CHAPTER 4

EXPORT AND PATENT SPECIALIZATION IN LOW-CARBON TECHNOLOGIES

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The low-carbon technology sector is going through a period of disruptive innovation and strongly increased investment, which is likely to continue. Global investment in new renewable power, at US$297 billion in 2016, is the largest area of electricity spending; newly installed capacity is predicted to continue increasing after reaching a record of 164 gigawatts in 2016.[1] The political momentum to combat climate change was reinforced in the Paris Agreement, when almost every country in the world agreed to aim for carbon neutrality in the second half of the century.

This chapter assesses the potential of countries to excel in technologies deemed essential for the low-carbon transition based on their export and technological specializations. Global trade and patenting patterns over the past two decades are analysed to uncover the persistence and current state of competitive advantages in the low-carbon sector.

Moreover, this chapter investigates countries' potential to develop a specialization—in terms of both exports and patenting—in certain technologies, based on their strength in related sectors and developments in similar countries. The analysis relies on systematic evidence originating from the regional growth literature triggered by Hidalgo et al. (2007), which found that countries diversify into industries that are closely related to current export strengths.

After introducing the data and main indicators, the chapter explores global dynamics in low-carbon technologies and the persistence of export and technology specialization profiles. Subsequently, it analyses which countries currently specialize in the low-carbon technologies considered and which countries have the potential to develop a competitive edge in the future.

Quantifying competitiveness in low-carbon technology sectors

This analysis is based on data from 132 countries between 2012 and 2015. The chapter focuses on four emerging sectors of low-carbon technology: photovoltaic (PV) systems and wind turbines (both examples of renewable energy generation), batteries (energy storage), and electric vehicles (which provide low-emission energy consumption). These technologies constitute four product and patent groups, following the concordance tables presented in EPO and UNEP (2015) and Fiorini et al. (2017), respectively.

To measure export specialization, the chapter relies on goods trade data from the UN Comtrade database. Exports are measured in gross terms and based on the six-digit level of the harmonized system (HS code). The assessment of the current competitive status of countries in the four sectors is based on its revealed comparative advantage (RCA). A country's RCA of a certain product is defined as its share of exports on total exports of that country divided by that product's world export share.[2] A high RCA indicates that a country exports more of a certain good than one would expect relative to the volume of its overall exports. Note that a comparative advantage in a good does not necessarily mean that a country is more productive than other countries in producing this good. It means only that, relative to all other goods produced by a country, it is better at producing this particular good.

Innovative activity is approximated by the number of patents filed in a specific patent category in a country. Patent data stem from the European Patent Office (EPO) PATSTAT database.[3] The analysis here is based on technology codes on patents according to the Cooperative Patent Classification scheme. The number of patents attributed to a country is based on the location of the inventor of patents applied for at the EPO or international patents under the Patent Cooperation Treaty (PCT). The earliest application of individual patent families is used and attributed in fractions to all inventor countries and technology codes.

The revealed technological advantage (RTA) is the RCA's equivalent in the patent realm: it provides an index to measure the relative specialization of a country in a technology and is based on patent applications. The RTA is defined as the share of a technology in a country's overall patents, divided by the global share of this technology in all patents.[4] For example, Denmark is highly specialized in wind technology. Although the country accounted for less than 0.7% of all patents globally between 2012 and 2014, around 16% of all wind technology patents during this period were developed by Danish inventors.

Both specialization metrics—the RCA for exports and the RTA for patents—are standardized to fit into a [0, 1] interval, where 0 to 0.5 reflects no specialization and 0.5 to 1 indicates a revealed advantage in a particular export category or technology.[5]

Persistence of specialization

If policy makers want to create or strengthen comparative advantages, they need to understand how volatile or path-dependent a country's specialization actually is. How easy is it to shift a country's export behaviour, and how dynamic are low-carbon sectors over time? It is particularly interesting to understand how easy it would be for countries to develop a comparative advantage in exports that are relevant to the transition to a low-carbon economy, since these are likely to be high-growth sectors.[6]

Figure 1 shows the correlation between current and past specialization patterns across countries in exports (Exports panel) and patenting (Technology panel). The high correlation between PV patenting in 2002 and PV patenting in 2014, for example, implies that many of the countries that were specialized in developing PV patents in 2014 were already specialized in 2002.

