alarms, signalling, telemetry and telecontrol and W07 – Electrical military equipment and weapons). With a further sampling of patent titles and abstracts, we found that some patents were still unrelated to (smart) manufacturing (such as domestic appliances, mobile phones, autonomous vehicles,

[2] The data used are from EPO PATSTAT, Release Autumn 2018.
[3] After obtaining the appropriate set of patent numbers using this approach, we extracted the relevant meta-data from PATSTAT. In the Appendix, we report the set of queries used to extract the relevant patent data.

etc.). Thus, we compiled a list of keywords that would eliminate these patents as well. This step includes eliminating patents with keywords such as hospital, gaming, teaching and multimedia.

In a final step of refinement of the set of patent families, the aim was to eliminate a set of "older" inventions that are not likely to belong to our target set. To achieve this, we search for patents with a relevance to digital data exchange or to machine learning, which we consider the two key characteristics of the Fourth Industrial Revolution for our purposes. For the digital data exchange criteria, we relied on the Derwent Manual Code W01-A: Digital information transmission, and two 4-digit IPC codes H04L: Transmission of digital information; H04W: Wireless communication networks.

For machine learning, we compiled a list of IPC codes and keywords that capture this technology. This list was constructed on the basis of several sources. First, we used the so-called J-tagging system (Inaba and Squicciarini, 2017). We examined all these IPC classes from the J-tagging system and excluded specific ones that did not seem relevant to us. Another valuable source to help identify patents related to machine learning/artificial intelligence was the 2019 WIPO Technology Trends report on artificial intelligence (WIPO, 2019), which—in addition to some CPC codes—uses a collection of keywords. We integrated this list of keywords into our search criteria for machine learning. Finally, we integrated a Derwent Manual Code (T01-J16: Artificial intelligence) into our search methodology.

The ultimate set of patent families contains manufacturing-related inventions on process and machine control which are also related to either digital data transmission/communication, or artificial intelligence/machine learning. The final dataset contains 18,302 patent families.

Until now, we have kept 3D printing out of our search process, as 3D printing from a technological point of view differs intrinsically from our other categories of interest. 3D printing brings chemistry and material sciences together with actuators, thermal processes and computer control. In 2016, the EPO and WIPO introduced a single IPC code (B33Y) to identify 3D printing-related inventions. We built our 3D printing patent set on the basis of this single IPC code, which yields 26,959 patent families. Unfortunately, because the B33Y code is rather new, and because it takes time to tag existing patents by it, we only have relatively new 3D printing patents in our dataset.

These patent families are classified into the underlying technology fields CAD-CAM, robots, machine leaning (ML) and 3D printing. This is straightforward for 3D printing (we use the B33Y IPC code). CAD-CAM is a very generic label: it can be argued that any process and machine control technology that is related to computers or digital data (transmission) is essentially some type of CAD-CAM technology. In other words, all the 18,285 patent families that are not 3D printing can be considered CAD-CAM, and we therefore do not consider CAD-CAM as a separate sub-category.

For the remaining categories, robot patents were tagged on the basis of having either a specific IPC code or having the word 'robot' in their title or abstract. Machine learning patents were identified on the basis of a mixed criterion based on IPC codes, keywords and Derwent codes. In addition to these two categories, we also identify an additional category, based solely on two sub-codes of the Derwent T06 class which, together, specify "Total Factory Control" (TFC). We consider this an interesting and highly relevant sub-category for analysing manufacturing inventions for the Fourth Industrial Revolution. After identifying these three categories, we also have several patents that are not sub-classified, and assign them to the sub-class "other".

Note that the three categories other than 3D printing are not mutually exclusive. For example, 990 of the patent families in our landscape of 18,285 non-3D printing families are classified as related to machine learning and robots simultaneously, and 144 families belong to both total factory control and robots.

3 World development in patenting in Fourth Industrial Revolution technologies

3.1 World developments

Figure 1 illustrates the trends in patenting in the 4IR fields included in our patent search. The lines indicate cumulative numbers (i.e. the total number of global patent families up to the year on the horizontal axis). We have separate trends for 3D printing and the other fields (RTMO – for Robots, Total factory control, Machine learning and Other), because data for 3D printing for early years are likely underestimated (as explained in the data section). As a result of this underestimation, the trend for 3D printing rises sharply towards the end of the period. The trend for RTMO is much smoother. Despite the underestimation of 3D printing, this field is larger than RTMO at the end of 2018.[4]

[4] The figure excludes 184 patent families in 2019, but these will be included in the subsequent analysis when we look at patents for all years.

Figure 1: Cumulative number of patent families in Fourth Industrial Revolution technologies

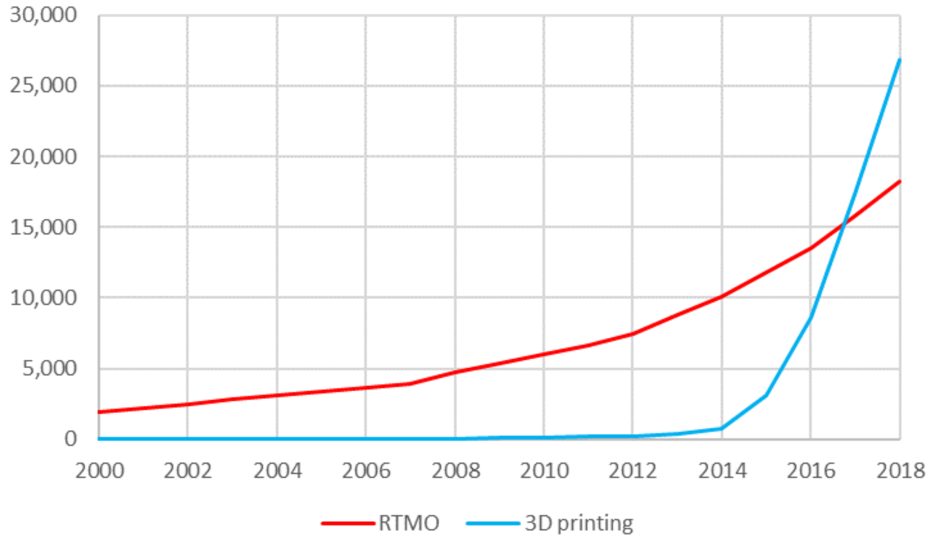
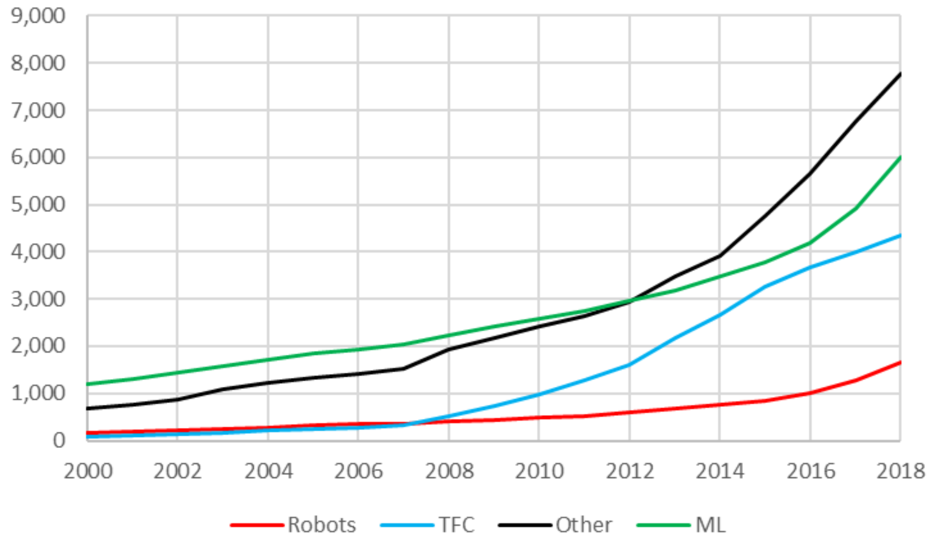


Figure 2 breaks the RTMO category down into sub-categories. The figure illustrates that machine learning (ML) and 'other' are the largest sub-categories, with total factory control (TFC) at an intermediate level and robots as a small category. Time trends slightly differ between the sub-categories, with TFC picking up strongly from 2007, and ML and robots from 2016.

Figure 2: Cumulative number of patent families in subfields of RTMO



3.2 Patenting in Fourth Industrial Revolution technologies by country

Next, we consider how total patenting in 4IR technologies is distributed over countries. There are two possible perspectives here: by country of origin (where the inventions were made and/or are owned), and by patent office jurisdiction (where the patents provide protection). We start by looking at the jurisdiction side.

A patent family typically consists of multiple patents, i.e. the same invention is often applied as a patent in multiple jurisdictions, so that protection covers more than a single country. In this respect, the European Patent Office (EPO) and the so-called Patent Cooperation Treaty (PCT) are of special significance. The EPO provides an opportunity to obtain a patent in all or a selection of its member states by just one application. The PCT is a similar construct, but at a global scale, offering potential protection at patent offices around the world in a procedure that is initiated by a single application. After an initial PCT filing, a search procedure is undertaken, which must be followed by applications at all national offices where the applicant wishes to obtain a patent.

Our database (45,261 patent families relating to 4IR technologies) contains 5,572 patent documents that were filed at the EPO, and 6,980 that were filed in the PCT procedure. We have so-called designated states for both EPO and PCT applications. In the EPO, this is a good indication of where the patent will have been applied. In the PCT procedure, however, the indication of designated states is much less committal because the decision on whether to seek protection in a country is only taken when follow-up filings at national offices are undertaken. These follow-up filings are not indicated in our database, which is why our information on PCT designated states is not very reliable.

Taking into account all designated states on EPO filings, but not those on PCT filings, as a unique document, our database consists of 273,822 documents for 45,261 families, an average of about 6 documents per family (this counts the PCT filings as 1, and EPO filings as the number of designated states). The importance of the EPO is clearly illustrated by the fact that 71 per cent of the 273,822 documents are patents in the 38 EPO member states (this includes both designated states at EPO and direct applications at these patent offices).

The dominance of the EPO member states in terms of where patents in 4IR technologies are protected is also evident when we compare the number of patent families applied for from these countries, with the number of patents that they protect. For the EPO member states, this ratio (protected divided by applied) has a median value of 128 (average 936), while for non-EPO members states, the median value is 2.7 (average 194). The country where this ratio is highest is

Greece (an EPO member), at >10,000, while the non-EPO member state with the highest value is Bosnia and Herzegovina, at approximately 4,400.

Non-EPO member states account for about 29 per cent (or 78,257) of the protected patent documents in the database (this includes PCT applications). Slightly more than half (53 per cent) of these documents were applied for in the two largest countries: China and the USA. Japan, Bosnia and Herzegovina and the Republic of Korea add another 18 percentage points to this, bringing the share of these five countries to 71 per cent.

These numbers seem to suggest that practical and institutional reasons (ease of application at the EPO), together with the economic importance of countries, determine where protection is sought for 4IR technologies. We note that the role of economic importance in this decision seems to lead to a very skewed result, i.e. outside the group of EPO member states, most protected patents are given by less than a handful of countries. Therefore, we do not use data on where patents are protected as an indicator of where these technologies are (potentially) used as suggested by e.g. Hafner (2008).

Conversely, the information on where patents are protected is useful to provide an indication of how important or valuable an individual patent family is. The idea here is that valuable and/or important inventions will typically be protected in a larger geographical area than less valuable or less important patents. This idea is widely applied in the patent valuation literature (e.g. Lanjouw et al., 1998) and is also used in the notion of a triadic patent as an indicator of technological competitiveness (Sternitzke, 2009).

A triadic patent is traditionally defined as an invention that is protected in Europe (EPO), the USA and Japan, or, in other words, it is a patent family that has members from at least these three patent offices. Applying this definition to our database leads to a very narrow interpretation of "patent quality": only 2,478 of 45,261 families in the 4IR field qualify as triadic in this traditional sense. We therefore slightly modify our definition to obtain a less narrow definition.

In this modification, we also consider that China is a large player in the field. As the elaboration of the data below shows, China is the leading nation in terms of patent families in 4IR technologies, with a share of 58 per cent of all patent families applied for from China. Our definition therefore recognizes China as an important country to seek protection in, i.e. we add the Chinese patent office to the existing triad (EPO, Japan, USA) to obtain a quartet of offices.

However, simply adding one more office to the list would narrow down the definition even further. We therefore lower the bar by requiring a patent family to contain at least two members that had applied for a patent at any of the four offices. In reference to the original definition, we call such a family a 'semi-triadic patent'. Applying this definition, we find that 16 per cent (or 6,994 families) of the observations in the database are defined as semi-triadic, and we use this as the definition of an important and/or valuable patent in the field of 4IR technologies.

While 16 per cent of all patent families still seems to be a small amount—i.e. most patent families do not qualify as important and/or valuable—it should be kept in mind that for applicants from Europe, China, Japan or the USA, we require only one additional (foreign) office in addition to their domestic one (considering the EPO as a domestic office for European applicants), which does not seem like an excessively high hurdle.

Applying the semi-triadic definition, Figure 3 presents the number of patent families per application (ownership) country. For every country, we show the number of families in 3D-printing and RTMO separately. Note that the value-axis is logarithmically scaled and that countries are ordered by the number of total (not necessarily semi-triadic) patent families in RTMO and 3D-printing together. A corresponding figure for all patent families is documented in the Appendix.

China is the country with most patent families, but in terms of semi-triadic families, it ranks fourth. The leading top-3 countries in terms of semi-triadic families are the USA, Japan and Germany, which are ranked 2-4 (in the same order) for all families. Taiwan Province of China completes the top 5. This distribution is very skewed: the top-3 countries hold 71 per cent of all semi-triadic patent families, the top-5 hold 79 per cent and the top-10 hold 91 per cent. The distribution for all patent families is even more skewed, with 83 per cent for the top-3, 92 per cent for the top-5 and 96 per cent for the top-10. This is considerably more skewed than the global distribution of all patent families, where we estimate that the top-3 countries (USA, China and Japan) hold 54 per cent of all families, the top-5, 72 per cent and the top-10, 86 per cent.

There is a clear correlation between the number of semi-triadic patent families in 4IR technologies and UNIDO's Competitive Industrial Performance (CIP) index, an indicator of an economy's ability to competitively produce and export manufactured goods. This is displayed in Figure 4, where the vertical axis is again logarithmic (only countries with >0 semi-triadic patent families). The figure displays the total of 3D-printing and RTMO patent families. The dotted line shows the (exponential) fit, which has a fairly high R^2 (0.69). Despite this high value, deviations from the fitted line can be substantial, especially on the righthand side, due to the logarithmic axis. Thus, Germany clearly "underperforms" in 4IR patents compared to its CIP value, while Japan and the USA overperform. China seems exactly on the trendline.

Figure 3: Number of semi-triadic patent families by country (entire period)

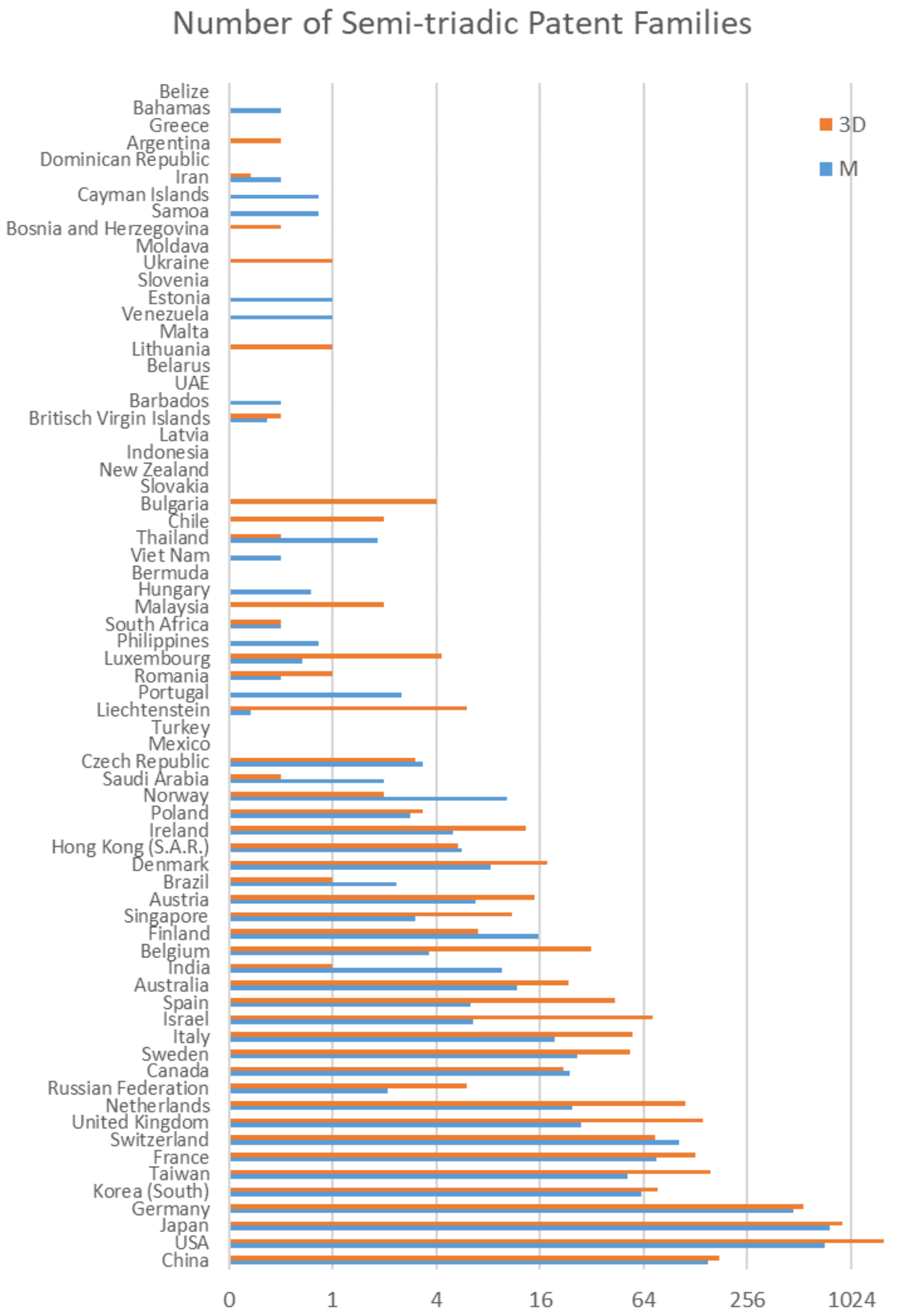
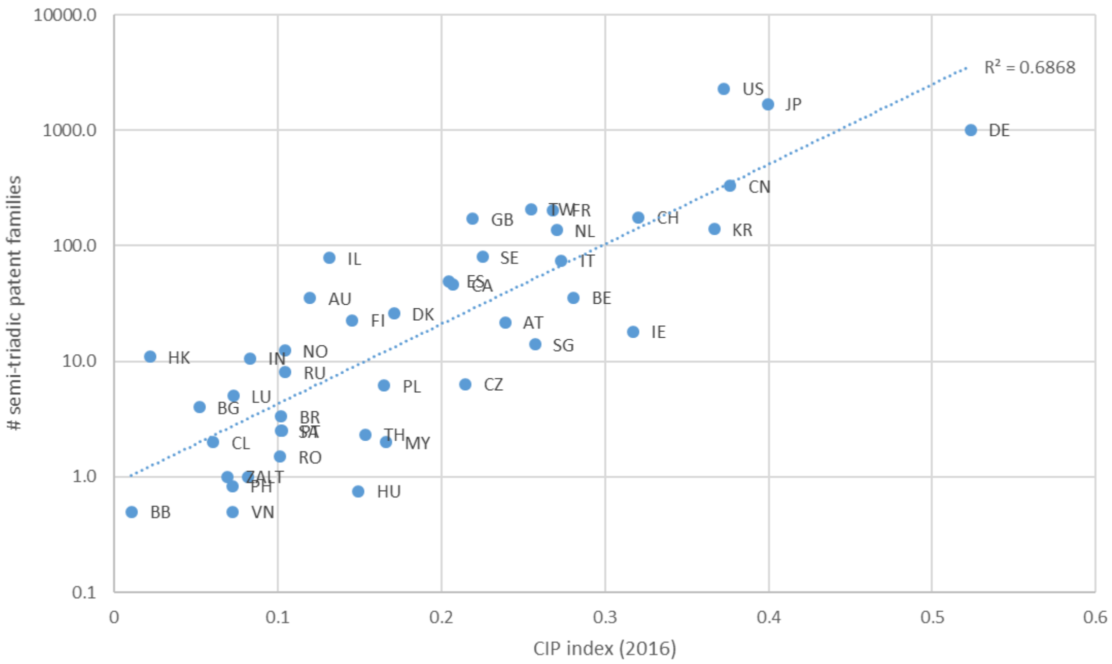


Figure 4: Association between the number of patent families and UNIDO's CIP index



3.3 Patenting in the Fourth Industrial Revolution by organization

We can also look at the largest organizations involved in patenting in 4IR technologies. Derwent standardizes organization names, including universities and firms, including daughter companies, etc. as well. This, however, is only done for the larger organizations, while smaller organizations are grouped together under a "non-standardized" tag. There are 172 standardized organization names that have more than 20 patent families. Together, these organizations account for 12,175 patent families in our database, which is 28 per cent of the total number of patent families in the database. There are 31 standardized organization names that are responsible for 50.5 per cent of the 12,175 patents, or 14.2 per cent of the total amount of patent families in 4IR technologies.

