Data & Policy (2023), 5: e18
doi:10.1017/dap.2023.17

RESEARCH ARTICLE

Fit for purpose? The patents regime, the Fourth Industrial Revolution, and sustainable development

Allison Bostrom[1] and Shivani Nayyar[2]

[1]Centre of African Studies, The University of Edinburgh, Edinburgh, Scotland
[2]United Nations Department of Economic and Social Affairs, New York, NY, USA
Corresponding author: Allison Bostrom; Email: allisoncbostrom@gmail.com

Received: 18 October 2022; **Revised:** 08 March 2023; **Accepted:** 08 May 2023

Keywords: Digital divide; Fourth Industrial Revolution; innovation; intellectual property; patenting

Abbreviations: 4IR, Fourth Industrial Revolution; EPO, European Patent Office; GDP, gross domestic product; HDI, human development index; ICT, Information and Communications Technology; IP, intellectual property; IPR, intellectual property rights; JPO, Japanese Patent Office; OECD, Organization for Economic Co-operation and Development; R&D, research and development; SDGs, sustainable development goals; TFM, Technology Facilitation Mechanism; TRIPS, the Agreement on Trade-Related Aspects of Intellectual Property Rights; UNDP, United Nations Development Program; UNFCCC, United Nations Framework Convention on Climate Change; USPTO, United States Patent and Trademark Office; WIPO, World Intellectual Property Organization; WTO, World Trade Organization

Abstract

This article uses data from several publicly available databases to show that the distribution of intellectual property for frontier technologies, including those useful for sustainable development, is very highly skewed in favor of a handful of developed countries. The intellectual property rights (IPR) regime as it exists does not optimize the global flow of technology and know-how for the attainment of the sustainable development goals and is in need of updating. Some features of the Fourth Industrial Revolution imply that the current system of patents is even more in need of reform than before. COVID-19 vaccines and therapies and the vast inequality in access to these has highlighted the costs of inaction. We recommend several policy changes for the international IPR regime. Broadly, these fall into three categories: allowing greater flexibility for developing countries, reassessing the appropriateness of patents for technologies that may be considered public goods, and closing loopholes that allow for unreasonable intellectual property protections.

Policy Significance Statement

Based on the static or growing gap between rich and poor countries in the development and commercialization of innovations, we recommend revisiting the international system of intellectual property rights. We argue that this is especially important for Fourth Industrial Revolution technologies that change on a rapid timescale and are essential for participation in the global economy. We contend that patents are not the appropriate tool for encouraging innovation of public goods, such as pharmaceuticals and climate technologies. Instead, we recommend other avenues such as awarding grants or prizes for innovations and the development of knowledge commons systems. The persistent gap in intellectual property development also illustrates that the Agreement Trade-Related Aspects of Intellectual Property (TRIPS) has not helped developing countries catch up.

© The Author(s), 2023. Published by Cambridge University Press. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (http://creativecommons.org/licenses/by/4.0), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

1. Introduction

As globalization has continued and the pace of technological advancement has intensified in recent decades, the "digital divide" between countries that began during the first Industrial Revolution has grown (UNCTAD, 2021). Technology plays an increasingly important role in development and in people's daily lives, but access to this technology is highly unequal. Because of its rapid pace and large impact on human life, recent technological development has been dubbed the Fourth Industrial Revolution (4IR). The 4IR technologies tend to involve information and communications technology (ICT), alternative energy sources, advanced algorithms, and more efficient manufacturing processes (Alimkhan et al., 2019). These technologies undoubtedly have the power to make life easier for people, but only a small portion of the global population has regular access to them.

The digital divide is part of a broader trend of increasing inequality around the world that includes other technological inequalities such as access to cutting-edge pharmaceuticals. This trend of inequality touches all aspects of life, including income, life expectancy, educational outcomes, and political power (United Nations Development Programme (UNDP), 2019). Advanced technology affects each of these factors that all reinforce each other so that (technological) inequality is cyclical. Those who have higher incomes and better health and educational outcomes are more likely to use and even develop advanced technologies that give them more advantages (Goedhart et al., 2019; Robinson et al., 2020). These advantages are highly concentrated in the global North, most especially in a handful of wealthy countries.