Export specialization patterns are found to be typically quite path-dependent.[7] The Exports panel in Figure 1 shows the historical correlations of RCA in the year 2015 in a range of products. For half of the products (the median), the correlation between the 2015 RCA and the RCA in the same product 10 years earlier is 0.7 or more. This persistence implies that countries rarely make large jumps in terms of the products that they are particularly good or bad at exporting.

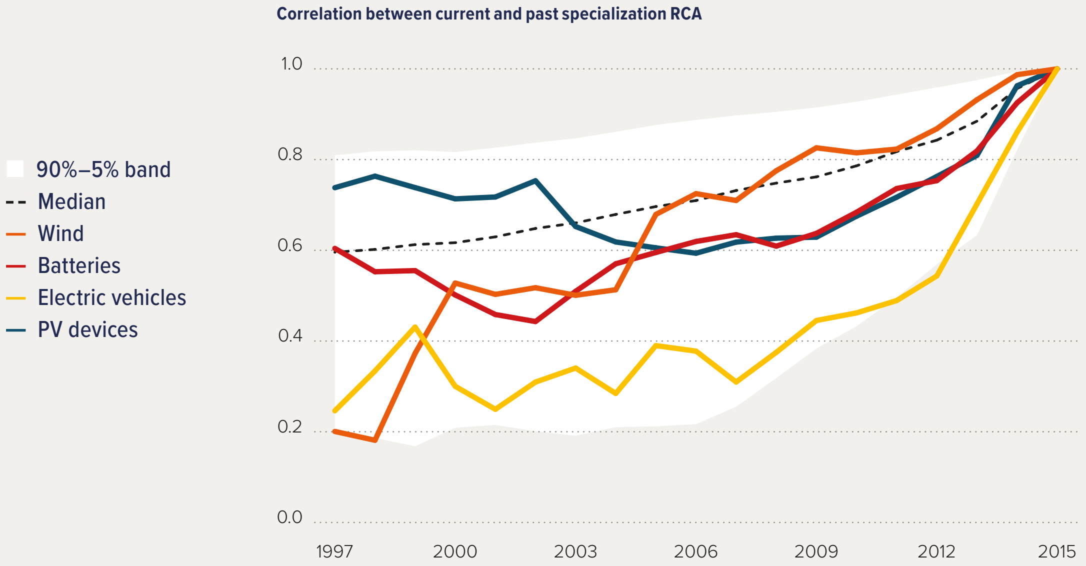
It seems that, compared with other export goods, a country's current strength in exporting these four low-carbon products is overall less correlated to its past strength. This is particularly evident for electric vehicles, which are among the products with the lowest persistence (they sit in the lower part of the shaded area in the Exports panel). But a country's current strength in exporting batteries, wind turbines, and PV technologies also tends to exhibit less correlation with past strengths than most other products. This finding is in line with the common narrative that low-carbon technologies are less mature and more dynamic than the average export sector. That means that these technologies represent opportunities on which policy makers can focus when attempting to foster comparative advantage.

The results illustrate that the comparative advantage of a country's exports is highly path-dependent—hence developing new comparative advantages is likely to be difficult for a country. However, the findings also show that the chances to do so are somewhat higher for immature sectors, such as electric vehicles.

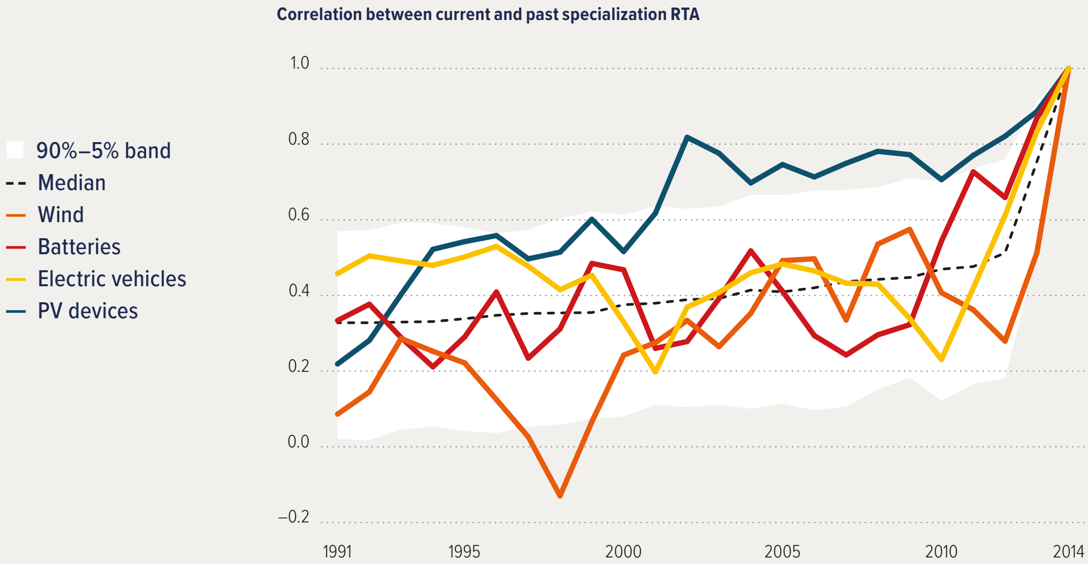
The correlation between current and past patenting activity (the Technology panel in Figure 1) shows that technological specialization is much less path-dependent than trade specialization. For half of all technological fields, a current technological advantage has less than 50% correlation with a technological advantage in the same field only two years ago. In comparison, more than 95% of the