Table 1: Largest organizations in Fourth Industrial Revolution patenting

Organization	Economy	# patent families	Shares	
			RTMO	3D printing
Siemens	Germany	675	0.75	0.25
General Electric	USA	558	0.15	0.85
Hewlett-Packard	USA	424	0.02	0.98
State Grid Corporation China	China	308	1.00	0.00
Toshiba	Japan	280	0.84	0.16
Canon	Japan	249	0.16	0.84
Seiko Epson	Japan	240	0.10	0.90
Mitsubishi Electronic	Japan	222	1.00	0.00
South China University of Technology	China	218	0.33	0.67
University of Zhejiang	China	216	0.59	0.41
Xerox	USA	211	0.05	0.95
Ricoh	Ricoh	195	0.18	0.82
Hitachi	Japan	194	0.86	0.14
Stratasys	Israel	190	0.00	1.00
XYZPrinting	Taiwan China	170	0.01	0.99
University of Xi'An Jiaotong	China	162	0.14	0.86
Fanuc	Japan	145	1.00	0.00
United Technologies	USA	144	0.05	0.95
IBM	USA	141	0.77	0.23
Graphic Creation	Japan	136	0.00	1.00
Omron	Japan	136	1.00	0.00
Huazhong Un. of Science and Technology	China	134	0.25	0.75
Print-Rite Unicorn Image Products	China	127	0.00	1.00
ABB	Sweden-Switzerland	127	1.00	0.00
University of Jilin	China	121	0.15	0.85
Honeywell	USA	121	0.74	0.26
Guangdong University of Technology	China	119	0.32	0.68
Panasonic	Japan	116	0.69	0.31
Roland DG	Japan	113	0.02	0.98
Rosemount	USA	112	1.00	0.00
Northwestern Polytechnical University	USA	111	0.50	0.50

Table 1 documents these leading (i.e. largest number of patent families) organizations in 4IR technologies. Japan has the largest number of entries (10 firms), followed by the USA (seven firms and one university). China has seven entries and interestingly, the majority (five) of them are universities. Among the two Chinese firms are one large firm (State Grid Company of China) and one small firm (Print-rite Unicorn). Most of the organizations (especially firms) in the table are specialized in either RTMO or 3D printing, suggesting that these are more or less separate technology fields.

3.4 Fourth Industrial Revolution patenting in China

Among the countries holding a relatively large number of patent families, China has a special position in terms of the ratio between the total amount of families and the semi-triadic families. For China, only 1.26 per cent of all patent families are semi-triadic, which is the lowest in all countries in the top-25 of semi-triadic patenting. The Republic of Korea has the next lowest share of semi-triadic families at 7.75 per cent, followed by India at 15.53 per cent. All other countries in the top-25 have above 25 per cent, and 12 of the top-25 countries have above 50 per cent.

Thus, it seems that patents in China are of relatively low quality/value (cf. Huang, 2012). However, a closer scrutiny of China's 4IR technologies is necessary before such a conclusion can be drawn with reasonable certainty. Such a more detailed investigation would probably have to rely on an in-depth technological evaluation of patents, and this is obviously outside the scope of this paper. However, we can use some of the underlying information from our database to further elaborate on the nature of Chinese patenting.

Figure 5: Cumulative number of patent families in Fourth Industrial Revolution technologies, China

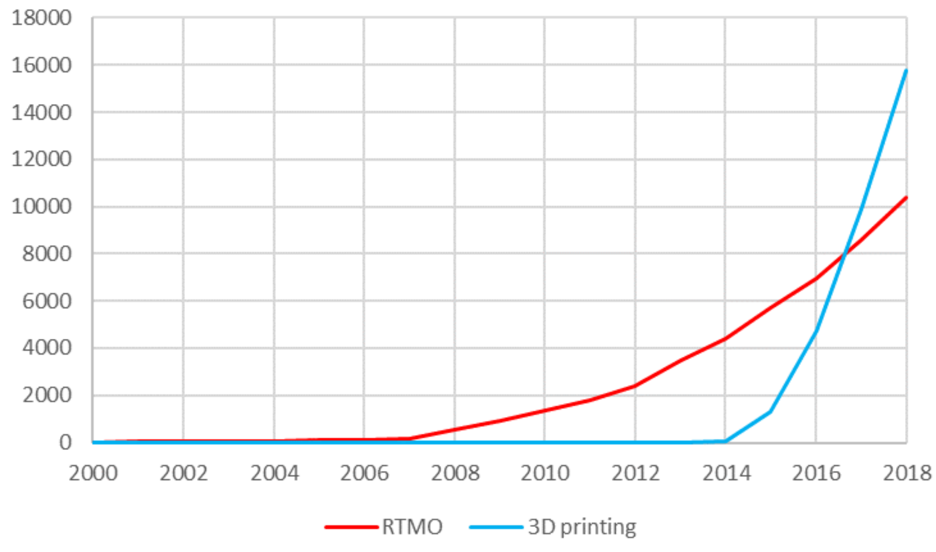


Figure 6: Cumulative number of patent families in sub-fields of RTMO, China

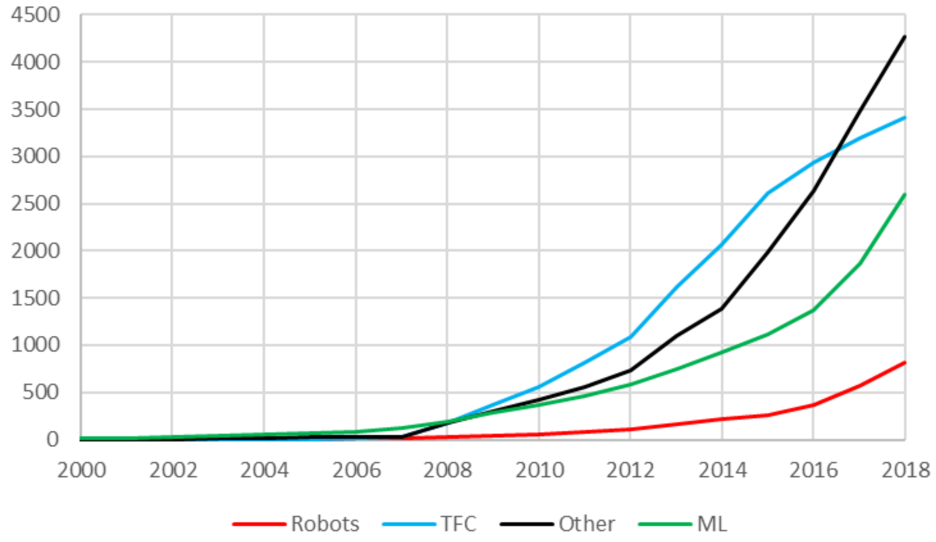


Figure 5 and Figure 6 illustrate cumulative Chinese patenting in the subfields of Fourth Industrial Revolution technologies (all patent families). Compared to the earlier figures for the entire world (Figure 1 and Figure 2), we observe that China is a relative latecomer. Patenting in these technologies took off in China in 2007 (TFC, ML, Other and RTMO as a whole) or later (3D printing, but note the time bias for this category). The trends for RTMO and its sub-categories are much smoother when we look at global patents. We compare this to the trend in total Chinese patenting (not documented) and observed that this is much smoother than that for Chinese 4IR patents. Total Chinese patenting shows no evidence of a break around 2007 (or later). Thus, the take off in Chinese patenting in IR4 is specific to this technology and does not coincide with a general increase in Chinese patenting.

Another interesting feature of Chinese patenting in this field is the fact that much of it comes from relatively small firms and universities. Table 1 clearly indicates this, with the State Grid Corporation of China (SGCC), whose main business activity is the transportation and distribution of electric energy, as the leading Chinese firm and only one other Chinese firm in the table. On the other hand, there are seven groups of Chinese organizations with non-standardized names with a total of 5,016 patent families, which illustrates the importance of small Chinese firms in this technology field. There are also five Chinese universities in Table 1, while there is only one non-Chinese university in this list of leading organizations.

The strong Chinese take-off in 4IR technologies seems to be related to government policy. We checked priority areas in the 2006 National Medium and Long Term Plan (the 5-year plan), and found Chapter III.7 ("Information Industry and Modern Service Industry"), Chapter V.2

(“Information Technology”, Chapter V.4 (“Advanced Manufacturing Technology”) to be crucially related to the building blocks of 4IR technologies. Given the observed trends in the Chinese data, there seem to be many universities and smaller businesses among those responding to this plan.

Whether the patents held by these Chinese organizations are a real and meaningful reaction to the policy initiative, or whether they are a kind of window dressing, will have to remain largely outside the scope of our analysis. There is no obvious way of assessing the quality of these Chinese patents, although the low interest in international protection suggests that these patents may not be very strong. In this sense, the large pool of Chinese IR4 patents appear much more like a set of “dark matter”, the basic characteristics of which must be investigated in future research than an established piece of evidence of Chinese capabilities in this emerging field.

3.5 Specialization profiles

Next, we look at how the main countries in 4IR technologies are specialized over the five sub-fields. Specialization is measured by the Revealed Technology Advantage (RTA) index, which is similar to the Revealed Comparative Advantage index that is commonly used in the analysis of trade. The RTA is calculated as the ratio of the share of a technology in the country’s total patents to the same ratio at the world level, which we can write as:

$$RTA_{cp} = \frac{P_{cp} / \sum_{p' \in T} P_{cp'}}{\sum_{c' \in C} P_{c'p} / \sum_{c' \in C, p' \in T} P_{c'p'}}$$

where P refers to patents, c and c' denote economies, and p and p' denote technology fields, with C and T being the set of economies and technologies, respectively. In our case, set T contains our 4IR technologies (R, T, M, O, 3D), so that we measure specialization within sub-fields of this broad set of technologies rather than specialization in the entire field compared to all technology fields.

The RTA is equal to the share of an economy’s patents that are of the class under consideration divided by the share of world patents of that class, with a country having a revealed technology advantage in the technology if the RTA>1. In our analysis below, we transform the RTA values as $(RTA - 1)/(RTA + 1)$ to make the figures appear more symmetric and easier to follow. As a result, a value of the transformed RTA index above 0 corresponds to a country having a revealed comparative advantage.

Figure 7 shows the specialization profile of the top-5 countries in terms of semi-triadic patent families. In the top-5 countries, we see that China has the most skewed specialisation pattern, with a clear specialization in total factory control (TFC) and weaker specializations in robots and other. Taiwan Province of China and the USA are specialized in 3D printing, Japan in robots and machine learning (ML) and Germany in TFC. In the second-tier countries (positions 6-10 in semi-triadic patenting) presented in Figure 8, the Netherlands has a strong specialization in 3D-printing, Switzerland in TFC, and the Republic of Korea and France in robots.

Figure 7: Specialization pattern of top-5 patenting countries

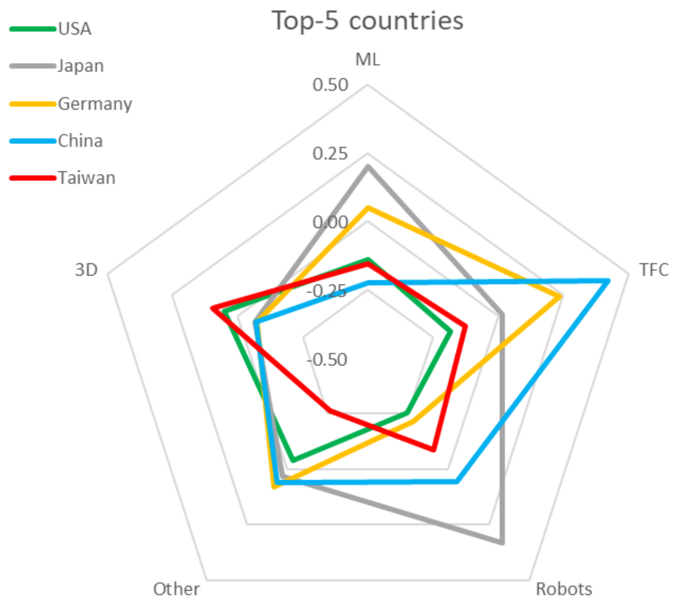
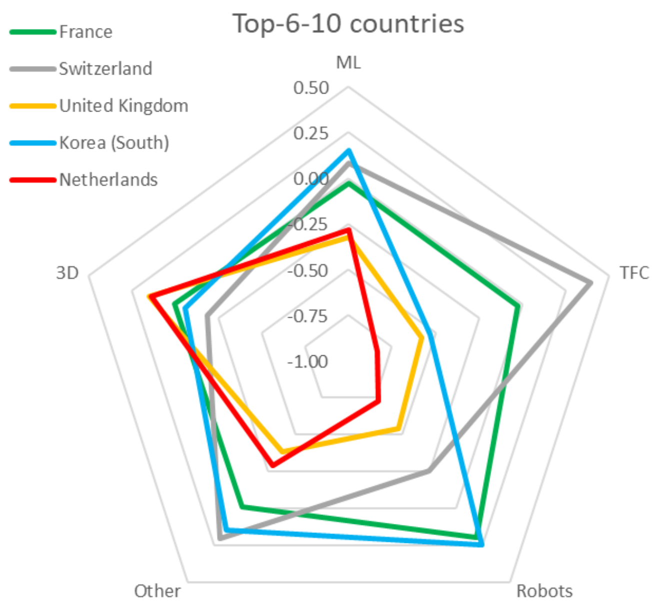


Figure 8: Specialization pattern of top-6-10 patenting countries



3.6 Is Fourth Industrial Revolution technology green?

Fourth Industrial Revolution technology is emerging in an era in which environmental sustainability is of key significance. Thus, one important factor in the ultimate success of this set of technologies will be whether it can contribute to a more sustainable economy. We therefore use the information on the "green" nature of patents to assess the potential of 4IR technologies.

We use the so-called Y02 tag, which is a code that can be attached to a patent if it is considered (by the patent examiners) as contributing to climate change mitigation. In our database, 12.7 per cent of all patent families have this "green tag." It is not easy to find a comparable number for patents that are not related to 4IR technologies.[5] The best comparison we could come up with is using (all) DocDB patent families in PATSTAT, of which 3.6 per cent has a Y02 tag for the period after 1999. Thus, 4IR patents seem to be a set of technologies with an above average green content. The green nature of these technologies relates in particular to RTMO patents, which are 19.4 per cent green, rather than 3D printing (8.1 per cent green).

Further investigation of the more detailed Y02 tag reveals that the majority of green patents in 4IR technology is found in two specific codes: Y02P 90/02 and Y02P 10/295. The first of these

[5] The Y02 tag is not available in the Derwent database and was retrieved from PATSTAT for the families that we identified as belonging to the Fourth Industrial Revolution technology domain.

accounts for 2,330 patent families in the RTMO group, and the latter for 1,811 patent families in 3D printing. Thus, these two classes hold 72.3 per cent of all green patents in the 4IR database.

The tag Y02P 90/02 refers to “Enabling technologies with a potential contribution to greenhouse gas [GHG] emissions mitigation” (Y02 P 90) and specifically “Total factory control, e.g. smart factories, flexible manufacturing systems [FMS] or integrated manufacturing systems [IMS]” (/02). Thus, it seems that TFC technology bears a promise to reduce GHG emissions. The tag Y02 P 10/295 refers to “Additive manufacturing of metals”.

4 Trade in 4th Industrial Revolution technologies

4.1 World developments

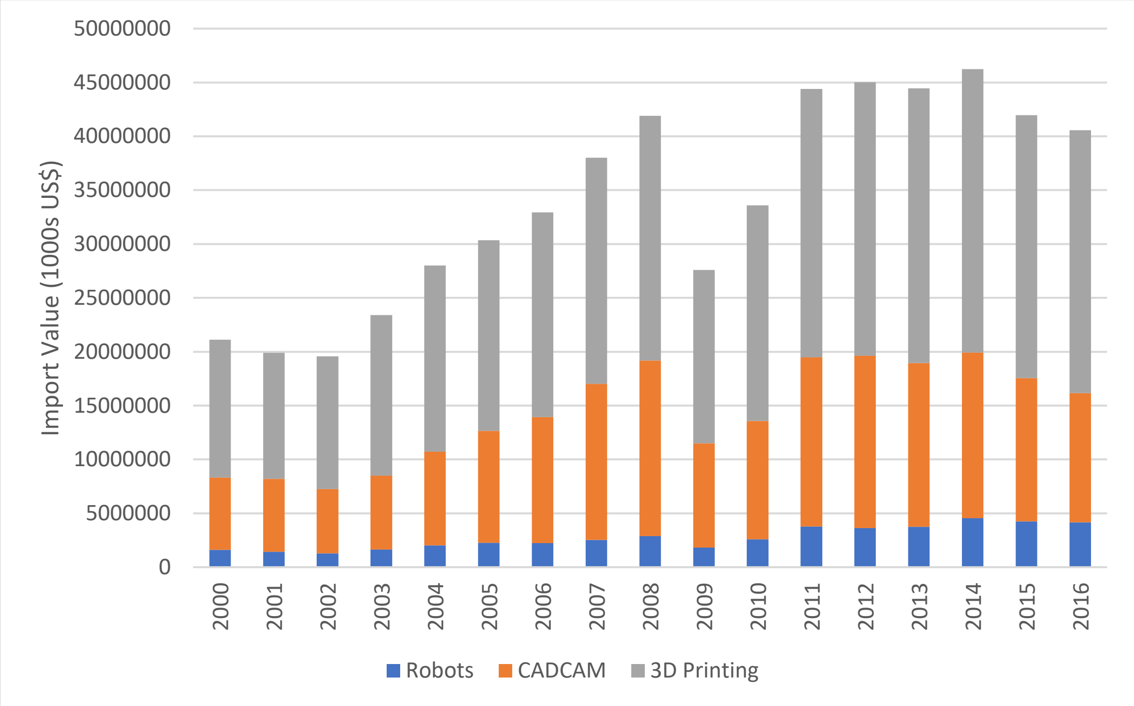
We begin the descriptive analysis of trade in the identified 4IR technologies by examining developments in the value of world imports.[6] Figure 9 reports the value of imports of these technologies for the years 2000-2016, with the data further divided into the three separate categories (i.e. robots, 3D printing and CAD-CAM). These data are in current prices and therefore reflect movements in both the volume of imports and the price of such imports. The figure shows that after remaining relatively stable throughout the end of the 1990s and the start of the 2000s, there was a relatively rapid rise in the import of these technologies, at least until the global financial crisis when import values dropped dramatically. Import values recovered slightly, but have again shown a tendency to decline since 2012. In terms of the composition of these imports, robots made up a relatively small share of these imports in 2000 (around 8 per cent of the total), with 3D printing (61 per cent) and CAD-CAM technologies (32 per cent) accounting for the major share of imports. Over time, we observe relatively little change in the composition of imports of these technologies. The share of robot imports has risen slightly, accounting for just over 10% of 4IR imports in 2016. The share of these imports captured by 3D printing has remained roughly constant (at 60 per cent), implying that there has been a slight decline in the share of these imports due to CAD-CAM technologies (the share dropped to 30 per cent in 2016).

This observed pattern tends to follow the general pattern observed for world imports of all goods over the same period. It should also be borne in mind that while we observe an increase in the import of these technologies between 2000 and 2016, the share of these products in total imports remains very small (and actually declined over the period). These products accounted for just 0.34 per cent of total imports in 2000, falling slightly to 0.27 per cent of total imports in 2016. In this

[6] Given that we are looking at world imports, these values are also equivalent to world exports in these products. There may, however, be some minor differences due to the fact that we exclude some smaller countries (whose trade need not be balanced).

latter period, robots accounted for 0.027 per cent of world imports, CAD-CAM 0.084 per cent and 3D printing 0.154 per cent.[7]

Figure 9: World import values of Fourth Industrial Revolution technologies



Source: UN Comtrade and BACI dataset, authors' own calculations

4.2 Trade in Fourth Industrial Revolution technologies by country

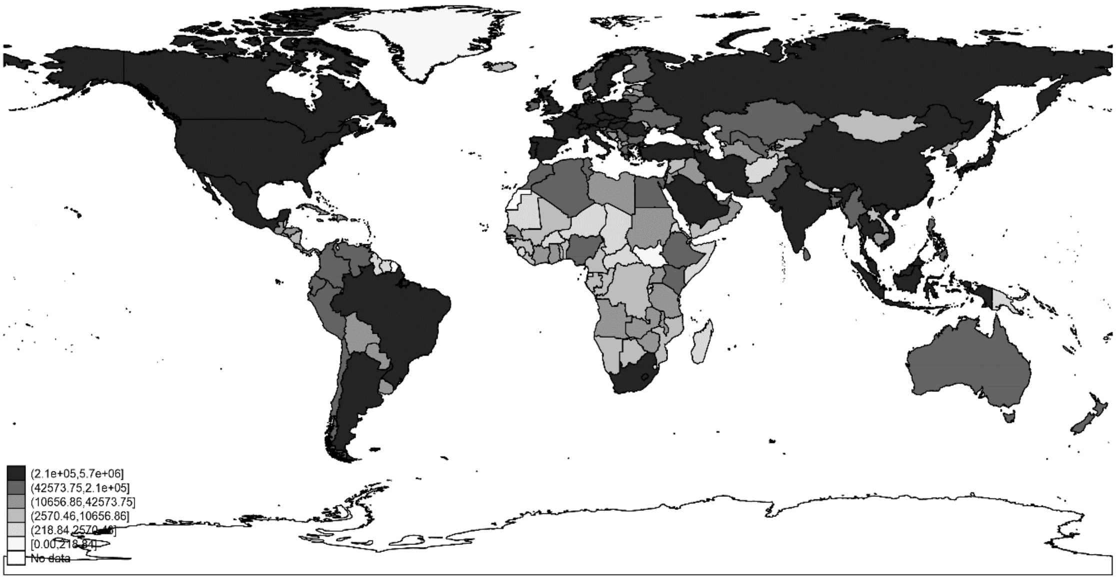
Moving beyond world aggregates, it is also instructive to consider the involvement of different countries in the trade of these products. The following two figures provide heat maps for the period 2014-2016 (averaged) of the value of imports in these technologies (i.e. all three technologies combined) and the ratio of import values to employment[8], the latter giving an impression of the intensity of imports in these products (as well as helping to remove the effects due to differences in the size of countries). Figure 10, unsurprisingly, reports that larger countries—in terms of GDP, GDP per capita or population—tend to import a higher value of I4R technologies, with countries in North America and Europe reporting high values, along with the larger countries in other regions of the world, including Japan, India, China, the Republic of Korea and Indonesia in Asia, and Brazil and Russia. When considering the intensity of the imports of

[7] It should also be remembered that these figures are based on values of imports, and thus reflect both price and quantity effects, with prices playing a potentially important role in driving the overall values and the share of these 4IR technologies in total imports.