For moral reasons alone, this is unacceptable, but inequality also contributes to a number of more concrete society-level problems. Even before the COVID-19 pandemic, growing intolerance of intrastate and interstate inequalities led to social unrest and, in some cases, democratic backsliding with the election of nationalist leaders in both the global North and South (Cox, 2017; Freedom House, 2019). Uneven effects of climate change have destroyed homes and livelihoods in some parts of the world, while in others carbon emissions continue unabated (Zaman, 2013). Though technology alone cannot solve all of these problems, it could be a tool for more sustainable development.

However, the current system of technological development and distribution is highly unequal. A given country's access to technology is determined by a combination of many factors, including availability of patented knowledge, technical know-how, trade secrets, relevant infrastructure (physical, institutional, regulatory, and digital), educational outcomes, and government and private expenditure on technology (Cheng and Parra-Lancourt, 2020). Developed countries have an advantage in each of these areas.

The COVID-19 pandemic has highlighted global inequalities, particularly in relation to technology access. More than 3 years after the start of the pandemic, access to lifesaving vaccines, therapeutics, and diagnostics remains highly stratified by income and geography. Intellectual property protections on the research needed to create vaccines and other pandemic tools have prevented these vital technologies from diffusing, leading to unnecessary deaths.

In this article, we examine the role of intellectual property rights (IPR) in perpetuating the technological divide, not least pandemic inequalities. We utilize several publicly available datasets to analyze the global distribution of patents. By design, patents keep technical knowledge from being used by society at large. The traditional argument is that this is required as an incentive for potential innovators to ensure that they can earn monopoly returns from their innovations. When the benefits to society are large and exceed the private returns to innovators, it is very possible to end up with too little in terms of scientific advancement. Empirically, the link between stringent patent regimes and the extent or speed of innovation has been studied, and no link has been found (Bessen and Hunt, 2007). For one, patents limit diffusion of technologies and diffusion and feedback are important factors for further advancing innovation (Jaffe and Stavins, 1995). The efficiency of patents in spurring innovation also varies by industry and it has been found that they have the most benefits in the pharmaceutical industry where innovations are easily identified and have clear boundaries, for example, the development or discovery of a new molecule (Bessen and Meurer 2009).

We show the distribution of intellectual property is very highly concentrated in a handful of developed countries. The effects of this concentration are exacerbated when combined with the rapid evolution and

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

everyday use of 4IR technologies. We argue that this imbalance is closely linked with the way patents are used, regulated, and distributed. We find that, due to specific features of 4IR technology, the patent regime is particularly unsuited to efficient development trajectories for the latest *frontier* technologies. The current IPR regime positions developed countries as the privileged keepers of legal rights to knowledge while the developing world largely lacks access to this resource. Given that the nature of innovation is cumulative, having exclusive access to cutting-edge technological knowledge gives a distinct advantage to firms and researchers in developed countries, allowing them to build upon existing technology, generating more patents.

To combat these glaring inequalities, we recommend several policy changes for the international IPR regime. Broadly, these fall into three categories: allowing greater flexibility for developing countries, reassessing the appropriateness of patents for technologies that may be considered public goods, and closing loopholes that allow for unreasonable intellectual property protections. Specific recommendations include expanding flexibilities in TRIPS (the Agreement on Trade-Related Aspects of Intellectual Property Rights). We also recommend considering non-patent options for rewarding innovation such as grants and prizes, enacting more stringent regulations that prevent patent thickets, and involving technology experts in making determinations of non-obviousness and novelty.

Since patent regimes play out differently by industry, pharmaceutical patents are justified from an efficiency point of view. The boundaries on new inventions such as a vaccine or a diagnostic test are much more well defined than, for example, for an algorithm. However, the experience with the COVID-19 pandemic and the worldwide distribution of vaccines, diagnostics, and therapeutics should act as a warning signal. Even though there may be an efficiency argument for stringent patent protection in pharmaceuticals, the equity argument, and the argument for fair and equal access for everyone in the face of a global pandemic, is exceptionally strong. Furthermore, when we account for the fact that unvaccinated populations have been breeding grounds for the evolution of new variants of the virus, and these have caused high levels of illness and death in repeated waves, the efficiency argument is also shaky. In the argument for restricting the intellectual property, this cost of lack of access to the vaccine is not accounted for.