Figure 1.
Correlation of export and technology specialization over time, by sector and technology

Exports, 1997–2015



Technology, 1991–2014



Sources: Calculations based on UN Comtrade Database, 2017, available at https://comtrade.un.org/; EPO PATSTAT, Autumn 2016, available at https://www.epo.org/searching-for-patents/business/patstat.html.

Note: The graphs show the correlation of a sector's RCA in 2015 with the same sector's RCA (Exports panel) and each technology's RTA in 2014 (Technology panel) with the same technology's RTA in each previous year, across countries. The dotted line is the median correlation, across all 5,482 export products and 640 technologies. The shaded area comprises the RCA correlations of all sectors and RTA correlations of all technologies between the 5th and the 95th percentiles of the distribution. PV = photovoltaic; RCA = revealed comparative advantage; RTA = revealed technological advantage.

export-based RCAs had more than 50% correlation with the corresponding two years before. Thus it appears much more likely that a country could develop a technological advantage without a prior specialization in the exact same technological field. These four low-carbon technologies are no exception. Correlations with past years largely track the median, sometimes above, sometimes below, with occasional outliers.

Less clearly defined is the channel linking the trade and technological dimensions. Export specialization in some sectors in 2014 is quite highly correlated with patenting specialization 10 years prior (e.g., for electric vehicles the correlation is around 0.4) but less for other technologies (e.g., in PV technologies the correlation is around 0.2). Hence the link of past patents to current exports might be strong for some products, but weaker for others. At the same time, 2014 patenting specialization is quite highly correlated with export specialization 10 years ago (e.g., for solar the correlation is around 0.4) but much less for other technologies (e.g., in electric vehicles the correlation is around 0.1). One reason for this finding might be that the specialization in a certain—persistent—sector such as the automotive industry stimulates a flow of patents in this sector.

More work needs to be done in this area to establish the direction and size of causality between patenting and export specialization. It can be argued that both export and patenting specialization are somewhat forward-looking indicators for future export strength.

Potential specialization in low-carbon technologies

The aim of this chapter is to determine which countries might have the potential for developing an advantage in patenting any of the four technologies of interest. The analysis builds on the fact that countries find it easier to innovate in technologies that are related to technologies they are already good at, or those that are developed in countries with similar patenting patterns.

To estimate the potential technological specialization of a country, this study uses a methodology developed by Hausmann et al. (2014). They show that a country's future comparative advantage in a particular product category can be estimated from its comparative advantage in related products, even if the country does not yet export these products. For example, export specialization in photovoltaic devices often appears together with the export of transistors or diodes. Furthermore, geographically proximate countries—such as Japan and the Republic of Korea (Korea), or Lithuania and Latvia—often exhibit similar export specialization. Hence Hausmann et al. (2014) use a weighted sum of RCA indicators in similar export sectors and a weighted sum of RCA indicators in similar countries to determine a country's potential RCA.