[8] We use data on total employment from ILOSTAT.

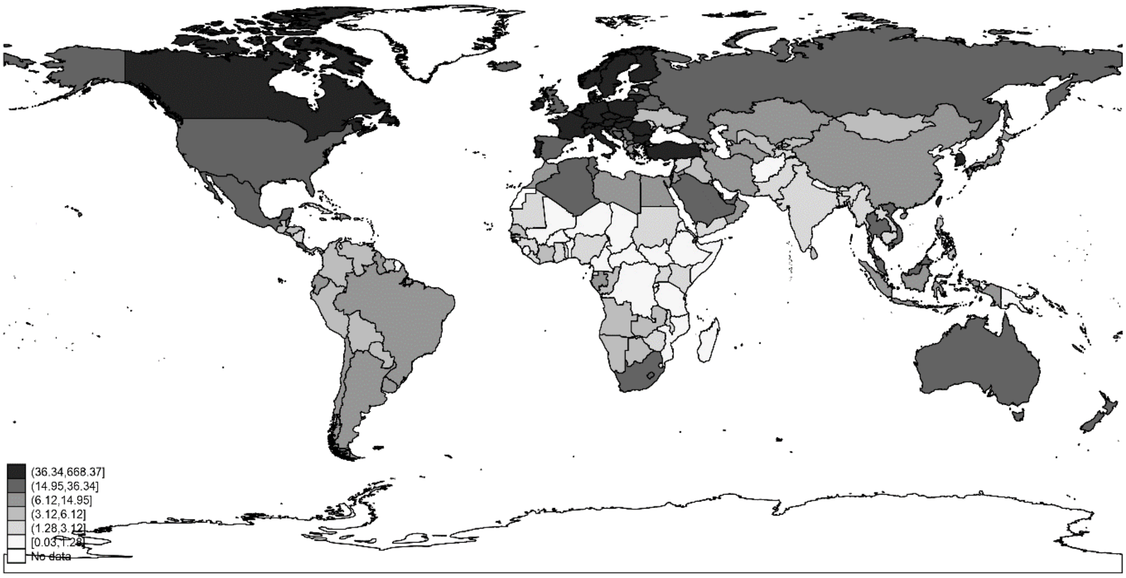
these technologies by looking at the ratio of imports to employment (Figure 11), we see a slightly different picture, with the highest ratios being reported across a large part of Europe, along with Canada, Mexico, the Republic of Korea and Saudi Arabia. When expressed in per employee terms, the importance of these technologies diminishes significantly for many countries, most notably India, but also China and the USA, with relatively low levels of diffusion of these technologies taking place to African countries, albeit with some moderate exceptions in North and southern Africa.

Figure 10: World import values



Note: Import values (current prices) of Industry 4.0 technologies, average 2014-2016.
Source: UN Comtrade and BACI.

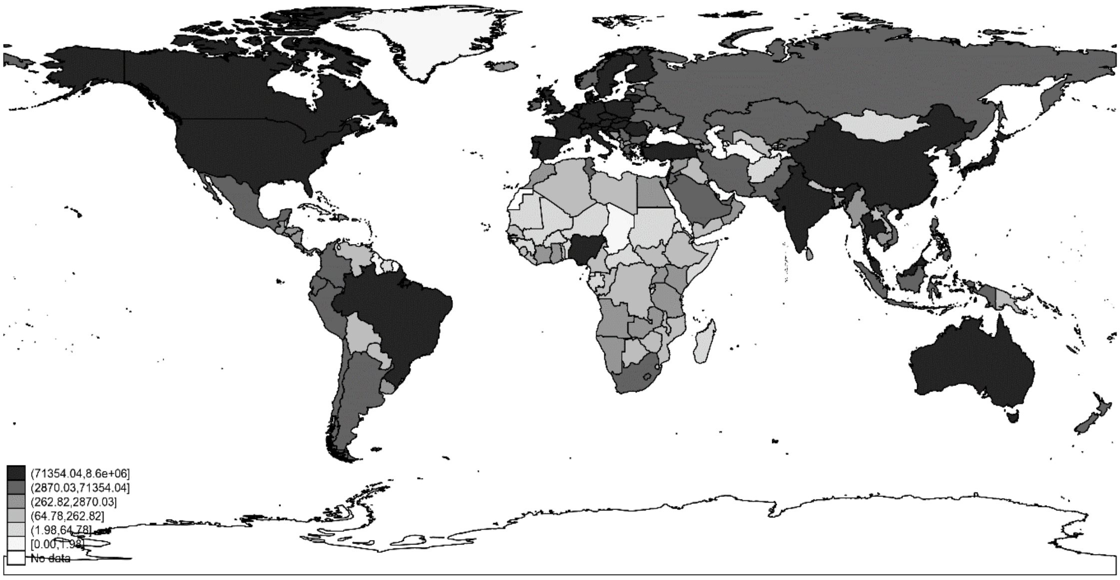
Figure 11: Import to employment ratio



Notes: Ratio of import values (current prices) of Industry 4.0 technologies to total employment, average 2014-2016. *Source*: UN Comtrade, BACI and ILOSTAT.

The following two maps report similar information, but for exports. Figure 12 reveals that the export of these technologies is heavily concentrated in North America and Western Europe, along with a small number of countries in Asia (most notably, China, India, Japan, the Republic of Korea) and Australia. When expressed in per employee terms (Figure 13), this pattern largely holds, albeit with declining importance for India, China and Australia. Africa performs relatively poorly across both indicators, with the exception of South Africa.

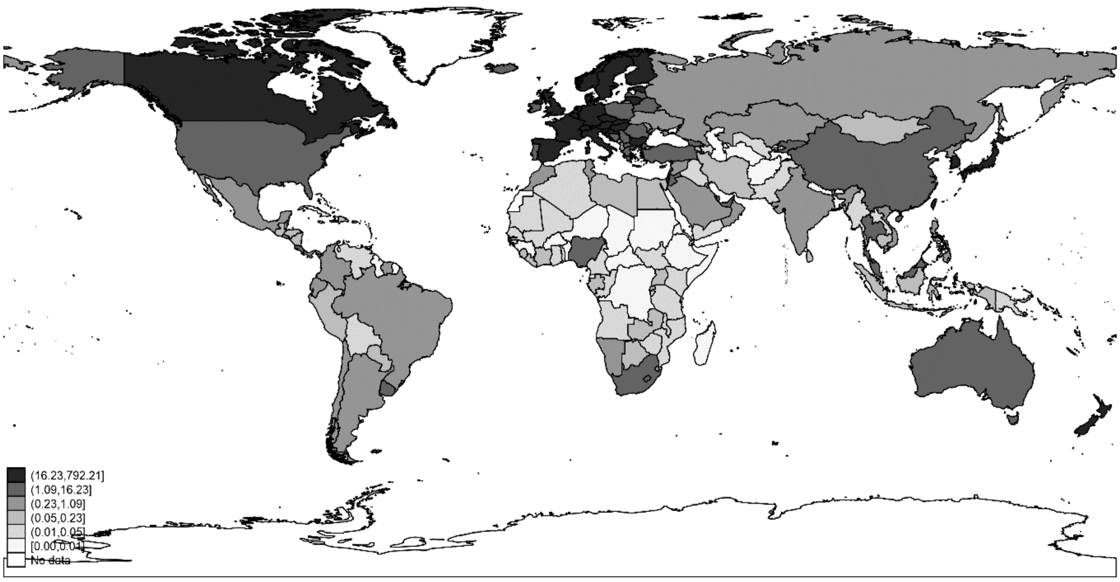
Figure 12: Export values



Notes: Export values (current prices) of Industry 4.0 technologies, average 2014-2016.

Source: UN Comtrade and BACI.

Figure 13: Export to employment ratios



Notes: Ratio of export values (current prices) of Industry 4.0 technologies to total employment, average 2014-2016.

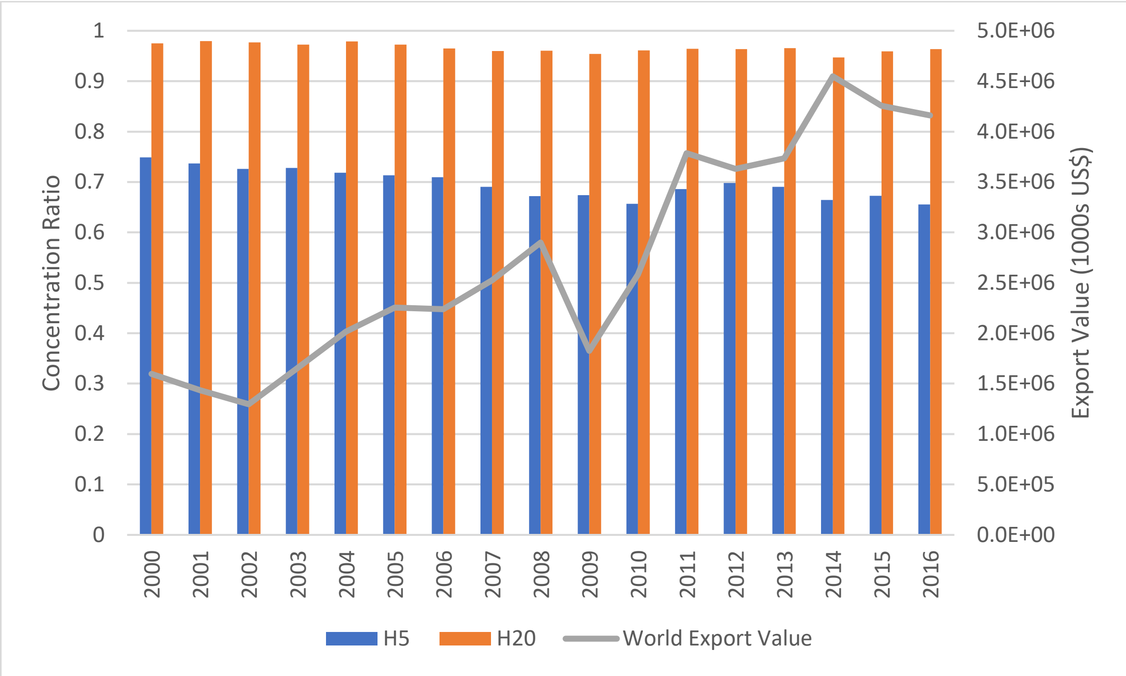
Source: UN Comtrade, BACI and ILOSTAT.

4.3 Export concentration ratios of 4th Industrial Revolution technologies

After considering the general developments in the trade of the identified 4IR technologies, we now focus on exports of these technologies and their composition across countries. We begin by reporting information on concentration ratios. Figure 14 reports information on the five- (H5) and twenty- (H20) country concentration ratios of exports of robots along with the development of export values of robots for the period 1998-2016. The figure reveals that the value of exports of robots rose rapidly over the period, except during the period of the global financial crisis and the most recent period during which exports of these technologies have also declined. The five-country concentration ratio is very high—ranging between 68 per cent and 78 per cent—implying that most exports of these products are supplied by just five countries. Given the relatively rapid increase in the value of these exports over time, it is perhaps not surprising that there is a downward trend in the five-country concentration ratio, though it had remained high at 68 per cent in 2016. The twenty-country concentration ratio was found to be 98.5 per cent in 1998, and while it dropped slightly between 1998 and 2016, the ratio remained above 96 per cent. Overall, the figure reveals a high rate of concentration in the export of robots, and while there has been some decline in concentration, it remains very high.

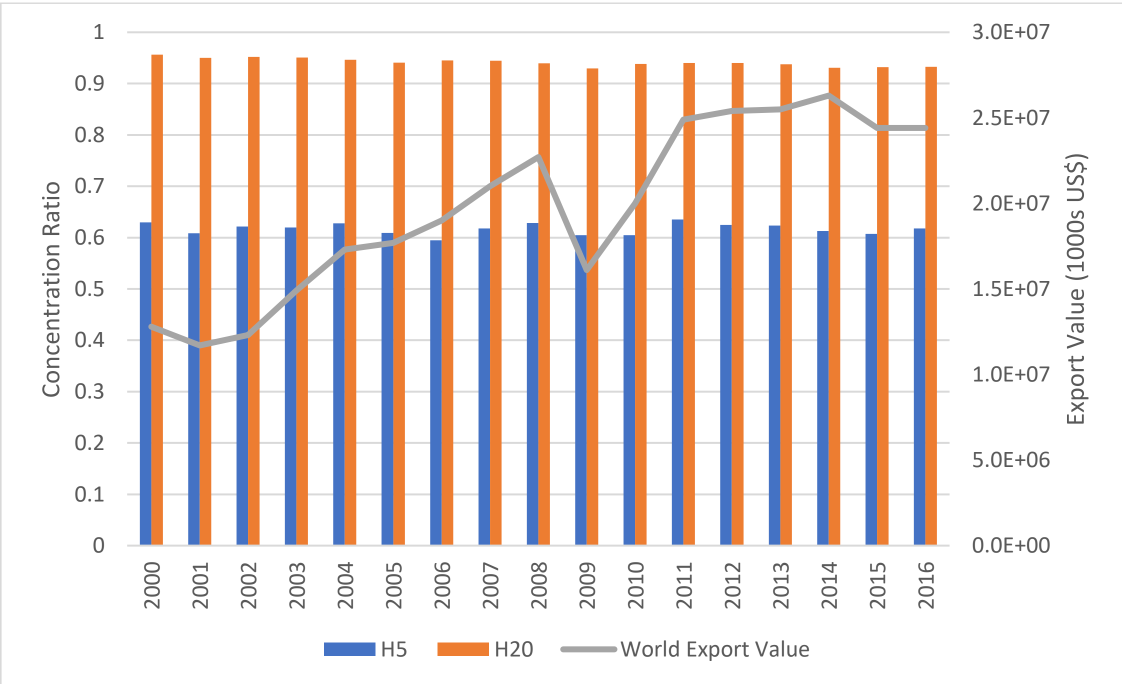
A similar pattern emerges when we consider the concentration ratios for exports of 3D printing (Figure 15) and CAD-CAM technologies (Figure 16). Developments in exports of these products follow a similar trend to that for robot exports, with a relatively rapid decline in exports in the most recent period for CAD-CAM technologies. While the concentration ratios are somewhat lower than for robots (the five-country concentration ratio ranging from 59 per cent to 66 per cent in the case of 3D printing and from 59 per cent to 69 per cent for CAD-CAM), they remain very high. Similar to robots, there is a tendency for the concentration ratios to fall over time, a tendency that is somewhat muted in the case of 3D printing.

Figure 14: World export values and concentration ratios of exports of robots



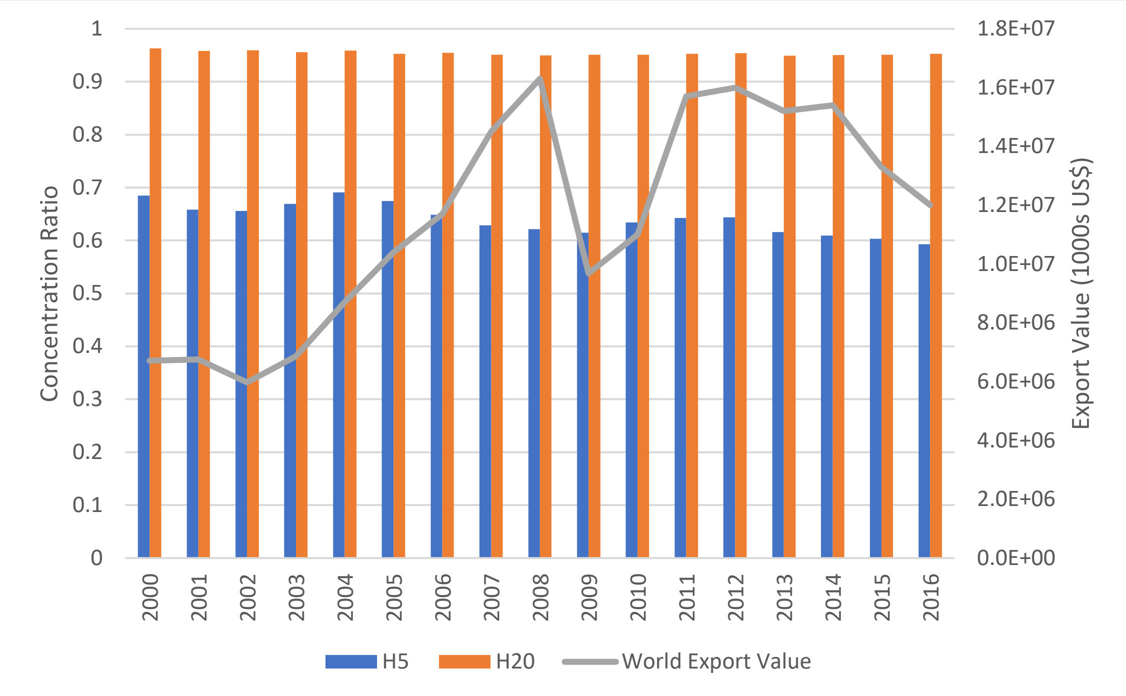
Source: BACI dataset and authors' own calculations

Figure 15: World export values and concentration ratios of exports of 3D printing technologies



Source: BACI dataset and authors' own calculations

Figure 16: World export values and concentration ratios of imports of CAD-CAM

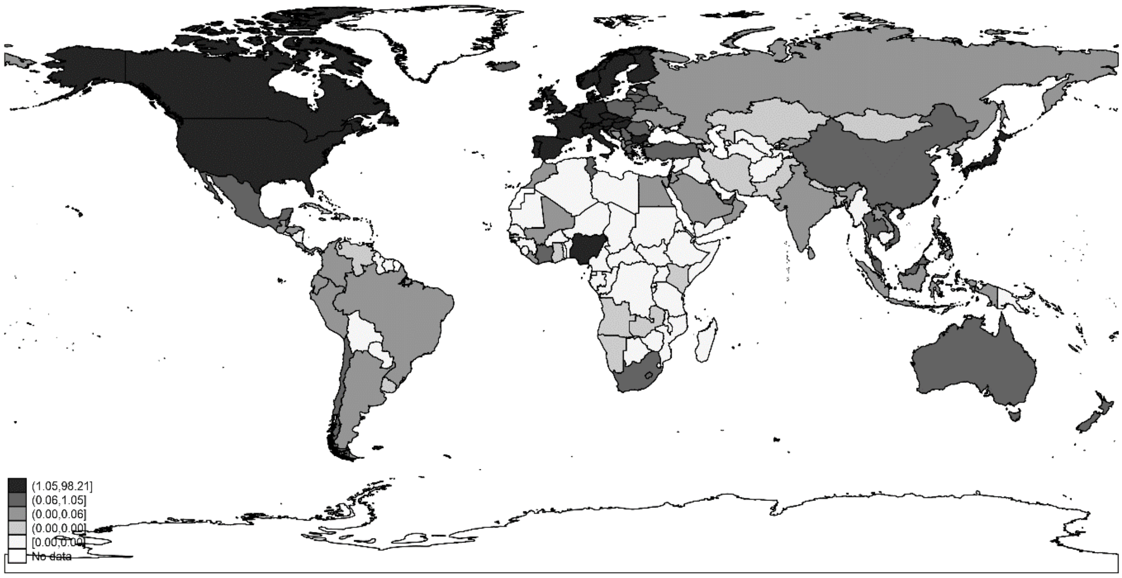


Source: BACI dataset and authors' own calculations

4.4 Export intensity of 4th Industrial Revolution technologies

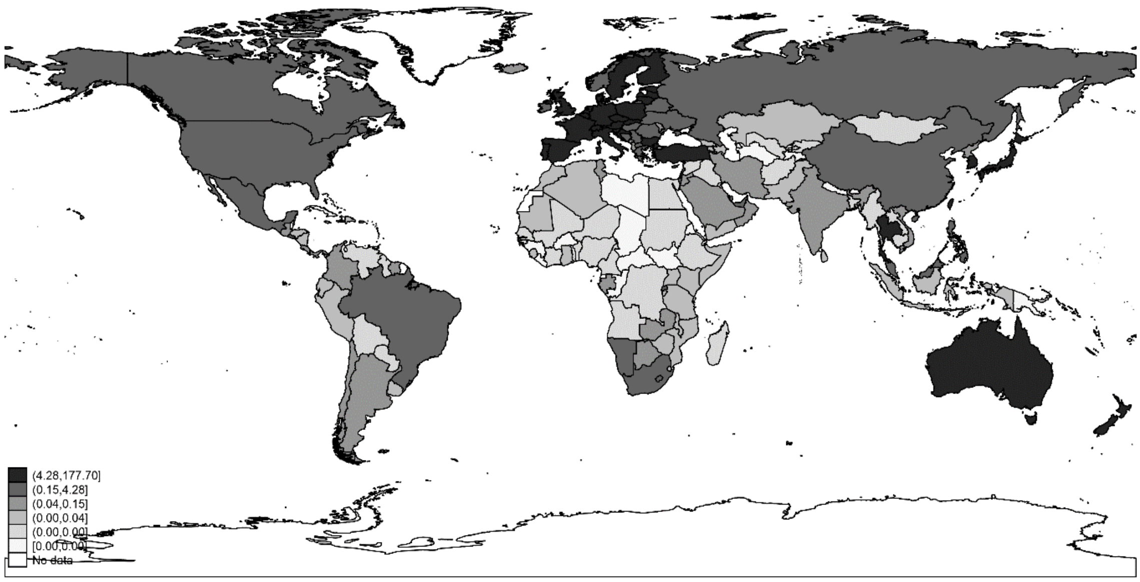
Building upon the concentration figures, the next set of maps reports the export intensity of the three identified 4IR technologies, with Figure 17, Figure 18 and Figure 19 reporting these intensities for robot exports, CAD-CAM exports and 3D printing exports, respectively. In line with the results reported above for the aggregate of these three technologies, the figures reveal that only a few countries have a relatively high intensity of exports in these products, with this group of countries being dominated by North America, western Europe, Japan and the Republic of Korea. While this result generally holds, some differences across the different technologies are visible. We find the intensity of CAD-CAM exports to be relatively high in a number of additional countries, including New Zealand and Australia, along with Thailand and Turkey. In the case of 3D printing, we observe relatively high export intensities for Turkey, China and Thailand in addition to the set of countries for which these ratios are always relatively large. Consistent with the results presented above, the comparison of export intensities across countries suggests that exports of robots are somewhat more concentrated than those of the other two technologies.