2. Data Sources

We utilized the World Bank DataBank for examining patent inequalities across all technologies. This database also allowed us to analyze inequalities in research and development expenditure and the number of researchers by country, indicators for Target 5 of Sustainable Development Goal 9. The World Intellectual Property Organization (WIPO) PATENTSCOPE database was most useful for understanding the disparity in COVID-19 vaccine-related patents due to its keyword search. We used the inventor country and applicant country data to understand the geographic trends. Finally, the Organization for Economic Co-operation and Development (OECD) Data Warehouse includes the number of triadic patents (defined as those filed at the United States Patent and Trademark Office (USPTO), European Patent Office (EPO), and Japanese Patent Office (JPO)) for the last several decades, drawn from the EPO's PATSTAT database. The ability to filter out triadic patents is an appealing feature because triadic patents are regarded as being "strongly" protected since they have been filed in three of the world's largest markets. Additional details on our search methodology can be found in the Appendix.

Because triadic patents are considered to be particularly valuable or important, they are a useful metric for understanding inequalities in innovation capacity at the global level. We thus decided to use the OECD Data Warehouse to compare the number of triadic patents in several important technologies, including telecommunications, pharmaceuticals, nanotechnology, green energy, digital communications, biotechnology, and artificial intelligence. The value of focusing on triadic patents can be seen clearly in the results of Foster-McGregor et al. (2019); though Chinese applicants hold the most patent families,[1] China only

[1] A patent family is a collection of patents that apply to the same or very similar technology. Analyzing by patent family can help to avoid double-counting patents filed at multiple offices, for example.

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

ranks fourth (behind the US, Japan, and Germany) in terms of "semi-triadic" patents (defined as those protected through at least two of the following: USPTO, EPO, JPO, and the Chinese Patent Office). Only 1.26% of China's patents were found to be semi-triadic, while most other countries that produced large numbers of patents had ratios of at least 10%. This indicates that, although China is a major producer of patents, not many of those patents contain knowledge that is commercialized on a global scale. We find a similar trend in our analysis below. This discrepancy validates an approach that focuses on those patents deemed to be of high quality or global importance. Further information about the way we extracted data and generated each figure can be found in the Appendix.

3. Science and Technology and Inequality

Some countries have established their positions as the originators of 4IR and other important technologies, such as pharmaceuticals. It has been argued that there is a global digital divide, with a handful of countries involved in creating and using frontier digital technologies to transform their economies, while others still try to develop basic industrial capabilities (United Nations Economist Network, 2020). According to our analysis, countries that hold a substantial lead in patenting frontier technologies include: the US, Japan, the Republic of Korea, China, Germany, France, the United Kingdom, the Netherlands, Switzerland, and Sweden.

The sustainable development goals (SDGs) specifically call for enhancing domestic technology development and innovation, including by increasing public and private investment in research and development, via Goal 9; and increased international cooperation in transferring technology, via Goal 17 (United Nations Development Programme (UNDP), 2022). However, there are still large gaps in the diffusion of technologies to developing countries. This means there is untapped potential in the productivity of developing economies. Additionally, even the technologies that do diffuse to developing countries tend not to be well-suited to the local context because they were developed elsewhere (Fu et al., 2011).

3.1. A handful of countries direct technology and own intellectual property rights

Here, we look at the distribution of patents across countries. Figure 1 gives the global breakdown of patent applications based on applicant residence in 2020, the most recent year available. China alone accounted for more than half of patent applications in 2020, with the US, Japan, the Republic of Korea, and Europe comprising all but the remaining 3.6%.

This massive inequality is alarming, but patents are only one indicator of domestic innovation capacity. Not all research is patented; for example, knowledge produced in the public sector may remain in the public domain. Patents would then be a poor measure of output since they represent the level of *commercialized* knowledge production. We thus explored other indicators of domestic innovation capacity, namely, research and development expenditure and the number of researchers involved in innovation. Expenditure as a proportion of gross domestic product (GDP) is typically regarded as a measure of a country's input, that is, the level of public resources it commits to research. Researchers (as a proportion of the population) can be regarded as both an input and an output: having more researchers is likely to lead to more knowledge production, but increased expenditure also likely results in more researchers being able to pursue projects.