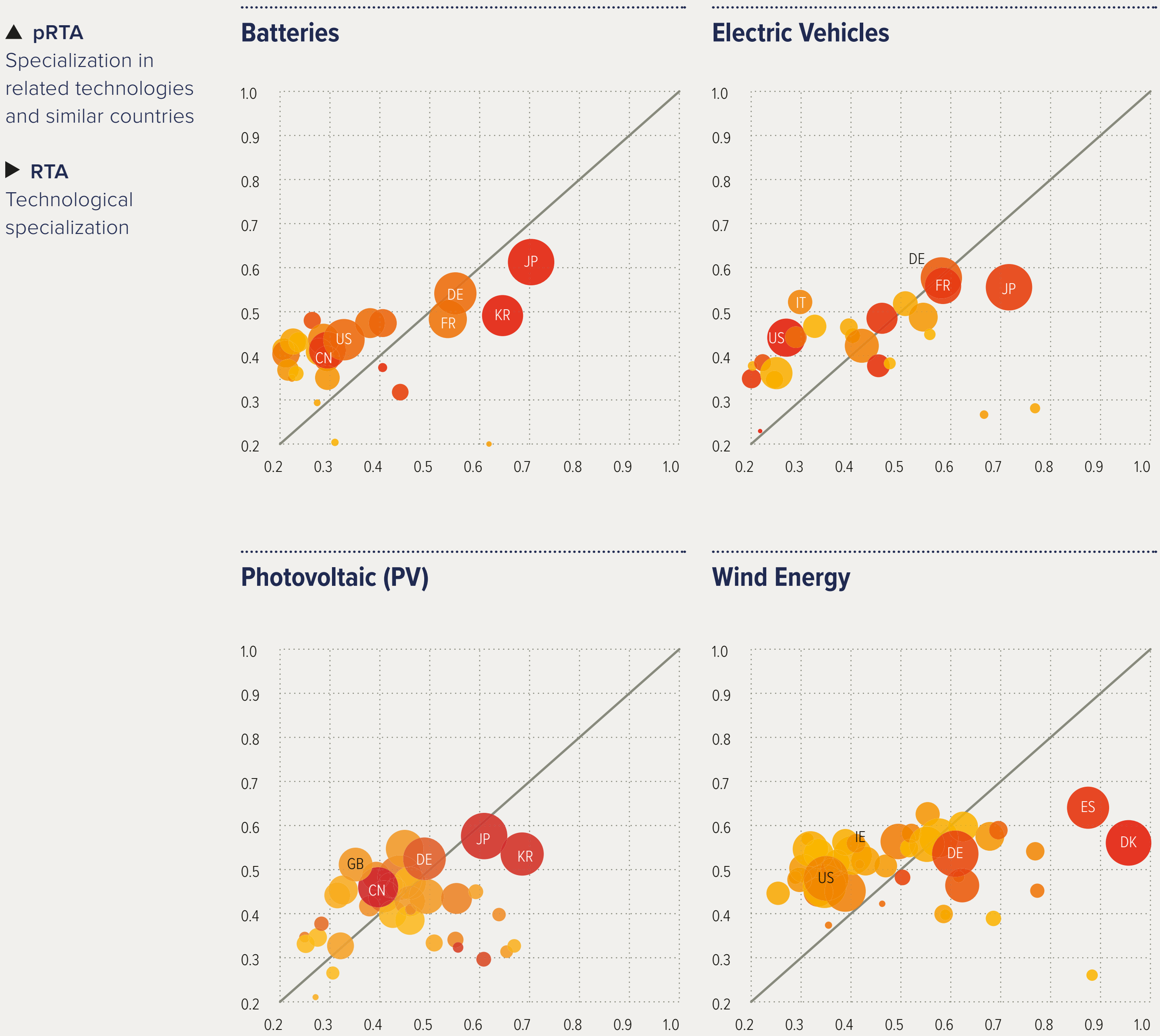
This approach can also be applied to patenting specialization—to estimate the potential RTA (hereafter *pRTA*) of the four technology groups. Technically, a weighted sum of product and country correlates is constructed to measure similarities.[8] Then an ordinary least squares regression is fitted, using these product and country similarities. The fitted values obtained from this regression are the pRTAs; these values represent the technological specialization expected from a country given current patenting patterns in similar technologies and countries.

To give one example, to establish Ireland's potential for wind turbine innovation, the study looks at related technologies, such as 'machines or engines for liquids' and 'dynamo-electric machines', and related countries, such as Denmark. Although Ireland has not yet developed a specialization in wind turbines, its pRTA is found to be rather high because it is already specialized in the two nearby technologies (see the Wind energy panel in Figure 2).

Figure 2 puts all parts together: the size of the country bubbles shows the number of patents in the sector. The darker a bubble, the higher the country's export specialization. For example, the large, dark red bubble for Denmark in wind-based energy generation depicts this country's high level of export specialization in combination with a large absolute number of patent applications by Danish inventors, comparable in number to those of Germany.