Figure 17: Intensity of robot exports



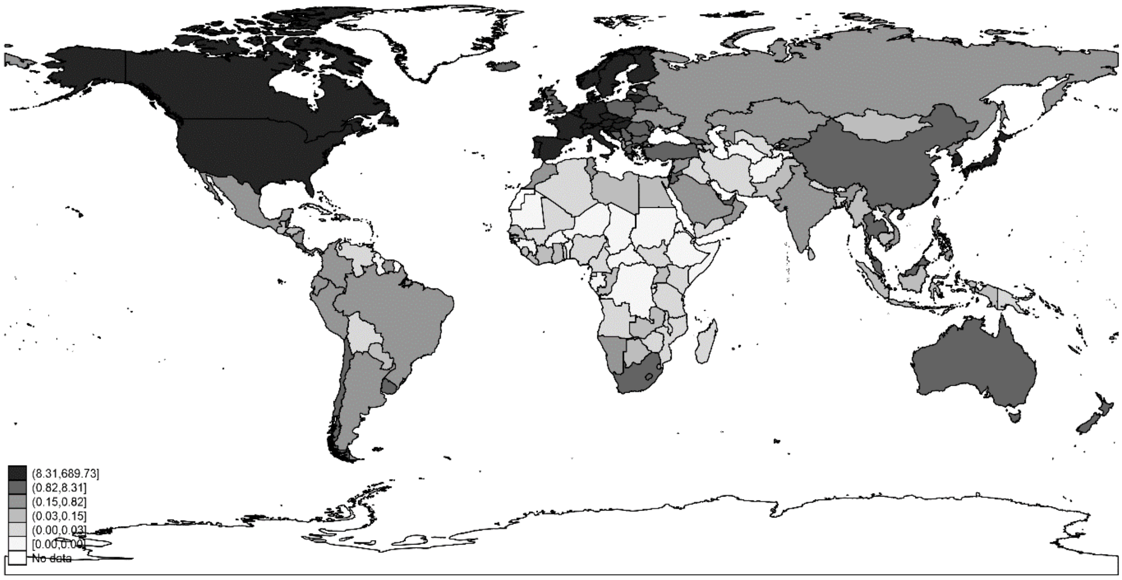
Notes: Ratio of export values (current prices) of Industry 4.0 technologies to total employment, average 2014-2016. *Source*: UN Comtrade, BACI and ILOSTAT.

Figure 18: Intensity of CAD-CAM exports



Notes: Ratio of export values (current prices) of Industry 4.0 technologies to total employment, average 2014-2016. *Source*: UN Comtrade, BACI and ILOSTAT.

Figure 19: Intensity of 3D printing exports



Notes: Ratio of export values (current prices) of Industry 4.0 technologies to total employment, average 2014-2016. *Source*: UN Comtrade, BACI and ILOSTAT.

4.5 The revealed comparative advantage of exports

We now consider the countries that are successful exporters of these 4IR technologies by exploring their revealed comparative advantage (RCA). The RCA is calculated in a similar way to the RTA index described above:

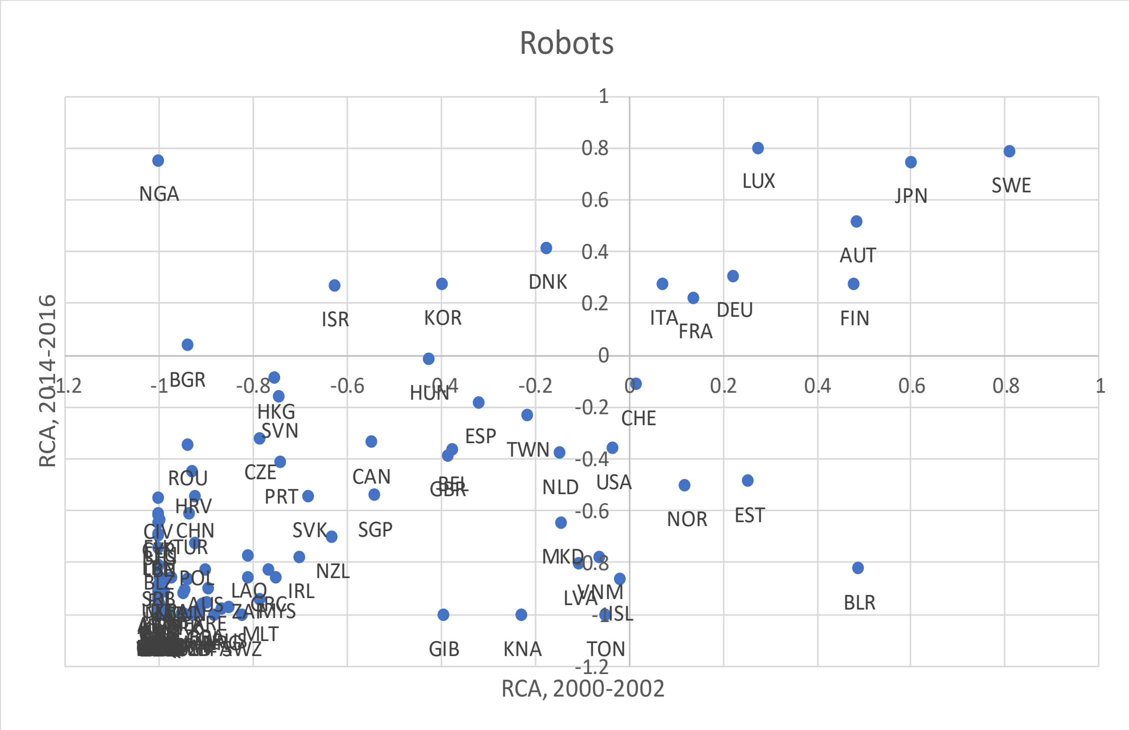
$$RCA_{cp} = \frac{E_{cp} / \sum_{p' \in P} E_{cp'}}{\sum_{c' \in C} E_{c'p} / \sum_{c' \in C, p' \in P} E_{c'p'}}$$

where E refers to exports, c and c' denote economies, p and p' denote products, with C and P being the set of economies and products, respectively. In this case, the set P of products includes all trade products, so that we can calculate specialization in 4IR products relative to all traded products. Again, we transform the RCA values as $(RCA - 1)/(RCA + 1)$ to make the figures appear more symmetric and easier to follow. As a result, a value of the transformed RCA index above 0 corresponds to a country having revealed comparative advantage. We construct this index for our three types of 4IR technology, reporting scatterplots in the figures below of the resulting RCAs for the average of the three years 2000-2002 and 2014-2016.[9] This allows us to identify the

[9] There is a degree of variation in RCA numbers over time, so we choose to take averages over three-year periods to smooth out this variation.

set of countries that are the most intensive exporters of these technologies and to consider how this set has changed over time.

Figure 20: Export RCA of robots in 2000-2002 and 2014-2016 (based on export values)



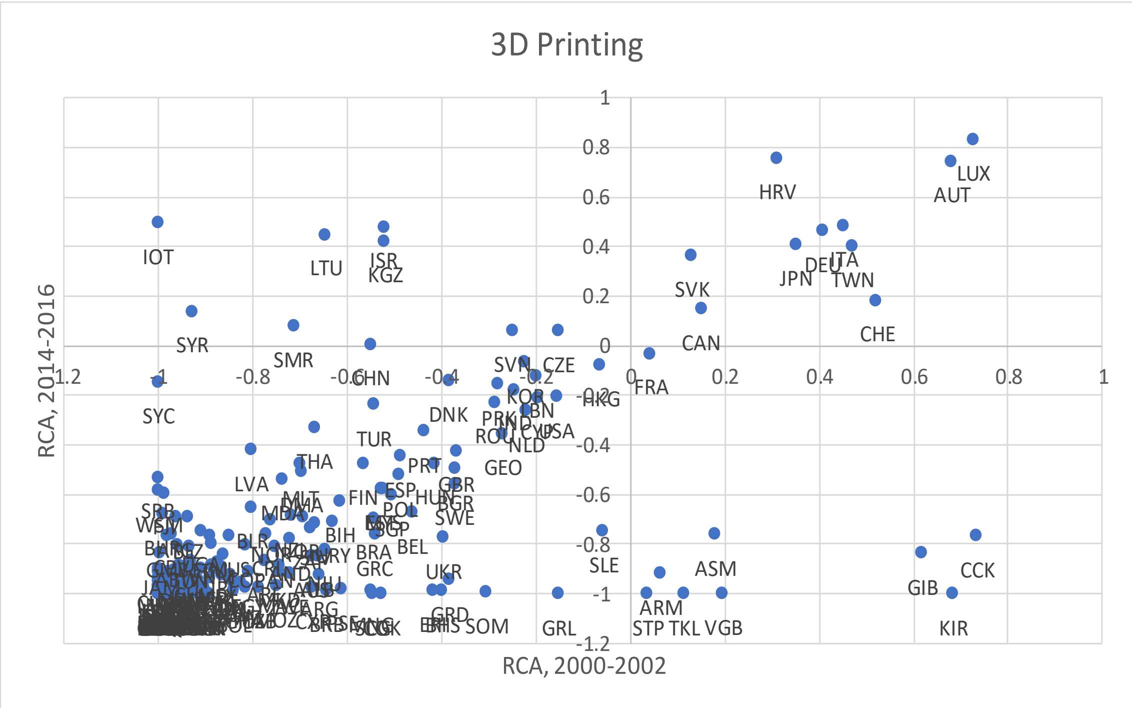
Source: UN Comtrade and BACI dataset and authors' own calculations

Figure 20 reports values of the (transformed) RCA index in the case of robot exports. The figure reveals that very few countries have an RCA in the export of robots. In 2000-2002, this was limited to Japan and a few other western European countries (e.g. Finland, Sweden, Germany, Austria, Italy, France, Norway and Switzerland), as well as a couple of countries that were less anticipated (i.e. Estonia, Belarus). The latter countries lost RCA between 2000-2002 and 2014-2016, however, with additional countries in Europe (e.g. Denmark, Bulgaria), as well as Israel, the Republic of Korea and, more surprisingly, Nigeria, gaining RCA. Overall, the figure reinforces the notion that the production of these technologies is concentrated in a small number of advanced countries, with most countries not exporting these products (or having very low exports).

While the data indicate that more countries are involved in the export of 3D printing technology, the results in Figure 21 are somewhat similar to those for robots, with a relatively small number of countries appearing to have an RCA in either 2000-2002 or 2014-2016. The countries with an RCA in both years are again countries in Western Europe, along with Japan, Taiwan Province of

China and Canada. Some countries, notably Armenia, had an RCA in 3D printing in 2000-2002, which disappeared by 2014-2016, while a relatively small number of countries achieved an RCA in 2014-2016 despite not having an RCA in 3D printing in 2000-2002. Once again, many of these countries are in Europe, with Lithuania, Israel, Kyrgyzstan and Syria also registering an RCA in 3D printing in 2014-2016.

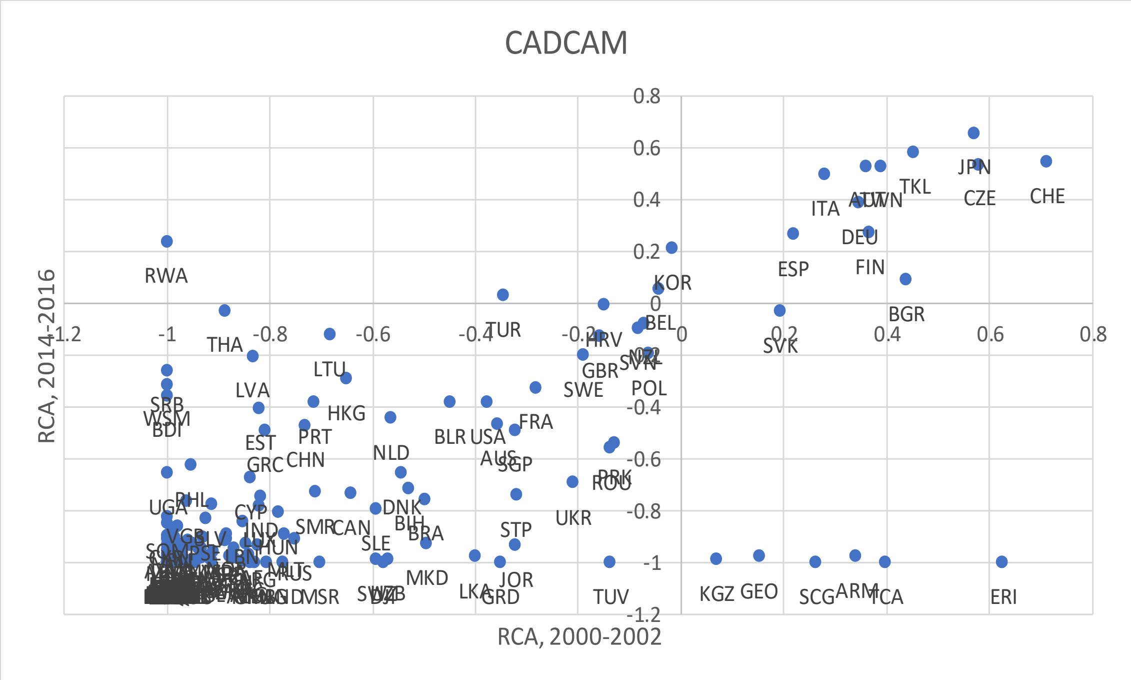
Figure 21: Export RCA of 3D printing technologies in 1998-2000 and 2014-2016 (based on export values)



Source: UN Comtrade and BACI dataset and authors' own calculations

Turning finally to CAD-CAM exports (Figure 22), we again find a large number of countries with positive exports in these technologies, but relatively few with an RCA in the export of such products. The set of countries with an RCA in both time periods is consistent with that found for robots and 3D printing, with several western European countries, Japan and Taiwan Province of China having a consistent RCA. As was the case for 3D printing, we observe some central Asian states (i.e. Armenia, Kyrgyzstan and Georgia) that had an RCA in 2000-2002, which was, however, lost between 2000-2002 and 2014-2016. In the case of CAD-CAM, very few countries were able to attain an RCA between 2000-2002 and 2014-2016, with only the Republic of Korea, Rwanda, Turkey and Belgium managing to achieve an RCA by 2014-2016.

Figure 22: Export RCA of CAD-CAM in 1998-2000 and 2014-2016 (based on export values)



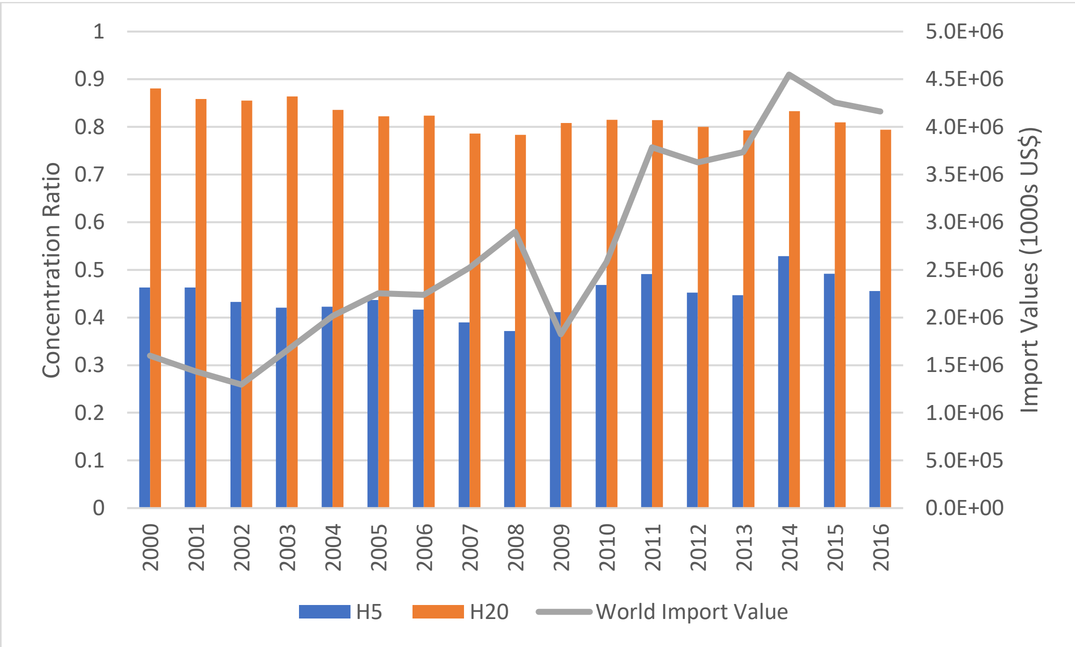
Source: UN Comtrade and BACI dataset and authors' own calculations

4.6 Import concentration ratios of Fourth Industrial Revolution technologies

We now move to repeat the descriptive exercise undertaken above but consider imports instead of exports. The aim of this is to document the diffusion of these technologies, identifying the extent of this diffusion and the countries that are intensive users of these technologies. In this sub-section we report information on the value of world imports of each of the three different types of technology along with the five-country (H5) and twenty-country (H20) concentration ratios of imports. Figure 23 reports this information for the import of robots. The five-country concentration ratio generally ranges between 0.4 and 0.5 throughout the period, with no clear trend observed. The results thus suggest that five countries account for between 40 per cent and 50 per cent of world imports of robots, with the ratio in 2000 essentially being the same as that observed in 2016. Data on the twenty-country concentration ratio are by definition higher, with the ratios ranging between about 75 per cent and 90 per cent. The trend in this ratio tends to be negative, indicating that while the top five countries in terms of imports of robots tend to maintain their import shares, there is a tendency for imports to become more widely spread among countries other than these top five. In general, therefore, the evidence suggests that the imports of robots are far less concentrated than the exports of these products.

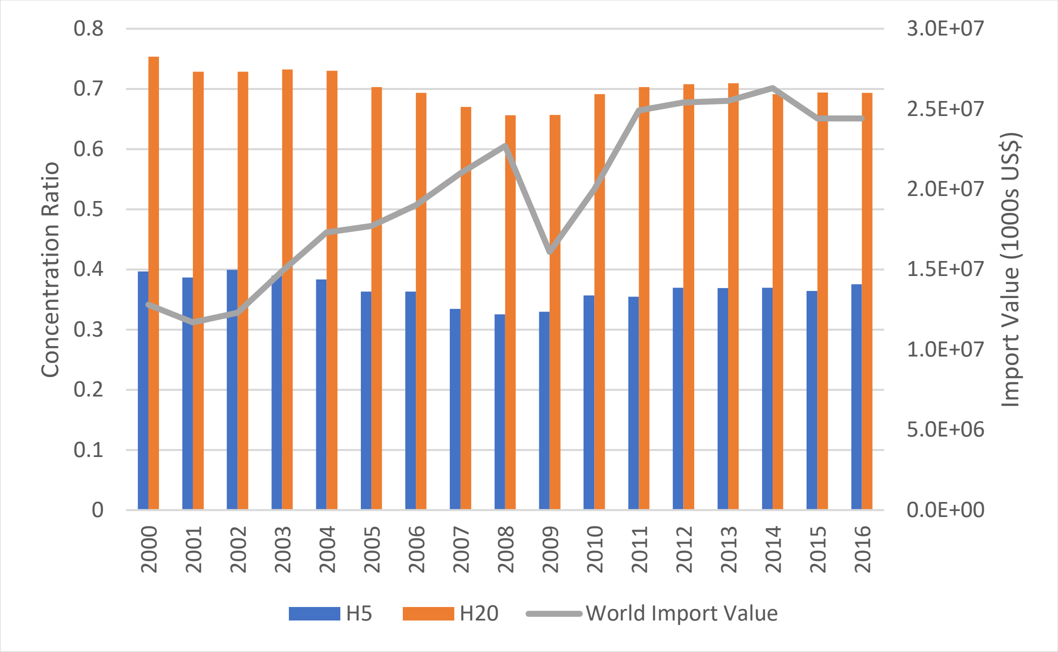
The results are largely similar to those for robots when we consider 3D printing (Figure 24). We observe a five-country concentration ratio that indicates little in the way of a trend, but a twenty-country concentration ratio that shows some sign of declining over time. Where the results differ slightly is in the values of the concentration ratios, with the five-country ratio being between 0.3 and 0.4 in the case of 3D printing as opposed to between 0.4 and 0.5 for robots, and the twenty-country concentration ratio being between 0.65 and 0.75 in the case of 3D printing and between 0.75 and 0.9 in the case of robots. This suggests that imports of 3D printing technologies are somewhat less concentrated than robots, with more countries engaged in the use of such technologies. The five- and twenty-country concentration ratios in the case of CAD-CAM technologies (Figure 25) tended to be somewhat higher than those for robots and 3D printing in the early 2000s, with a tendency for these ratios to decline over time.