Figure 2 shows the latest available patent application data for each country, plotted against R&D expenditure as a percentage of GDP (Figure 2a) and the number of researchers per million residents (Figure 2b). These points are color-coded by human development index (HDI). Note that the axes are scaled logarithmically; residents in the very high-HDI group tended to file between 10 and 1,000 times the number of patents per million residents as the low-HDI group. Though the R&D data only cover public expenditure, that divide alone has substantial implications for domestic innovation capacity. Many of today's developed countries have a reputation for private research and development, but their technological advancement relied heavily on public funding to create technologies that were later privatized

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

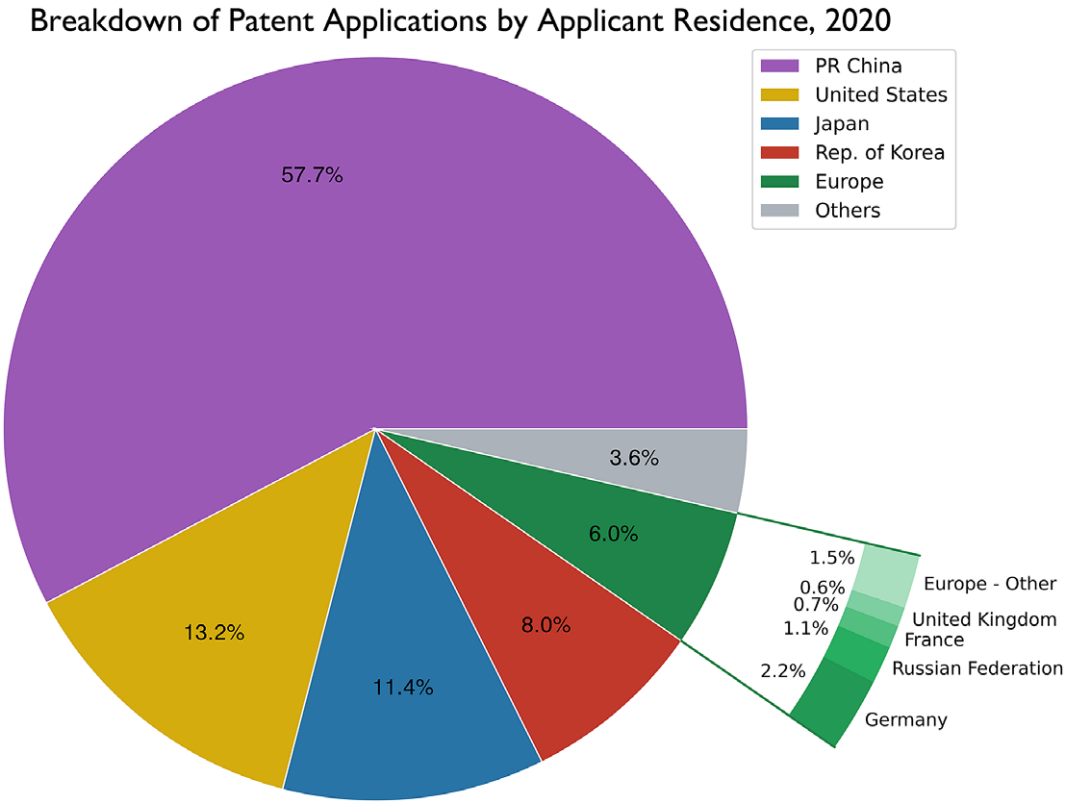

Figure 1. *Global patent applications by country. These data were downloaded from the World Bank DataBank's World Development Indicators Database. The most recent data are from 2019, so we ranked the states based on the number of patent applications filed by residents in 2019. Noting that several European states were high in the rankings, we decided to aggregate the data for the European region using a list of states from the United Nations Population Division.*
Source*: World Bank Database (2022).*

(United Nations Development Programme (UNDP), 2019). To a degree, their innovation systems still rely on public funding, especially in risky sectors (Cheng and Parra-Lancourt, 2020). These results additionally point to the economic and innovation risks associated with "brain drain," or the out-migration of a country's intellectual base. With fewer researchers at their disposal, such countries risk falling further behind the technological frontier.