The bubble's position in the chart shows the relation of current technological specialization to potential technological specialization. Countries that appear above the 45° line exhibit a higher indicator of potential specialization than current specialization. Patenting profiles in these countries, together with knowledge about technology patterns in similar countries, suggest that diversifying their technology profile in this direction is low-hanging fruit. Conversely, countries situated below the 45° line can be

Figure 2.
Actual and potential specialization in technology (x,y) and exports (colour), 2012–14



Source: Calculations based on UN Comtrade Database, 2017, available at https://comtrade.un.org/; EPO PATSTAT, Autumn 2016, available at https://www.epo.org/searching-for-patents/business/patstat.html.

Notes: Horizontal axes show standardized RTAs between 2012 and 2014; vertical axes show standardized pRTA—that is, implied specialization in related technologies and similar countries. Bubble size is relative to the size of the technological sector in the number of patents (log scale) while the dark colour shades show revealed comparative advantage (RCA) specialization in exporting goods in this sector. RTA, pRTA, and RCA range from 0 to 1; values above 0.5 indicate a specialization. RTA = revealed technological advantage; pRTA = potential RTA. ISO-2 country codes: CN = China; DE = Germany; DK = Denmark; ES = Spain; FR = France; GB = United Kingdom; IE = Ireland; IT = Italy; JP = Japan; KR = Republic of Korea; US = United States of America.

Countries that are most specialized in patenting in a certain sector are also specialized in exporting in this sector.

seen to have matured sectors and are already leading in terms of relative strength.[9] Based on this methodology, China and the United States of America would be expected to specialize more into battery patents than they already do; and Denmark and Spain would be expected to reduce their outstanding specialization in wind patents.

In general, it can be observed that the upper-right corner in all four technologies is inhabited by countries with strong export specialization (dark red). That is, countries that are most specialized in patenting in a certain sector are also specialized in exporting in this sector. Competitive advantages in sectors such as Danish wind turbines or German electric vehicles coincide with high innovative activity.

However, the converse statement—that countries with high export specialization also exhibit high technological specialization—is not confirmed by the data; there are highly specialized exporters, such as the U.S. electric vehicle sector, that do not exhibit a relative strength in innovation. In these cases, competitive advantages appear to be based on other factors (e.g., factor cost) that are not related to patenting specialization. As mentioned earlier, indicators of relative strength do not capture global leadership but rather a comparative advantage in relation to global peers and in relation to competing industries within the country.

One example of a sector that gained a competitive advantage in the absence of a technological specialization is the Chinese PV sector. China is the world leader in domestic investment in renewable energy and associated low-emission energy sectors in absolute terms.[10] The Chinese PV sector exhibits one of the strongest export specializations globally; five of the world's six largest solar-module manufacturing companies in 2016 are located in China. However, China does not produce more PV patents than other technologies; it has not developed a technological specialization in this sector.

A second general observation is that in some low-carbon technology areas—such as batteries and PV energy—the number of patents is high while less patenting occurs in relation to electric vehicles and wind turbines. The former group are types of technology for which patenting is common practice, commercial interest in the technologies is high, and the categories are broadly defined.

A similar finding relates to the country context. Institutional factors, the legal system, and various domestic factors related to the size of the country affect national patenting activity and largely explain the high number of patent applications in Japan and Korea across all four technologies.[11] Nevertheless, Japan was able to develop a competitive edge both in exporting and innovating in three out of four examined low-carbon technologies (batteries, electric vehicles, and PV energy) and Korea in two out of four (batteries and PV energy). In sectors where Japan and Korea lag in terms of relative technological specialization, the model indicates high potential.

For **electric vehicles,** a dispersed picture emerges. Only five countries (with more than 10 patents in the period between 2012 and 2015) exhibit a larger number of electric vehicle patents than their size would suggest (shown in the top right quadrant of the Electric vehicles panel of Figure 2); these countries also specialize in related technologies. France and Germany have significantly increased the number of patents in electric propulsion technology in the past decade, which has helped them to keep pace with the growing patenting field and develop a comparative advantage. Other car manufacturing countries, such as Italy and the United States of America, have not yet developed a technological specialization but have high potential. These countries lie above the 45° line in the Electric vehicles panel of Figure 2.

Comparable to electric vehicles, patenting in **battery technologies** is characterized by the dominance of few large players. Korea and Japan lead the distribution of technologically specialized countries; both have more than twice as many battery patents as one would expect from their overall patenting activity. Japan has 43% and Korea 14% of all battery patents considered. Germany and France closely trace the technological specialization of Korea and Japan, while many smaller players have a high potential to develop a comparative advantage.