Figure 23: World import values and concentration ratios of imports of robots



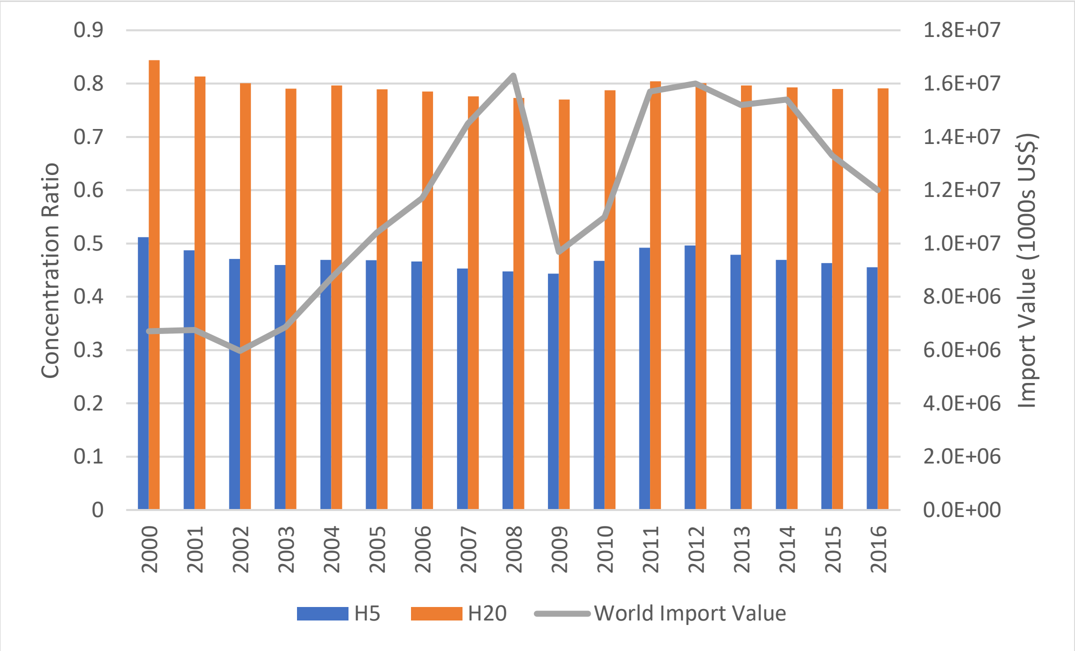
Source: UN Comtrade and BACI dataset and authors' own calculations

Figure 24: World import values and concentration ratios of imports of 3D printing



Source: UN Comtrade and BACI dataset and authors' own calculations

Figure 25: World import values and concentration ratios of imports of CAD-CAM



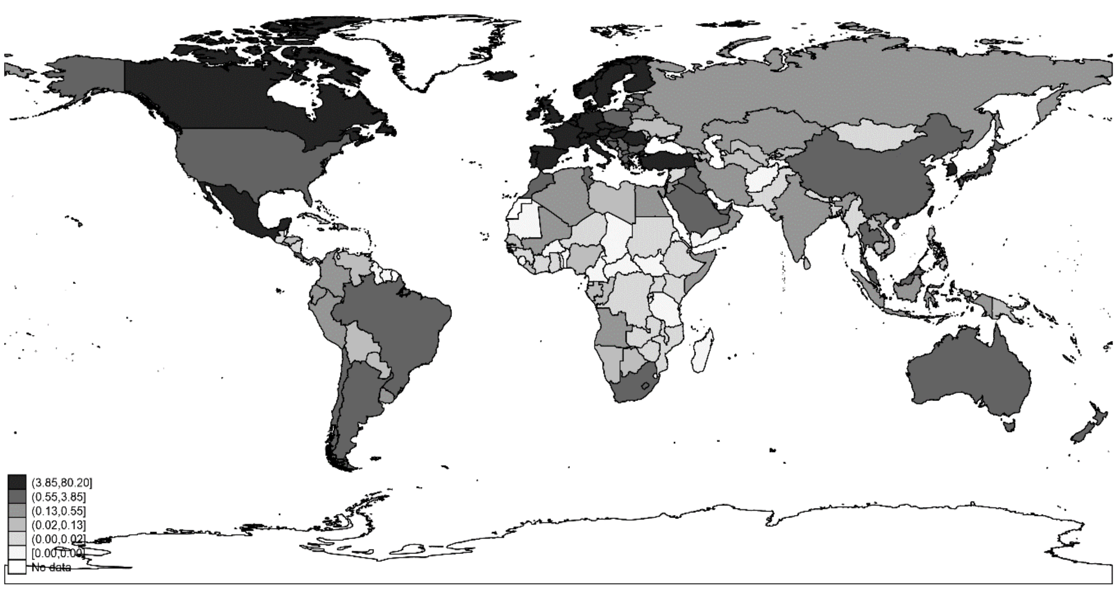
Source: UN Comtrade and BACI dataset and authors' own calculations

4.7 Import intensity of Fourth Industrial Revolution technologies

While concentration ratios of imports are slightly lower than those for exports, when we consider the intensity of imports—defined as the ratio of imports to employment—in these technologies, we find that the intensity of imports tends to be high in only a small subset of rich countries (Figure 26, Figure 27 and Figure 28). We observe that import intensity tends to be relatively high in Western Europe, Canada, the Republic of Korea, and usually in the USA (the exception being for robot imports), irrespective of which of the three technologies we consider. Other countries are found to have a relatively high intensity in certain technologies, with the intensity of robot and CAD-CAM imports being relatively high in Turkey, and the import intensity of 3D printing being relatively high in Turkey, Saudi Arabia and Thailand.

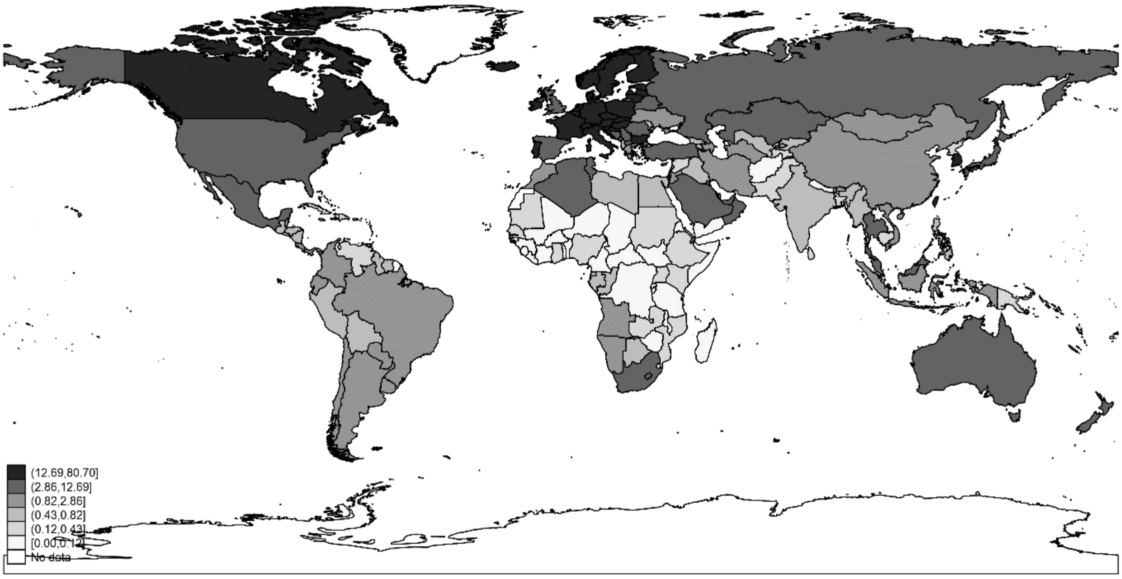
Of the three kinds of technology, import intensities show signs of being higher for most countries in CAD-CAM and 3D printing relative to robots. This could reflect the fact that these technologies are more relevant for countries away from the technological frontier, but may also suggest that these technologies may possibly be less well defined (i.e. they are based on a number of HS codes that perhaps make a less clear distinction between 3rd and 4th Industrial Revolution technologies). There is some evidence to indicate that these technologies are being used in countries in Africa, particularly in South Africa and parts of northern Africa. Of the three technologies, the evidence seems to indicate that the intensity of imports of 3D printing technologies in other parts of Africa is higher than the other two forms of imports.

Figure 26: Intensity of robot imports



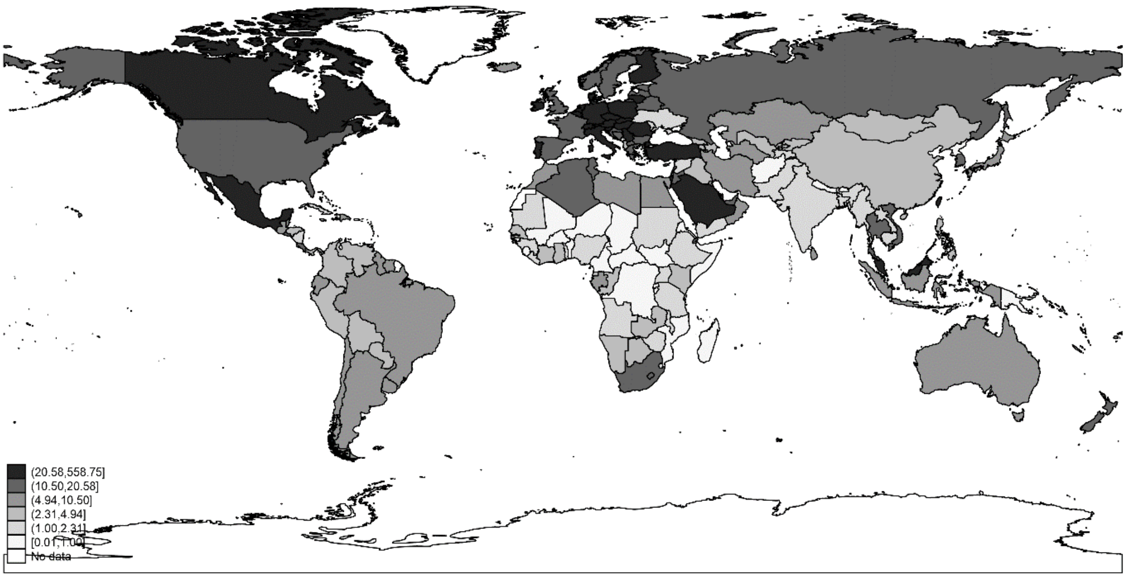
Notes: Ratio of export values (current prices) of Industry 4.0 technologies to total employment, average 2014-2016.
Source: UN Comtrade, BACI and ILOSTAT.

Figure 27: Intensity of CAD-CAM imports



Notes: Ratio of export values (current prices) of Industry 4.0 technologies to total employment, average 2014-2016.
Source: UN Comtrade, BACI and ILOSTAT.

Figure 28: Intensity of 3D printing imports



Notes: Ratio of export values (current prices) of Industry 4.0 technologies to total employment in 2016.
Source: UN Comtrade, BACI and ILOSTAT.

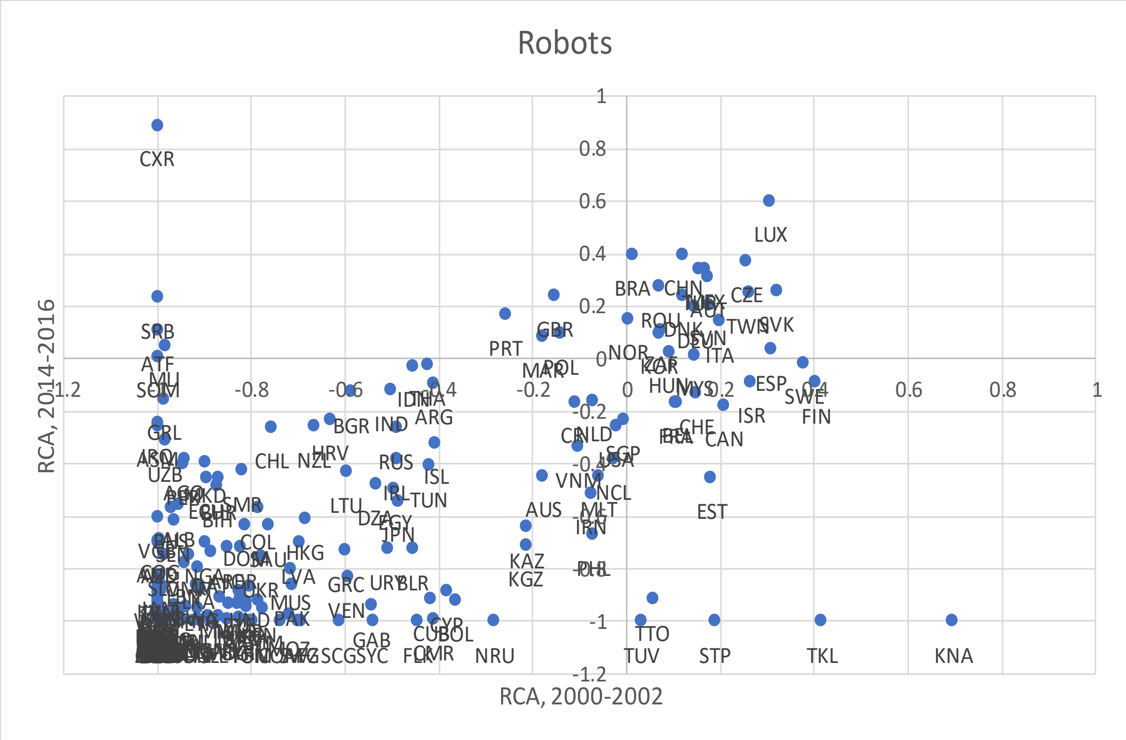
4.8 The revealed comparative advantage of imports

Analogous to the export RCA, we can also construct an import RCA to capture whether countries import these types of technologies more intensively than the world as a whole. Such a measure is linked to the use and diffusion of 4IR technologies. For the purposes of our analysis, we concentrate on RCA constructed using import values, though it should be borne in mind that a similar measure could be constructed using import volumes.

Figure 29 reports a scatterplot of the import RCA of our sample of countries for the years 2000-2002 (vertical axis) and 2014-2016 (horizontal axis) for imports of robots. In comparison to export RCA, we find a larger number of countries with an RCA in imports, suggesting that the use of these technologies is broader—and less concentrated—than the production of such technologies. The data indicate that there were 29 countries with an import RCA in robots in 2014-2016, down from 33 countries in 2000-2002. Countries with an RCA in both years include emerging economies such as China, Brazil and Mexico, as well as European countries such as Austria, Germany, Finland and Sweden. Countries such as China and Brazil have seen large increases in their RCAs over time. Many European countries—particularly East European countries—appear to have developed and increased their import RCA in robots between 2000-2002 and 2014-2016. Such developments may represent the increasing role of these countries in European GVCs, particularly automotive GVCs. Interestingly, countries that lost RCA between 1998 and 2016 include Canada, Israel and Switzerland.

Figure 30 reports the import RCA of 3D printing for the years 2000-2002 and 2014-2016. An initial point to note is that there are many more countries with an RCA in 3D printing in both 2000-2002 and 2014-2016 than in the case of robots. This suggests that the diffusion of these types of technology has been wider than for robots. We observe 74 countries with an RCA in 2014-2016, up from 71 in 2000-2002. Unsurprisingly, this larger number of countries with an RCA also results in a broader geographical spread of countries with an import RCA in 3D printing. Of the 74 countries with an import RCA in 2014-2016, 22 were African countries, with countries from Eastern Europe, Asia and Latin America also featuring strongly in this list. Richer countries in Europe, as well as the USA and Japan, tend to not have an import RCA in 3D printing.

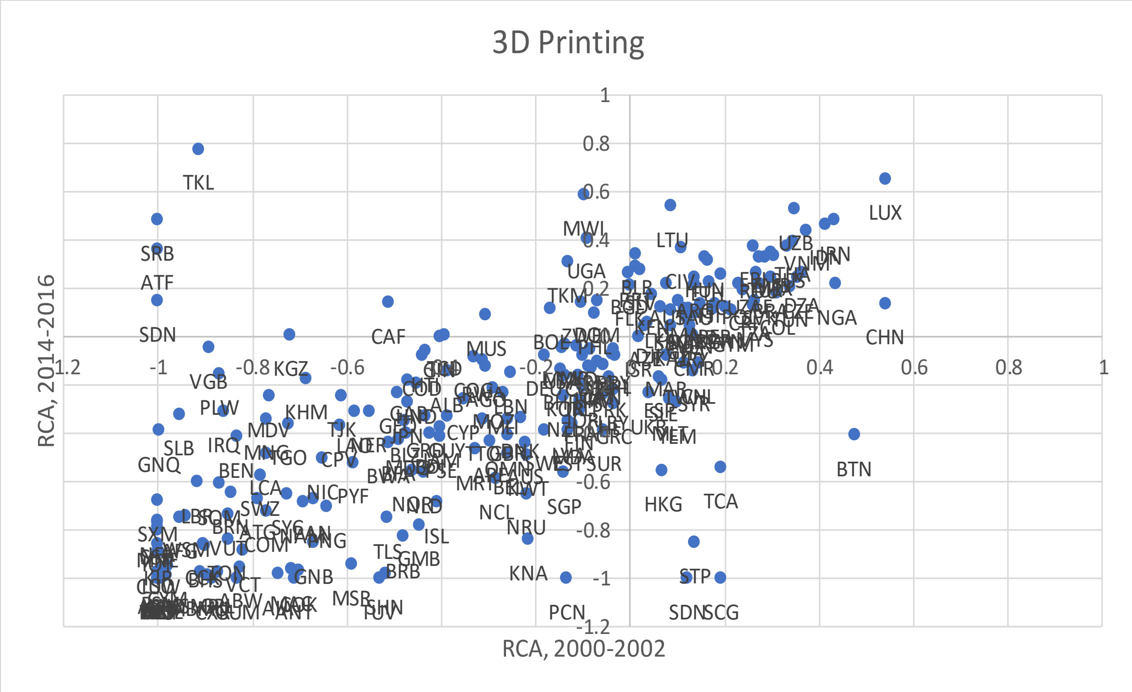
Figure 29: Import RCA of robots in 2000-2002 and 2014-2016 (based on import values)



Source: UN Comtrade and BACI dataset and authors' own calculations

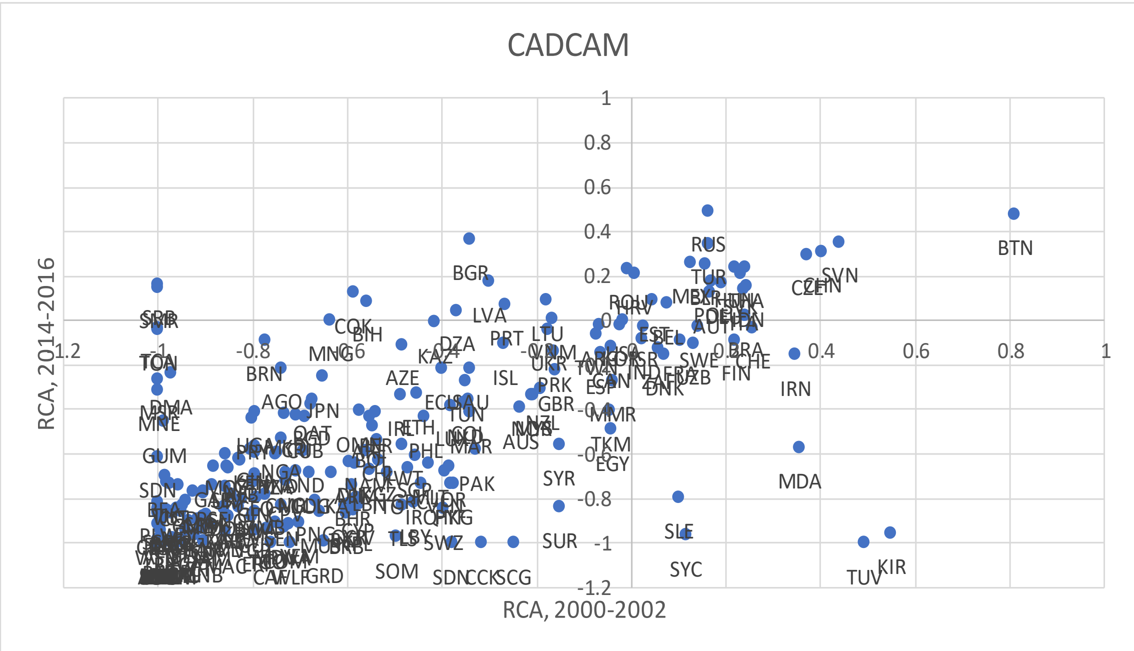
Finally, we report the 2000-2002 and 2014-2016 values of import RCA in the case of CAD-CAM technologies. The figure for CAD-CAM (Figure 31) looks more similar to that for robots than for 3D printing, with just 33 countries with an import RCA in these technologies in 2014-2016 (down from 35 in 2000-2002). Some of the larger emerging countries, such as China, Mexico, Russia and Brazil, are found to have an RCA in either or both 2000-2002 and 2014-2016, with European countries—particularly Eastern European countries—also registering an import RCA in one of the two periods. Countries that lost RCA between 2000-2002 and 2014-2016 include developed countries, such as Sweden, Switzerland, Finland and France, as well as emerging economies such as India and South Africa. Results for CAD-CAM are thus less straightforward and suggest that some developed and emerging countries have become less reliant on imported CAD-CAM technologies. This may reflect the development of own production capacities in the case of emerging economies or a movement away from production based upon these technologies.

Figure 30: Import RCA of 3D printing in 1998 and 2016 (based on import values)



Source: UN Comtrade and BACI dataset and authors' own calculations

Figure 31: Import RCA of CAD-CAM in 2000-2002 and 2014-2016 (based on import values)



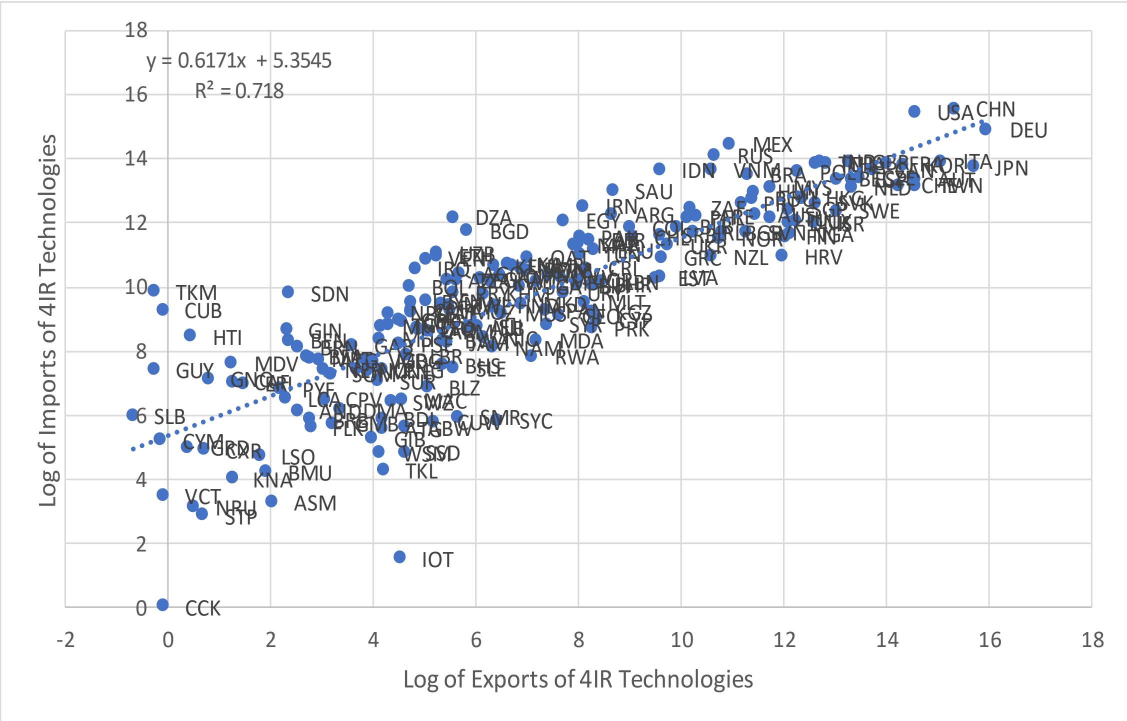
Source: UN Comtrade and BACI dataset and authors' own calculations

4.9 Identifying producers and consumers of Fourth Industrial Revolution technologies

The above analysis indicates that relatively few countries are intensive importers of the different 4IR technologies, with even fewer countries being intensive exporters of these products. In this section, we combine this information to address the question of the extent of overlap of producers and consumers and to categorize countries along these two dimensions. While the analysis above suggests that there is a strong overlap between the producers and consumers of these technologies, the analysis in this section aims to provide a more concrete categorization of countries along these dimensions.