It is therefore clear that the technological divide reaches across multiple indicators and that, broadly speaking, patent applications correlate with these other indicators. Though patent holdings are only one part of the divide, they reflect its magnitude and, we will argue, perpetuate and exacerbate the problem.

The distribution of triadic patents across countries sheds light on how the aforementioned inequalities are reflected in some frontier technologies. These categories include some 4IR technologies such as green energy, digital communications, and artificial intelligence. Five entities seem to be the dominant issuers of patents across these modern technologies. These are the US, Japan, Germany, the Republic of Korea, and China.

The data show that over the last decade and a half, China has caught up in every category. Otherwise, the breakdown has remained largely static. The top 10 countries have consistently accounted for 60–80% of triadic patents in important technologies (Figure 3). Due to imbalances in technological capacity and the terms of global agreements, as discussed below, these technologies tend to remain largely in the

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

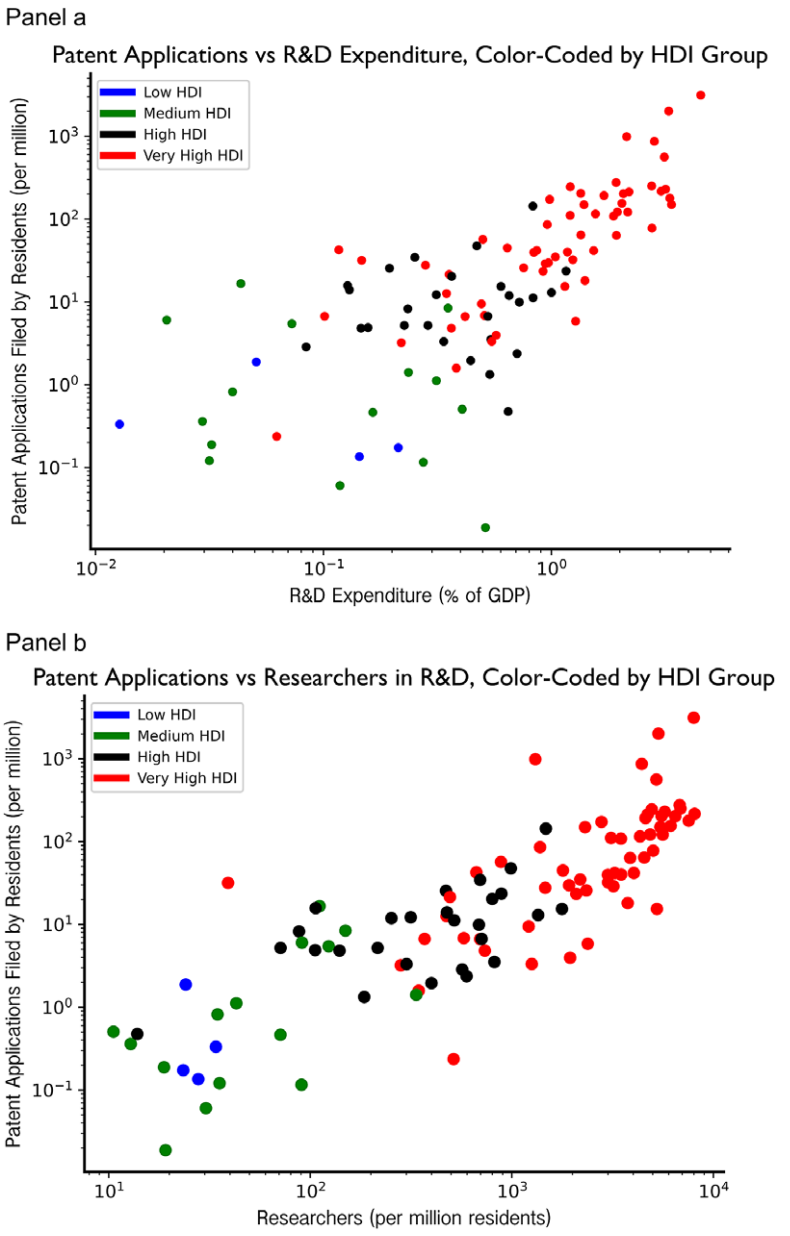

Figure 2. *R&D expenditure and researchers versus patent applications, coded by HDI. Countries were sorted into human development index (HDI) groups based on Human Development Report Office (HDRO) designations. Patent application data were retrieved from the World Bank DataBank using the "Patent Applications, Residents" dataset. The most recent available data point was used for each country. Panel (a) was constructed using the "Research and Development Expenditure (% of GDP)" dataset from the World Bank DataBank. The most recent available data point on R&D expenditure was used for each country. Panel (b) was constructed using the "Researchers in R&D (per million)" dataset from the World Bank DataBank. The most recent available data point on researchers was used for each country. Note that both axes are in logscale for these panels.* Source*: World Bank database and HDRO.*