Many countries have developed a specialization in energy generating technologies based on **wind.** Nevertheless, the distribution is topped by the three global wind powerhouses—Denmark, Germany, and Spain—which together accounted for 43% of worldwide wind turbine patents from 2012 to 2014. All three have a high export specialization, but Germany's innovation profile is broader than that of Spain or Denmark, resulting in a lower index of technological specialization.

Despite massive solar subsidies, Germany has not specialized in **photovoltaic** technology innovation. Interestingly, China is also responsible for fewer patents in PV than would be expected for a country with China's total number of patent applications.

The results show that a strong technological specialization correlates with export specialization whereby countries with high relative advantage in patenting also exhibit relative strength in exports, while the absence of technological specialization does not hinder countries from becoming specialists in exporting these low-carbon goods. Whether technological specialization implies a competitive export sector demands further analysis.

Conclusion

Given the global decarbonization push, the wide array of low-carbon technologies now available offers significant growth potential. This study assessed the potential of countries to excel in low-carbon energy sectors based on their export and technological specialization. Global trade and patenting patterns over the past two decades were analysed to uncover the persistence and current state of competitive advantages in the low-carbon sector. Moreover, the chapter investigated countries' potential to develop a specialization in the future based on knowledge spillovers and strength in similar technologies.

A country's relative strength in exporting a certain product was found to be related to its past relative strength of exporting this product, exporting related products, and patenting in the corresponding technology. Concurrently, specialization in patenting a certain technology is itself related to past relative strength of patenting in this technology and patenting in related technologies. Hence a country's product and technology space entails information about the ease with which a country might move into specializing in new sectors. However, the strength of the above relationship depends on the sector. Comparative advantages in exporting low-carbon products are found to be less persistent than similar advantages for the majority of other goods.

Technological advantages measured by patent specialization are less path-dependent than comparative advantages in exports and, thus, possibly more prone to be affected by policy instruments. This finding is more pronounced for immature sectors, such as electric vehicles, which might witness larger shifts in the innovation landscape and global competition in the future. Even if a country is currently not good at exporting or patenting in a certain sector, it might acquire this capability in the future. Spillover effects across countries, as well as strength in related technological fields, may play important roles in developing a competitive advantage in these emerging sectors. Policy can leverage strength in similar technologies by shaping innovation paths; strengthening learning capabilities; targeting sector-specific innovation regimes; and coordinating sectoral, national, and regional policies.

Data show that strong technological specialization often correlates with export specialization, although the absence of technological specialization does not prohibit countries from becoming specialists in exporting low-carbon goods. Although other factors play an important role in determining competitive advantages, technological specialization can promote competitive industries, thereby shaping long-run growth dynamics.

Most of the inspected sectors are dominated by few important players. For batteries and PV systems, China has a strong comparative advantage in exports while Japan and Korea are leaders in terms of both technological and export specialization. Denmark and Spain export and patent more wind technology than their size would suggest. The electric vehicle sector, however, shows a more dispersed picture with a larger number of specialized countries.

Strength in related technologies and patterns in similar countries can provide insight into low-hanging fruit for policy intervention. The small number of leading countries is matched with a large number of countries that have a high potential to develop a technological specialization in the four low-carbon technologies in the future.

Notes

1 IEA 2017a, 2017b.

2 Balassa, 1965.

3 The EOP PATSTAT (Autumn 2016) database is available at https://www.epo.org/searching-for-patents/business/patstat.html.

4 Innovation in low-carbon technologies poses several methodological difficulties, such as the narrow technological scope that leads to low patent counts, missing information, and the classification of relevant patents, all of which are addressed by Haščič and Migotto (2015) and Haščič et al. (2015).

5 Laursen, 2015.

6 Zachmann and Kalcik, 2017.

7 Zachmann and Nano, 2017.

8 What constitutes similarity between technologies and regions is a matter of ongoing research (Alstott et al., 2016; Joo and Kim, 2010; Leydesdorff et al., 2017; Stellner, 2014; Yan and Luo, 2017). Similar to Hausmann et al. 2014, this study opts for an approach based on the correlation of countries' specialization patterns. Alternatively, one can think of the co-occurrence of technology codes on individual patents or what combinations of technologies are researched by inventors or within firms.

9 An interactive version of these findings can be found in the online report at http://www.i2-4c.eu/lowcarbongrowth/.

10 Buckley and Nicholas, 2017.

11 OECD, 2009.

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