We begin with Figure 32 by reporting information on the logged values of the import and export intensity of 4IR technologies for the period 2014-2016. The figure reveals a strong positive correlation between the two intensity variables, with an R^2 of 0.72, indicating that in general, intensive importers of 4IR technologies are also intensive exporters of these products.

Figure 32: Log of imports and exports of 4IR technologies, average 2014-2016



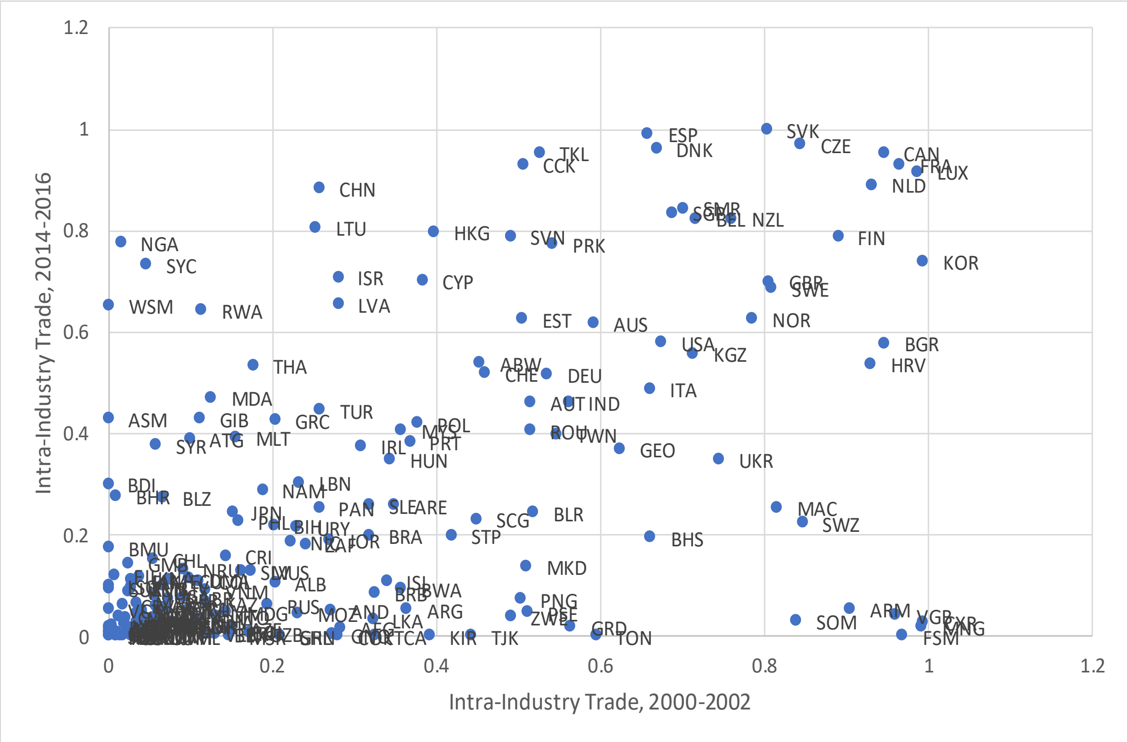
Source: UN Comtrade and BACI dataset and authors' own calculations

An alternative approach to consider the overlap between import and export intensity is to construct an indicator of intra-industry trade, namely the Grubel-Lloyd (GL) index:

$$GL_i = 1 - \frac{|X_i - M_i|}{X_i + M_i}$$

where X and M refer to exports and imports of 4IR technologies, respectively. A higher value of the GL index is associated with more intra-industry trade, suggesting a high degree of simultaneous export and import of 4IR products. Adopting an arbitrary threshold of 0.5, Figure 33 reveals that there is a number of developed countries that appear in the top right quadrant, indicating a high degree of intra-industry trade in both 2000-2002 and 2014-2016. These countries include many European countries, along with countries in North America and Asia (e.g. Singapore, the Republic of Korea). Most countries are, however, in the lower left quadrant, indicating a lack of intra-industry trade (i.e. they either import (or export) these technologies more intensively than they export (or import) them) in both countries. A relatively large number of countries appear in the lower right quadrant, indicating a high level of intra-industry trade in 2000-2002 that diminished by 2014-2016. This group includes developed countries, including Austria, Italy and Taiwan Province of China, along with emerging and transition countries, such as India and Romania. A smaller number of countries appear in the upper-left quadrant, indicating a movement towards higher levels of intra-industry trade over time. Notable in this group are China, Hong Kong SAR, China and Israel, with the results suggesting that this set of countries has seen their export of 4IR technologies rise, thus increasing the extent of intra-industry trade.

Figure 33: Intra-industry trade indicators in 2000 and 2016



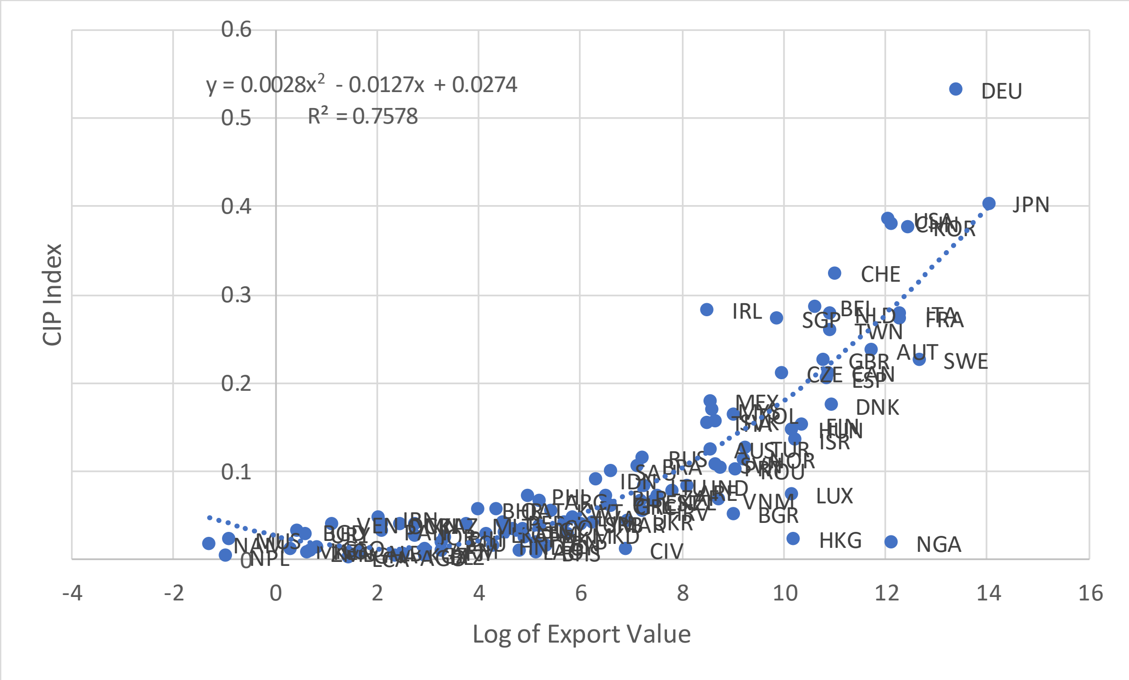
Source: UN Comtrade and BACI dataset and authors' own calculations

4.10 Trade in Fourth Industrial Revolution technologies and competitive industrial performance

In this section, we relate exports and imports of 4IR technologies to indicators of manufacturing performance. We relate the indicators of the three technologies' export and import values for the average of the three years from 2014-2016 to UNIDO's (CIP) index (also for the average of the period 2014-2016).

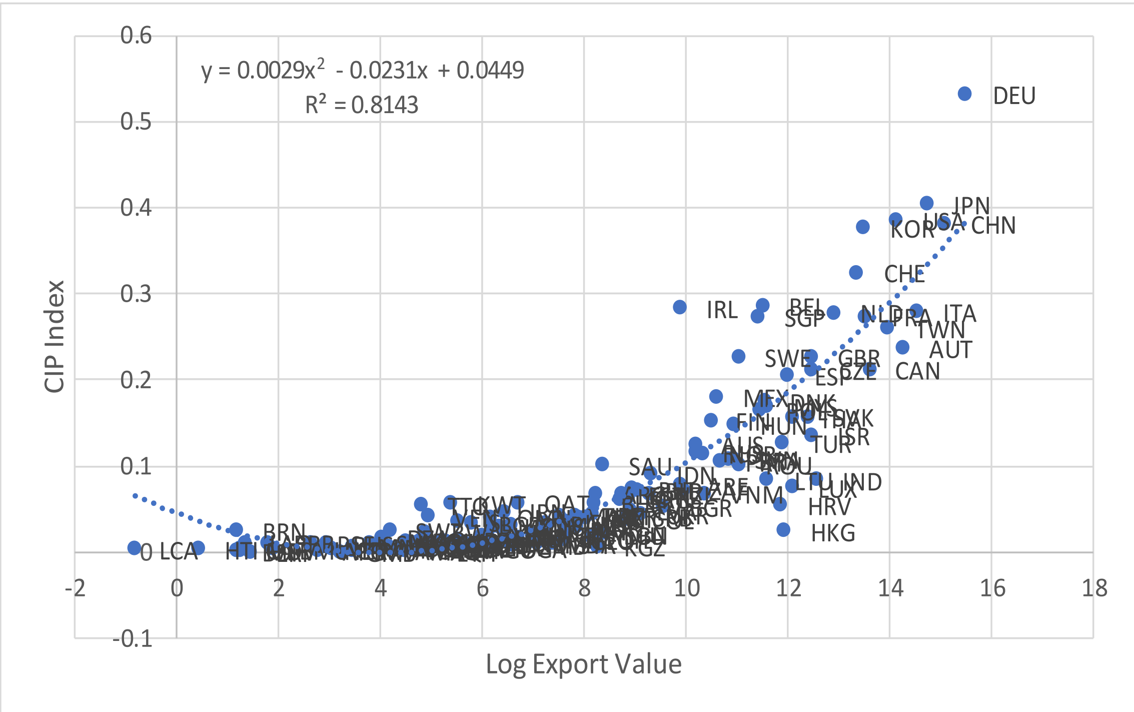
Figure 34, Figure 35 and Figure 36 report scatterplots of the three technologies' log of export values to the CIP index in 2014-2016. The results are consistent across the three different 4IR technologies. There appears to be a positive (non-linear) relationship between the exports of these technologies and the CIP index. While not intending to hint at any causal relationship between these two variables, the non-linear fitted line has an R-squared of between 76 per cent and 82 per cent, suggesting that the association between the exports of these technologies and the CIP index is a strong one.

Figure 34: Relationship between export value of robots and CIP Index for 2014-2016



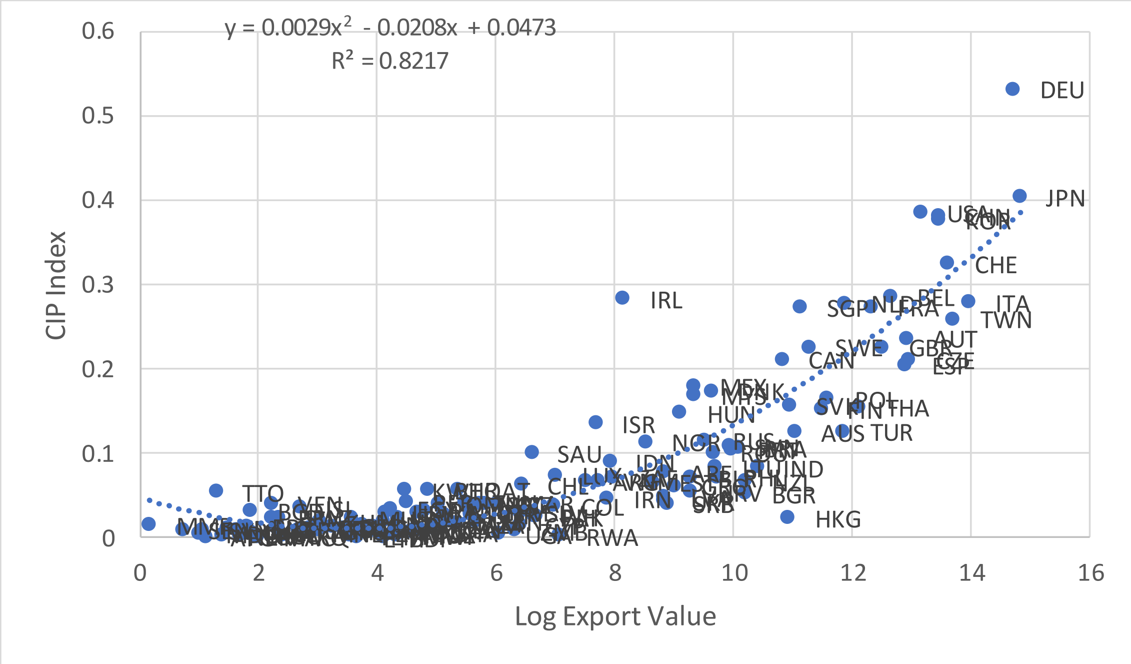
Source: UN Comtrade and BACI and CIP dataset

Figure 35: Relationship between export value of 3D printing and CIP index for 2014-2016



Source: UN Comtrade and BACI and CIP dataset

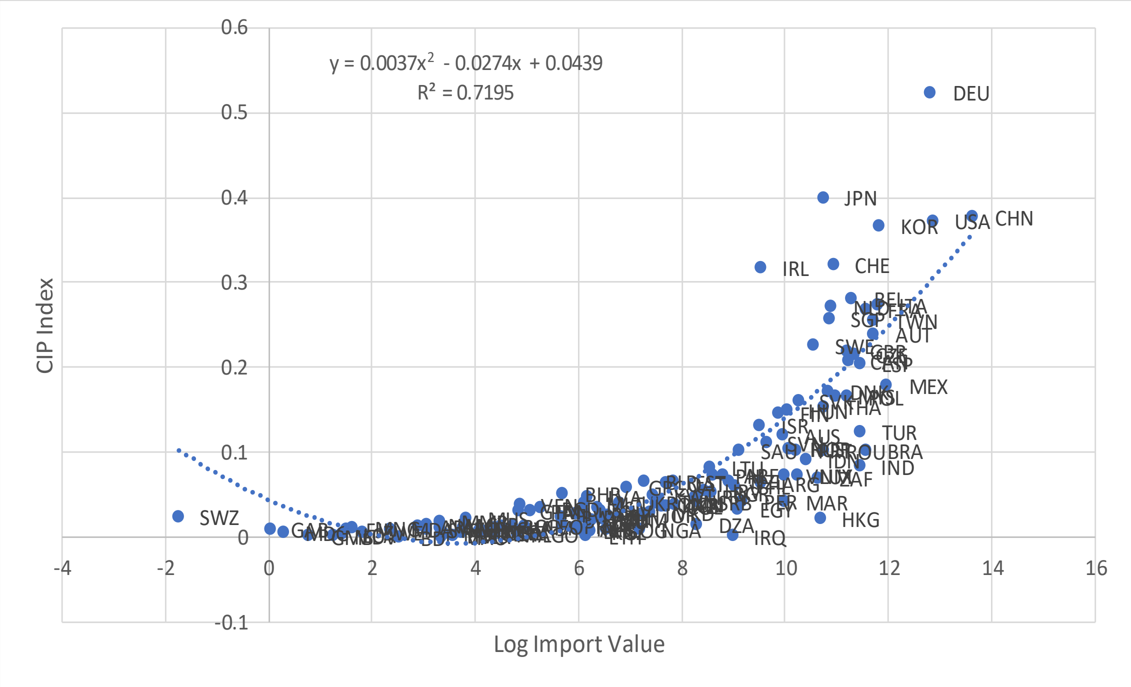
Figure 36: Relationship between export value of CAD-CAM and CIP index for 2014-2016



Source: UN Comtrade and BACI and CIP dataset

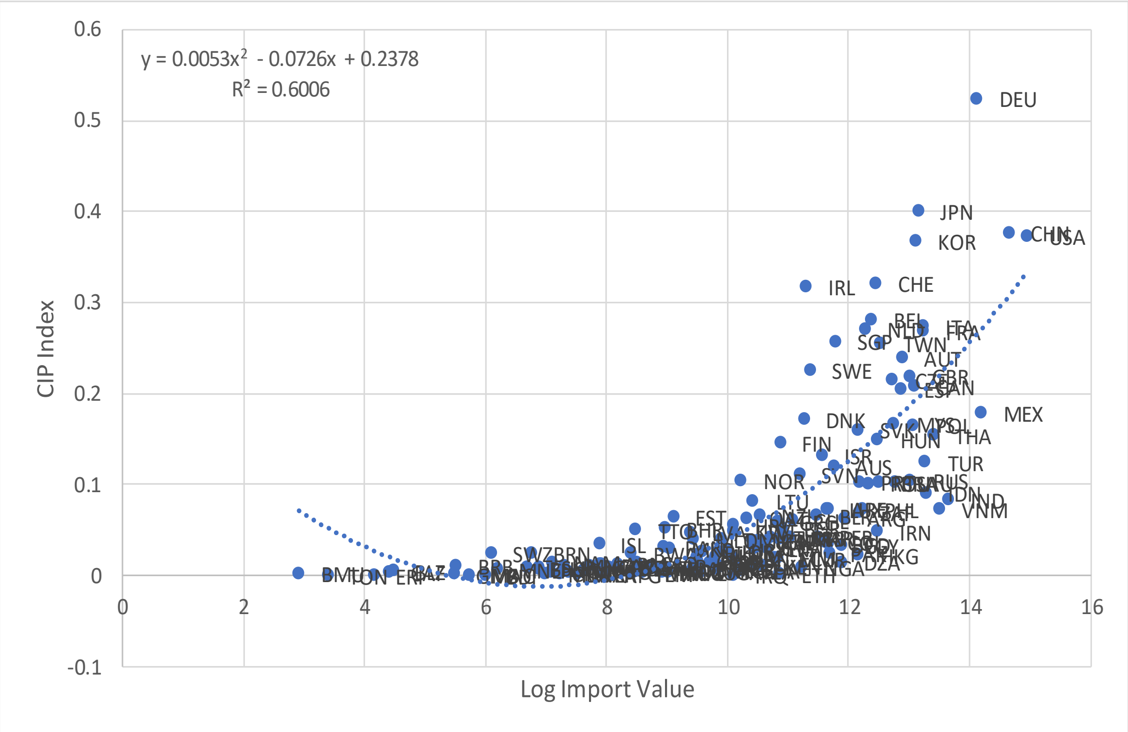
Figure 37, Figure 38 and Figure 39 present similar scatterplots of the three technologies to the CIP index in 2014-2016. The three figures report a similar pattern to those for exports, with a positive (non-linear) relationship between imports of these technologies and the CIP index observed. A simple quadratic regression model of the association between import volumes and the CIP index can ‘explain’ between 60 per cent and 74 per cent of the variation in the CIP index, suggesting a strong association between industrial performance and imports of these technologies.

Figure 37: Relationship between import value of robots and CIP index for 2014-2016



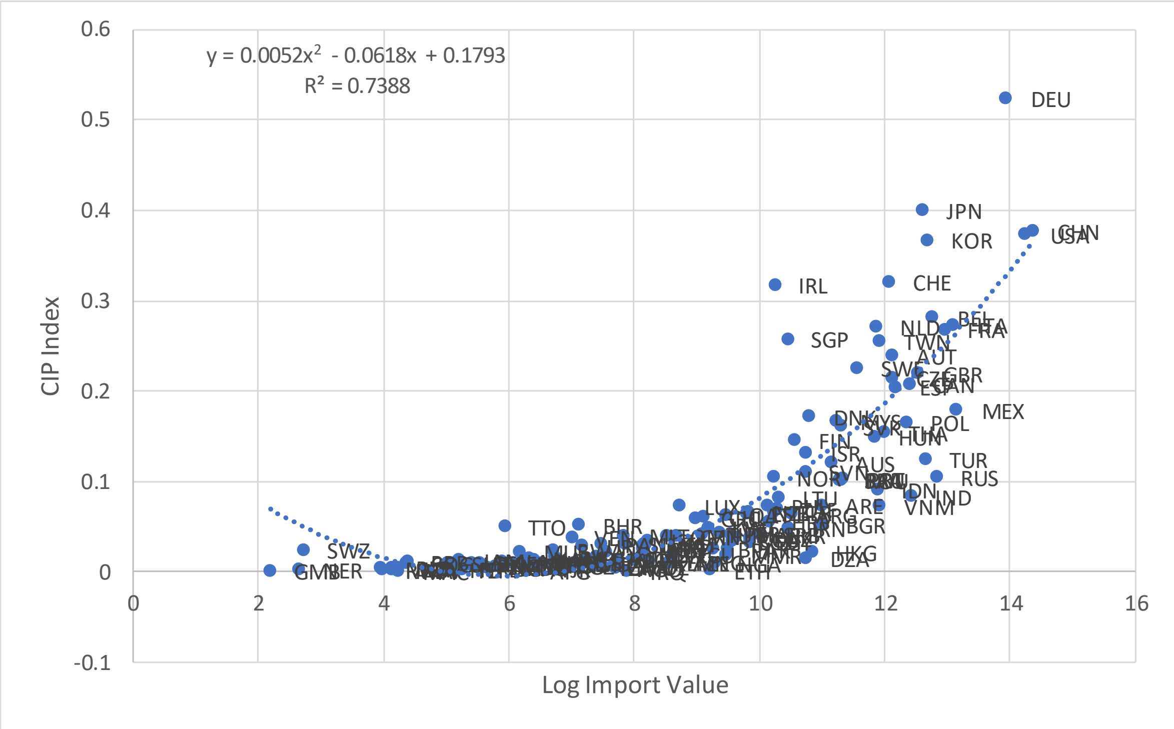
Source: UN Comtrade and BACI and CIP dataset

Figure 38: Relationship between import value of 3D imports and CIP index for 2014-2016



Source: UN Comtrade and BACI and CIP dataset

Figure 39: Relationship between import value of CAD-CAM imports and CIP index for 2014-2016



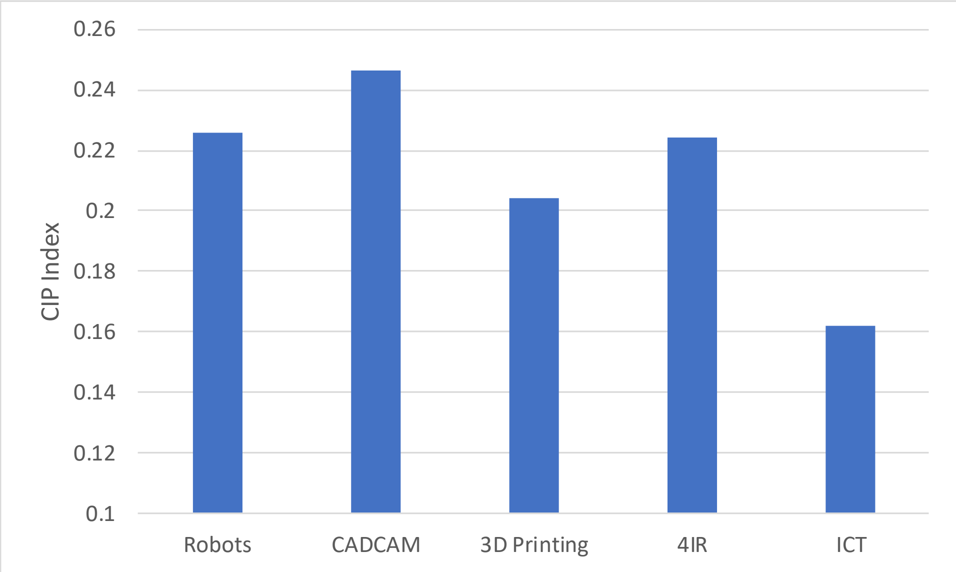
Source: UN Comtrade and BACI and CIP dataset

Concentrating on countries that have an RCA in these three technologies, Figure 40 reports the average value of the CIP index for countries with an export RCA in these technologies in 2016 (along with the average value for countries with an RCA in ICT goods for comparison purposes). One interesting thing to note from this figure is the difference in the average CIP index for 3D printing relative to robots and CAD-CAM. The value of the CIP index is found to be around 0.204 in the case of 3D printing, with values of just above 0.225 and 0.246 in the case of robots and CAD-CAM technologies, respectively. A further interesting feature of this data is the lower level of the CIP index for countries with an RCA in ICT exports (i.e. around 0.16) compared with those exporting the other 4IR technologies with an RCA.

Figure 41 presents similar results but for countries with an import RCA in these technologies in 2014-2016. Once again, we find a significant difference in the average CIP index for 3D printing relative to the other two technologies. Another thing to note from this figure is that the values of the CIP index are lower in the case of imports than in the case of exports. The average value of the CIP index in the case of robots and CAD-CAM is 0.183 and 0.147, respectively, while in the case of 3D printing, the average value is just 0.067. This suggests that the import of 3D printing technologies is intense in countries with lower manufacturing capabilities and may thus suggest that these technologies are being used as a substitute for an existing manufacturing capability.

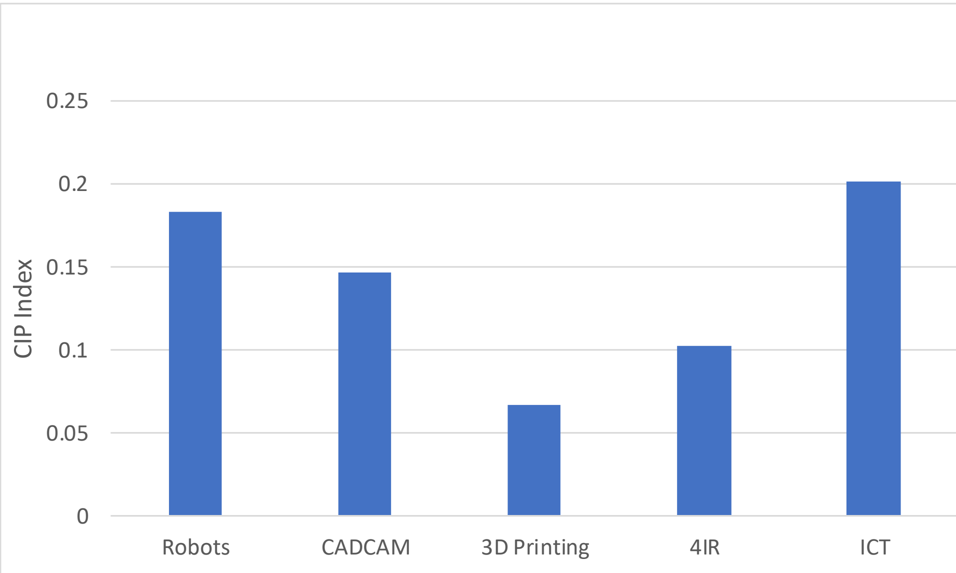
Interestingly, the CIP index for importers with an RCA in ICT is considerably higher, at 0.2 on average, than for any of the 4IR technologies.

Figure 40: Average CIP of countries with export RCA in 4IR technologies in 2014-2016



Source: UN Comtrade and BACI and CIP dataset, and authors' calculations

Figure 41: Average CIP of countries with import RCA in 4IR technologies in 2014-2016



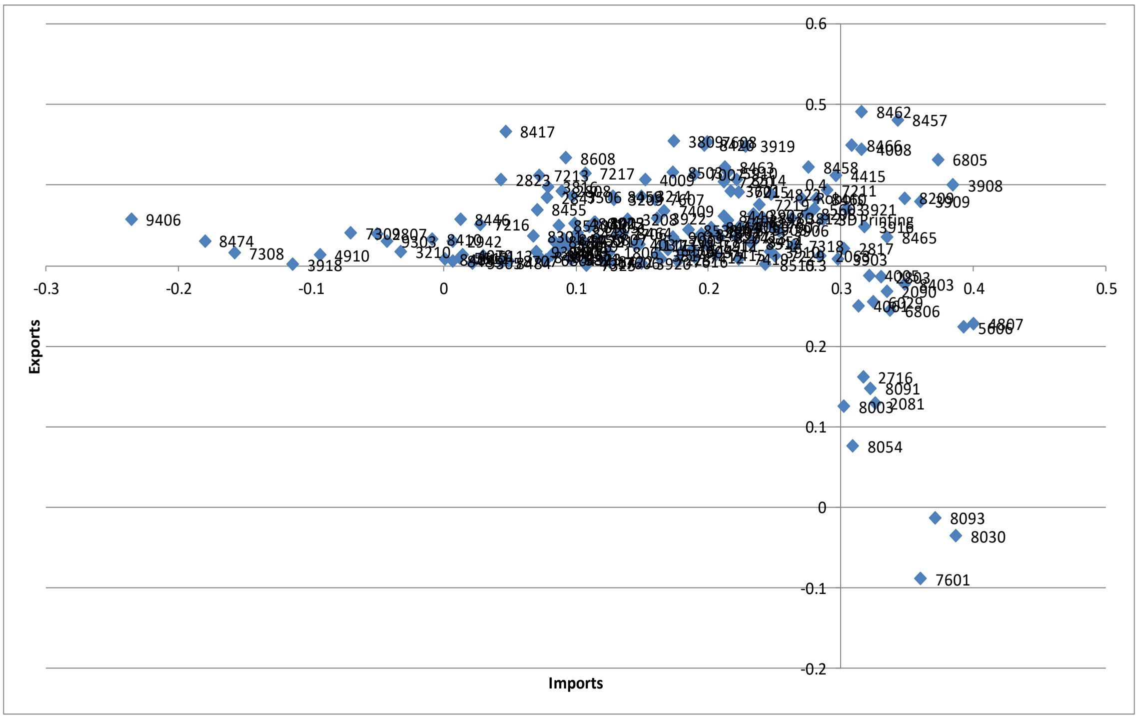
Source: UN Comtrade and BACI and CIP dataset, and authors' calculations

5 Future prospects

To consider the future prospects for countries in developing comparative advantage—on either the import or export side—in these technologies, we use information on the probability of countries exporting or importing different products. This is in line with the idea of the so-called product space literature, which looks at how products are related to each other as indicated by which countries are specialized in them (see Hidalgo and Hausmann, 2009). The unconditional probability of a particular good being exported (imported) is simply given by the share of countries in the dataset that export (import) that good with a revealed comparative advantage. The conditional probability of specializing in a product (say X) given a specialization in another product (Y) is the probability that a country was specialized in product X in the years 2014-2016 (i.e. it exported product X with a revealed comparative advantage in 2014-2016), given that it was also specialized in product Y. This conditional probability is calculated as the number of countries specialized in both X and Y divided by the number of countries that specialized in Y. In other words, it is the share of countries specializing in product Y that are also specialized in product X. If the conditional probability of being specialized in X given Y is (much) larger than the unconditional probability of being specialized in X (that is, the share of all countries that are specialized in X), then the two products are likely to share similar production capabilities. Using these statistics, we proceed in a number of ways.

Initially, we consider the set of products that are likely to be co-exported (or imported) with our 4IR technologies (i.e. robots, CAD-CAM, 3D printing). We begin by calculating the conditional probability bonus (i.e. the difference between the conditional and unconditional probability) of exporting with an RCA a (non-4IR) product, given a specialization in one of the 4IR technologies. We then impose a threshold to identify the set of products that are most likely to be exported (or imported) alongside the 4IR technologies. In the analysis, a threshold of 30 per cent is applied, meaning that the conditional probability of specializing in a product X given a specialization in one of the 4IR products Y must be at least 0.3 higher than the simple probability of being specialized in X.

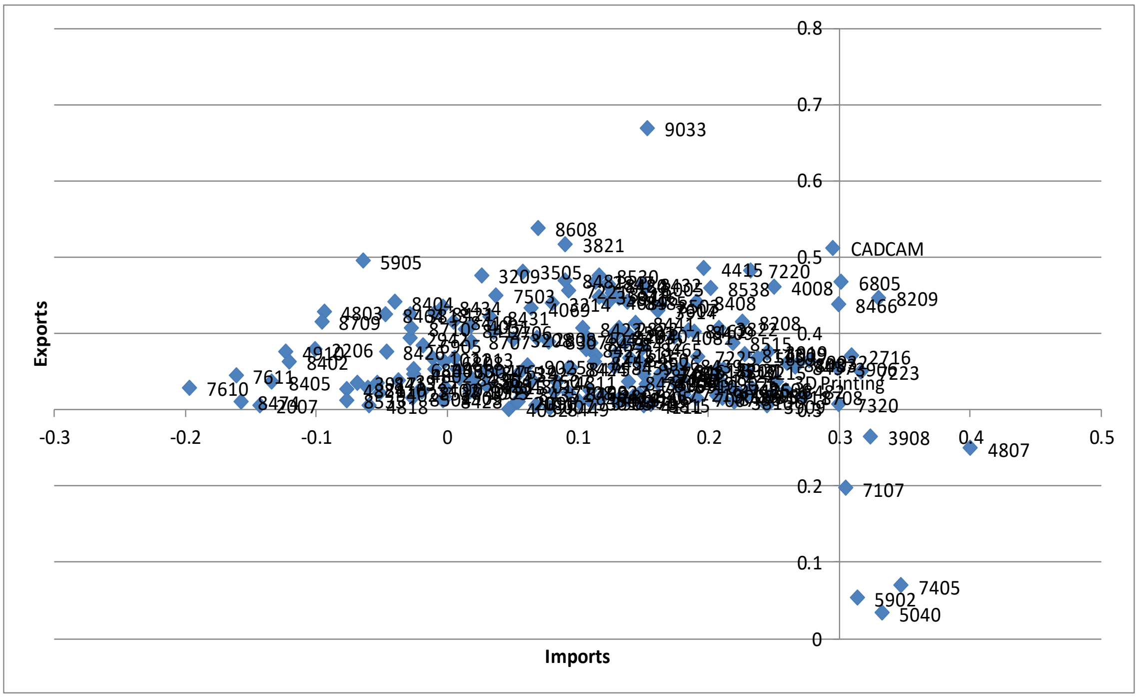
Figure 42: Scatterplot of four-digit categories most likely to be imported and exported with CAD-CAM



Source: Authors' calculations based on UN Comtrade and BACI

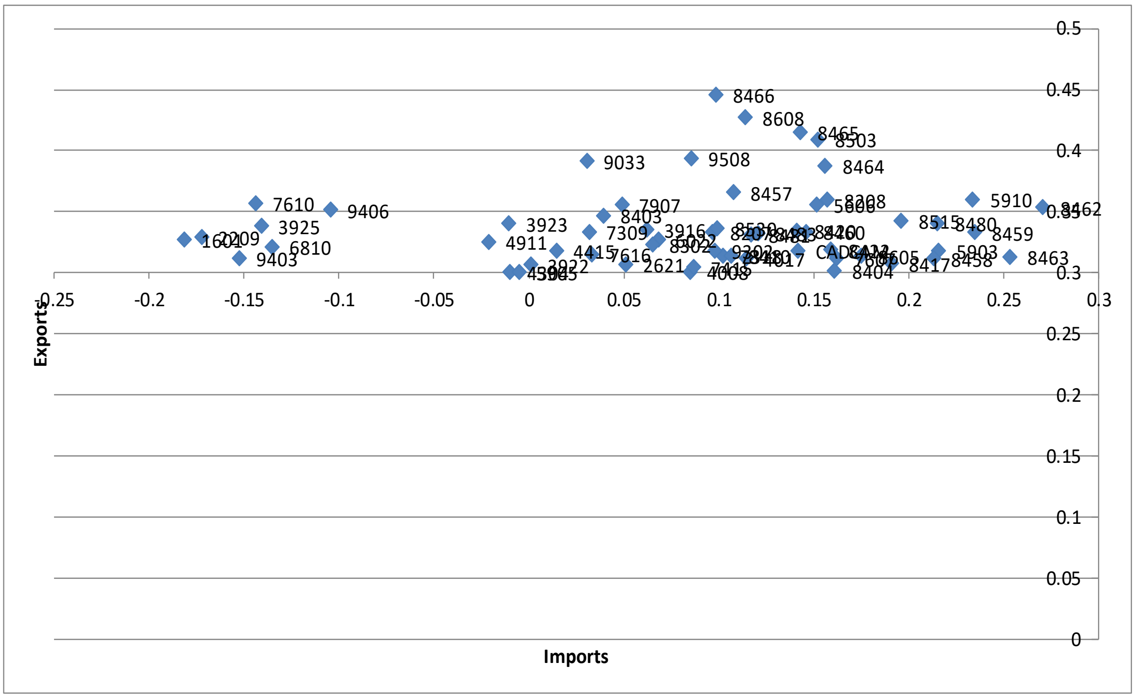
Using this approach, we construct the probability bonus of either importing or exporting a six-digit category conditional upon importing or exporting one of the three 4IR technologies using data averaged over the period 2014-2016. We then average the probability bonus at the six-digit level across the four-digit categories to identify the set of four-digit product categories for which the threshold of 0.3 is met. Figure 42, Figure 43 and Figure 44 present the set of product categories for which this 0.3 threshold is met in the case of imports and exports for CAD-CAM, robots and 3D printing, respectively. The figures reveal that there are a large number of four-digit product categories that are above the 0.3 threshold, with the numbers being larger for exports. Indeed, in the case of 3D printing, there is not a single four-digit category that meets the 0.3 threshold on the import side.

Figure 43: Scatterplot of four-digit categories most likely to be imported and exported with robots



Source: Authors' calculations based on UN Comtrade and BACI

Figure 44: Scatterplot of four-digit categories most likely to be imported and exported with 3D printing



Source: Authors' calculations based on UN Comtrade and BACI

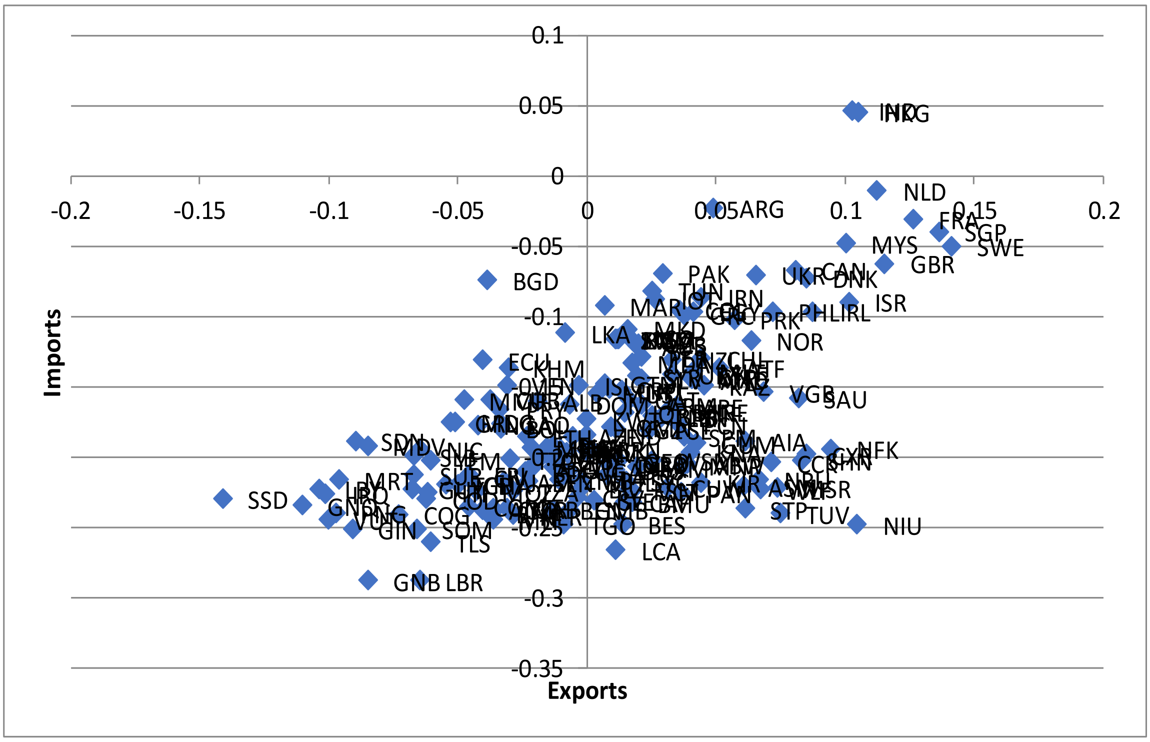
To provide an overview of the set of four-digit products that are most likely to be co-imported or co-exported with 4IR technologies, Table *2* reports the number of four-digit categories within each one-digit category in which the 0.3 threshold is met. On the import side, we observe few four-digit categories that meet the 0.3 threshold. In one-digit category 8, we observe 11 four-digit categories that meet the 0.3 threshold. This one-digit category includes, amongst other things, machinery, electrical machinery and various forms of transport. On the export side, we find far many more four-digit categories that meet the 0.3 threshold, with the one-digit category 8 again being the category in which most such four-digit categories are observed. In the case of CAD-CAM and robots, we further find a relatively large number of four-digit categories for which the threshold is met in one-digit categories 3 (pharmaceuticals and chemicals), 7 (metals) and, to a lesser extent, 4 (rubber, leather, wood).

Table 2: Number of four-digit products within each one-digit category above threshold

	Imports			Exports		
1-Digit	**CAD-CAM**	**Robots**	**3D**	**CAD-CAM**	**Robots**	**3D**
1	0	0	0	1	5	1
2	5	1	0	8	13	2
3	4	1	0	27	26	4
4	4	1	0	13	22	5
5	1	2	0	9	5	4
6	3	1	0	3	4	2
7	1	3	0	31	28	7
8	11	1	0	46	73	26
9	0	0	0	5	10	5

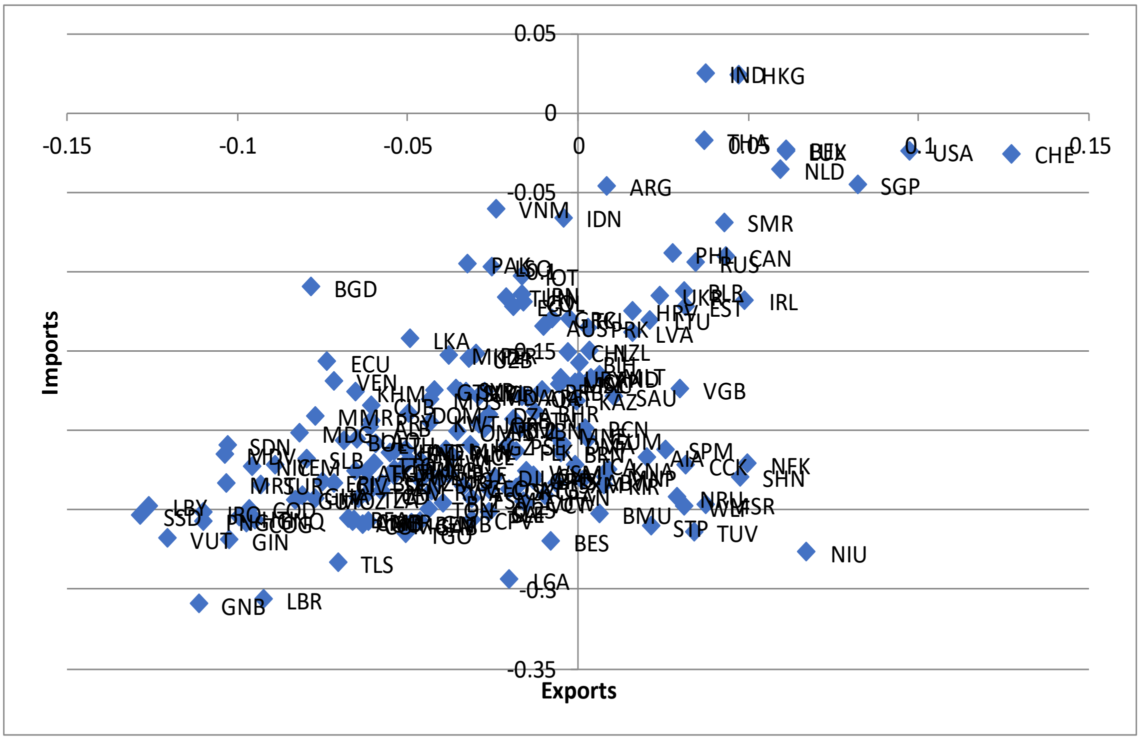
A second use of the probability bonus data involves calculating the average probability bonus associated with the products for each country and each 4IR technology that each country exports (or imports) with an RCA. To do so, we proceed by: (i) constructing the probability bonus of exporting (or importing) each of the 4IR technologies with an RCA, given the export (or import) of each six-digit product; (ii) for each country, multiplying this probability bonus with a vector of RCA dummies (i.e. a vector of zeros and ones that indicate whether the country has an RCA in each product); and (iii) calculating the average probability bonus for each country. The resulting data provide an indicator of the likelihood of exporting (or importing) a particular 4IR technology, given the set of products it currently exports (or imports) with an RCA. For the purpose of this analysis, we only consider countries that neither have an RCA in the export nor in the import of a particular 4IR technology.

Figure 45: Scatterplot of probability bonus of CAD-CAM, given the country's specialization patterns



Source: Authors' calculations based on UN Comtrade and BACI

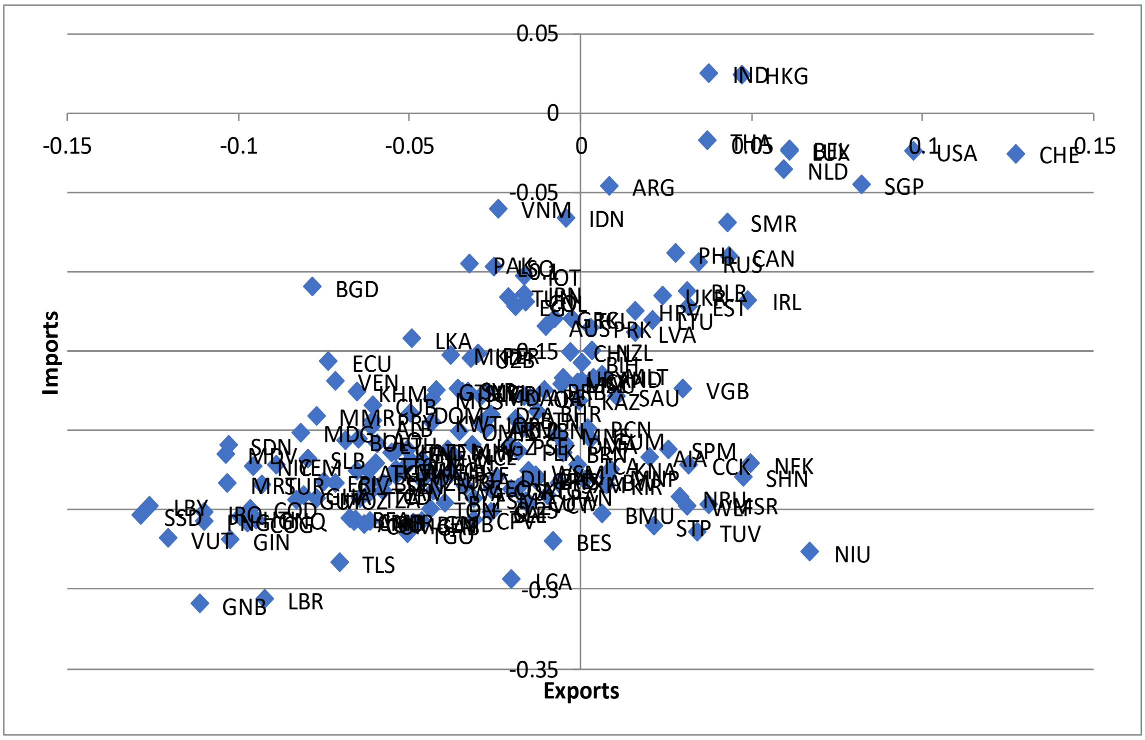
Figure 46: Scatterplot of probability bonus of robots, given country's specialization patterns



Source: Authors' calculations based on UN Comtrade and BACI

Figure 45, Figure 46 and Figure 47 report scatterplots of the resulting average conditional probability bonuses of both exports and imports for CAD-CAM, robots and 3D printing, respectively. In the case of CAD-CAM, for instance, there are only two countries/regions—India and Hong Kong SAR, China—that have a higher probability of developing specialization in CAD-CAM on both the import and the export side, given their current specialization patterns. A much larger set of countries has the potential to develop an export specialization in CAD-CAM given their current specialization, with no countries found to have a higher probability of developing import specialization in CAD-CAM (only) given their current specialization. Results for the other two technologies—3D printing and robots—are largely similar.

Figure 47: Scatterplot of probability bonus of 3D printing given the country's specialization patterns



Source: Authors' calculations based on UN Comtrade and BACI

6 Summary and conclusion

We now summarize the main findings of our analysis. With regard to technology, we found that the number of inventions (indicated by patent families) has been on a steep rise since the early 2000s. This trend is realized by a relatively small number of countries, with the three most actively patenting countries holding 71 per cent of all important patents in the field, and the top-10 countries holding 91 per cent. We may thus safely conclude that 4IR technologies are being invented in a very small number of leading countries. Moreover, these leading countries are well-established manufacturing powers, as indicated by UNIDO's CIP index.

China is certainly one of the countries that is very active in 4IR patenting. According to a commonly used indicator (the degree of international protection sought), there are, however, fewer Chinese patents compared with other leading countries. This indicates that, in terms of quality, more in-depth research is necessary to examine China's technological efforts in this field to obtain more comprehensive insights into their impact on future developments.

Regarding world trade, the share of 4IR products is increasing, but remains a rather small portion of global trade, even in recent times. Developments in global trade of these technologies tend to follow the global pattern of trade in recent years, such as a sharp decline in 2009 (related to the financial crisis), picking up afterwards, but stagnating since 2011. Trade in these technologies is dominated by 3D printing, with significant contributions from CAD-CAM technologies, and relatively minor contributions from robots.

As for inventions, we find that the export of these products tends to be highly concentrated, suggesting that only few countries have the capabilities to produce these technologies. Concentration ratios are less extreme than for patents, but not by much. Concentration ratios in exports have been declining somewhat over time, but not much. The export of robots and CAD-CAM equipment seems slightly more concentrated than for 3D-printing. The leading export countries show great overlap with the countries leading in invention, i.e. a number of western European countries, the USA and certain Asian economies and regions (notably, China, Japan, the Republic of Korea and Taiwan Province of China).

Looking at revealed comparative advantage, we find that the number of countries with relatively intensive imports in 4IR products tends to be much larger than the number with relatively intensive exports. This suggests that the use of these technologies is much broader than their production. Especially in 3D printing, we find a large set of countries that are relatively intensive importers of this technology. We also see a fair amount of imports into Africa, a continent that is otherwise lagging in terms of the use (and production) of these technologies. Imports of 4IR products seems to be positively associated with indicators of industrial competitiveness, but countries with lower levels of industrial competitiveness are more likely to import 3D printing technologies (with an RCA) than the other two technology types.

Overall, the results suggest a particularly high degree of specialization in the development, production and use of 4IR technologies, with only the most developed countries (and a select number of emerging economies) playing a leading role in these technologies. This suggests that the current global dividing lines in terms of development are at risk of becoming stronger, if left without policy intervention.

References

Abeliansky, AL, Martinez-Zarzoso, I. and Prettner, K. 2015, The impact of 3D printing on trade and FDI, *Center for European, Governance and Economic Development Research Discussion Papers no.* 262, University of Göttingen.

Hafner, K. 2008, The pattern of international patenting and technology diffusion, *Applied Economics*, 40(21), 2819-2837.

Hidalgo, C. and Hausmann, R. 2009, The building blocks of economic complexity, *PNAS*, 106(26), 10570-10575.

Huang, C. 2012, Estimates of the value of patent rights in China, UNU-MERIT Working Paper no. 004, UNU-MERIT, Maastricht.

Inaba, T. and Squicciarini, M. 2017, ICT: A new taxonomy of based on the international patent classification, *OECD Science, Technology and Innovation Working Papers no.* 2017/07, OECD, Paris.

Lanjouw, JO., Pakes, A. and Putnam, J. 1998, How to count patents and value intellectual property: The uses of patent renewal and application data, *Journal of Industrial Economics*, 46(4), 405-432.

Sternitzke, C. 2009, Defining triadic patent families as a measure of technological strength, *Scientometrics*, 81, 91.

WIPO, 2019, *WIPO Technology Trends 2019: Artificial Intelligence*, World Intellectual Property Organization, Geneva.

World Bank, 2016, *World Development Report 2016: Digital Dividends*, The World Bank, Washington, DC.

Appendix

Queries used to construct the patent database

The starting point of our methodology to extract IR4 patent families is to select all families with Derwent class code DC=T06.

We then eliminate patent families that are associated with the following Derwent Subject Areas: TRANSPORTATION, GENERAL INTERNAL MEDICINE, MUSIC, AGRICULTURE, WATER RESOURCES, PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH.

Further refinement is achieved by eliminating patent families classified by one or more of the following Derwent class codes:

- *W05 (Alarms, Signalling, Telemetry and Telecontrol (G08B, C) Burglar and fire alarms. Personal calling arrangements. Paging systems. Signal transmission systems. Home bus systems, vehicle remote control bus systems. Advertising arrangements (electrical aspects).),*

- *W06 (Aviation, Marine and Radar Systems (G01S) Radar, sonar and lidar. Velocity and depth measuring equipment. Airport control systems. Ship and aircraft control and instrumentation. Flight simulators. Space vehicles, including satellites.),*

- *W07 (Electrical Military Equipment and Weapons (F41) Target indicating systems. Sighting devices. Missile direction control. Military training equipment. Arming and safety devices.),*

- *X26 (Lighting (F21, H01J, H01K) Discharge, incandescent and electric arc lamps. Operating and control equipment. Light fittings Portable lighting devices. Stage lighting equipment.),*

- *X27 (Domestic Electric Appliances (A47, F24) Washing machines, dryers, irons. Vacuum cleaners. Electric cookers, microwave ovens. Kitchen equipment. Refrigerators. Water heaters. Space heating and air conditioning equipment. Personal and hygiene electrical appliances.),*

- P1* (**AGRICULTURE, FOOD, TOBACCO**),

- P2* (**PERSONAL, DOMESTIC**),

- P3* (**HEALTH, AMUSEMENT**).

Then we specify a list of keywords that eliminate patent families that are irrelevant to (smart) manufacturing (such as domestic appliances, mobile phones, autonomous vehicles, etc.), and we eliminate families with these keywords in the abstract and/or title. The keywords are:

hospital, medical, surgery, surgical, home*, domestic, household, house-hold, vehicle*, automobile, phone*, telephone*, smartphone, "mobile phone", "smart phone", conference, conferencing, game*, gaming, teaching, multimedia, multi-media)*

We call the resulting set of patent families *T06_Manuf*.

We specify four different criteria of relevance for IR4. The first is digital data exchange, for which we used the Derwent Manual Code

DC=W01-A: Digital information transmission

as well as two 4-digit IPC codes

IP=H04L: TRANSMISSION OF DIGITAL INFORMATION

IP=H04W: WIRELESS COMMUNICATION NETWORKS.

We refer to all patents that are tagged according to at least one of these three codes as

Digtl_Transm_Comm: DMC=W01-A* OR IP=H04L* OR IP=H04W*

Second, we use a list of IPC codes that capture machine learning. This list was constructed on the basis of the so-called J-tagging system (Inaba and Squicciarini, 2017), and contains the following codes:

IPC_ML: IPC=G06F-019/24 OR G06F-019/28 OR G06K-009/00 OR G06K-009/03 OR G06K-009/18 OR G06K-009/46 OR G06K-009/48 OR G06K-009/50 OR G06K-009/52 OR G06K-009/54 OR G06K-009/56 OR G06K-009/58 OR G06K-009/60 OR G06K-009/62 OR G06K-009/64 OR G06K-009/66 OR G06K-009/68 OR G06K-009/70 OR G06K-009/72 OR G06K-009/74 OR G06K-009/76 OR G06K-009/78 OR G06K-009/80 OR G06K-009/82 OR G06T-007/30 OR G06T-007/32 OR G06T-007/33 OR G06T-007/35 OR G06T-007/37 OR G06T-007/38 OR G06T-007/40 OR G06T-007/41 OR G06T-007/42 OR G06T-007/44 OR G06T-007/45 OR G06T-007/46 OR G06T-007/48 OR G06T-007/49 OR G06T-007/50 OR G06T-007/507 OR G06T-007/514 OR G06T-007/521 OR G06T-007/529 OR G06T-007/536 OR G06T-007/543 OR G06T-007/55 OR G06T-007/557 OR G06T-007/557 OR G06T-007/564 OR G06T-007/571 OR G06T-007/579 OR G06T-007/586 OR G06T-007/593 OR G06T-007/60 OR G06T-

007/62 OR G06T-007/64 OR G06T-007/66 OR G06T-007/68 OR G08G-001/017 OR G08G-001/04 OR G08G-001/042 OR G08G-001/048 OR G08G-001/16 OR G06N-003/00 OR G06N-003/02 OR G06N-003/04 OR G06N-003/06 OR G06N-003/063 OR G06N-003/067 OR G06N-003/08 OR G06N-003/10 OR G06N-003/12 OR G10L-025/63 OR G10L-025/66 OR G06N5* OR G10L15* OR G10L17*

Third, we use a list of machine learning keywords from the 2019 WIPO Technology Trends report on artificial intelligence. We looked for these keywords in patent titles and abstracts:

KW_ML: TS=(((ARTIFIC* OR COMPUTATION*) NEAR/1 INTELLIGEN*) OR (NEURAL NEAR/1 NETWORK*) OR NEURAL_NETWORK* OR NEURAL_NETWORK* OR (BAYES* NEAR/1 NETWORK*) OR BAYESIAN-NETWORK* OR BAYESIAN_NETWORK* OR (CHATBOT?) OR (DATA NEAR/1 MINING*) OR (DECISION NEAR/1 MODEL?) OR (DEEP NEAR/1 LEARNING*) OR DEEP-LEARNING* OR DEEP_LEARNING* OR (GENETIC NEAR/1 ALGORITHM?) OR ((INDUCTIVE NEAR/1 LOGIC) 1D PROGRAMM*) OR (MACHINE NEAR/1 LEARNING*) OR MACHINE_LEARNING* OR MACHINE-LEARNING* OR ((NATURAL 1D LANGUAGE) NEAR/1 (GENERATION OR PROCESSING)) OR (REINFORCEMENT NEAR/1 LEARNING) OR (SUPERVISED NEAR/1 (LEARNING* OR TRAINING)) OR SUPERVISED-LEARNING* OR SUPERVISED_LEARNING* OR (SWARM NEAR/1 INTELLIGEN*) OR SWARM-INTELLIGEN* OR SWARM_INTELLIGEN* OR (UNSUPERVISED NEAR/1 (LEARNING* OR TRAINING)) OR UNSUPERVISED-LEARNING* OR UNSUPERVISED_LEARNING* OR (SEMI-SUPERVISED NEAR/1 (LEARNING* OR TRAINING)) OR SEMI-SUPERVISED-LEARNING OR SEMI_SUPERVISED_LEARNING* OR CONNECTIONIS* OR (EXPERT NEAR/1 SYSTEM?) OR (FUZZY NEAR/1 LOGIC?) OR TRANSFER-LEARNING OR TRANSFER_LEARNING OR (TRANSFER NEAR/1 LEARNING) OR (LEARNING NEAR/3 ALGORITHM?) OR (LEARNING NEAR/1 MODEL?) OR (SUPPORT VECTOR MACHINE?) OR (RANDOM FOREST?) OR (DECISION TREE?) OR (GRADIENT TREE BOOSTING) OR (XGBOOST) OR ADABOOST OR RANKBOOST OR (LOGISTIC REGRESSION) OR (STOCHASTIC GRADIENT DESCENT) OR (MULTILAYER PERCEPTRON?) OR (LATENT SEMANTIC ANALYSIS) OR (LATENT DIRICHLET ALLOCATION) OR (MULTI-AGENT SYSTEM?) OR (HIDDEN MARKOV MODEL?)) OR MAN=(T01-J16*)

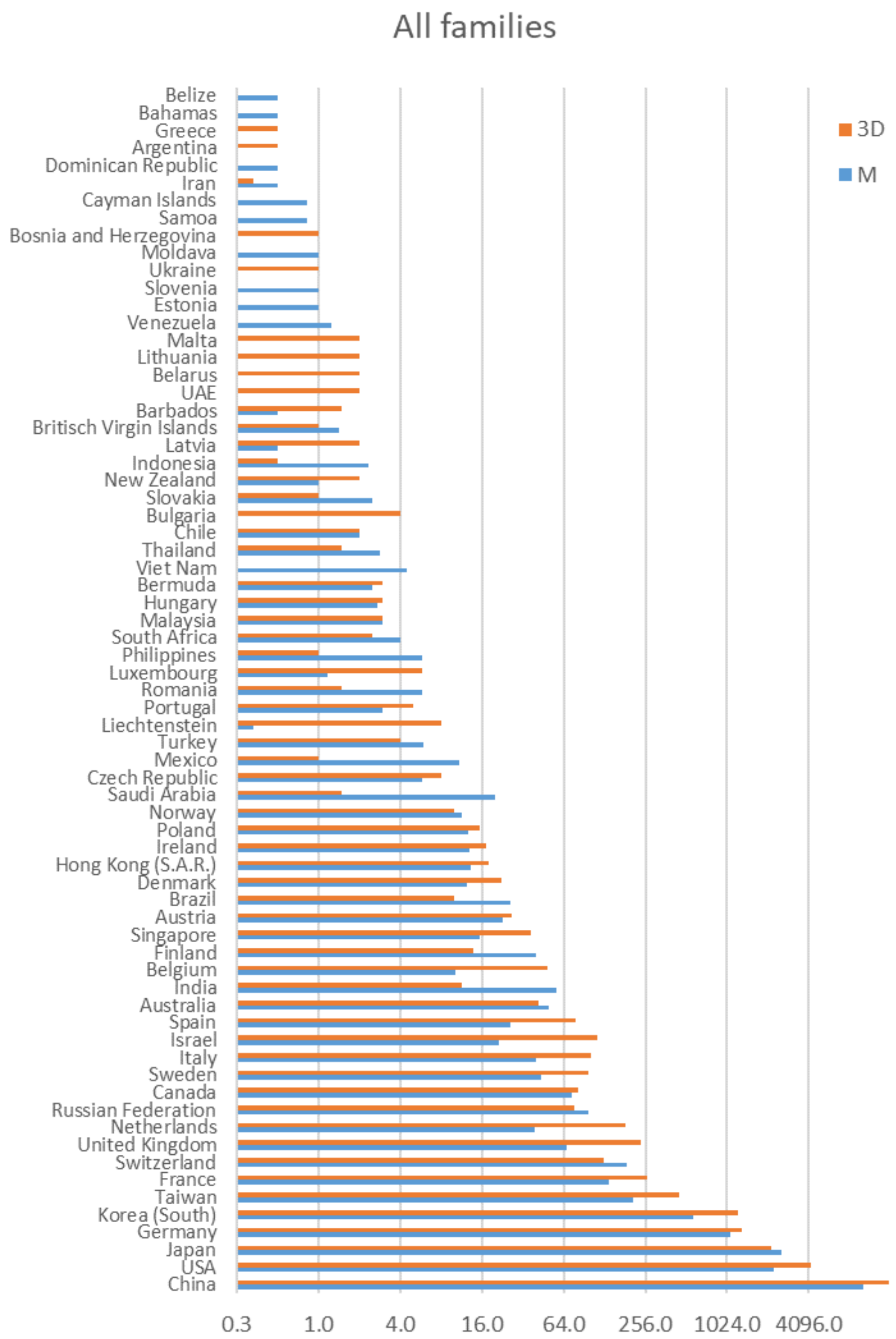
Fourth, we use the Derwent Manual Code (T01-J16: Artificial Intelligence)

Derwent_AI: MAN=T01-J16*

Our final set of IR4 patents is the set

IR4_Set = T06_Manuf **AND (***Digtl_Transm_Comm* **OR** *IPC_ML* ***OR*** KW_ML **OR** Derwent_AI**)**

Figure A1: Number of semi-triadic patent families by country (all patent families, entire period)



UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Vienna International Centre · P.O. Box 300 9 · 1400 Vienna · Austria
Tel.: (+43-1) 26026-0 · E-mail: info@unido.org
www.unido.org