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

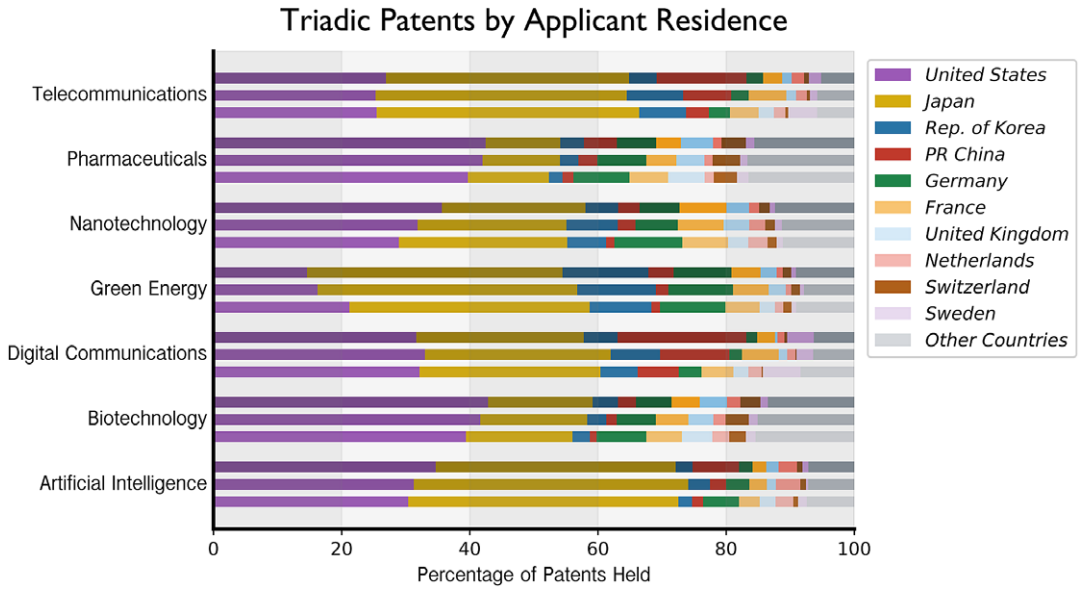

Figure 3. *Triadic patents in 4IR technologies, 2013–2016, 2009–2012, and 2005–2008. The top bar in each category is 2013–2016, the middle is 2009–2012, and the bottom is 2005–2008. We retrieved these data from the OECD Data Warehouse. After downloading the triadic patent counts for each country, we examined the share of patents held by applicants from all countries for each technology, using categories predetermined by the database. We generated lists of the top 10 countries for each technology in the timeframe 2013–2016 and then identified the 10 countries that placed in the top 10 most frequently. The shares of patents held by applicants residing in these countries is shown as a function of time for each technology in the figure.* Source*: OECD (2021).*

developed world, with little benefit for other countries. A recent report from WIPO does show that some countries are outperforming expectations based on their level of development; for example, the four countries in this category for the lowest income group are Rwanda, Madagascar, Mozambique, and Burundi (World Intellectual Property Organization (WIPO), 2022). Future research could seek to understand how these countries have outpaced their cohort and perhaps use that information to inform future policy. For example, Rwanda is a famed example of a developmental state, in which the government takes an active role in development (Mann and Berry, 2016). Perhaps this has helped to spur innovation.

3.2. Pharmaceutical patents—The case of COVID-19

Consider the COVID-19 vaccine. COVID-19 vaccine patents are similarly concentrated in just a few countries. Even among the top 10 jurisdictions,[2] there is an enormous disparity. The US, the jurisdiction with the most vaccine patents (2,335), has more than 100 times the number of patents of the tenth jurisdiction (Japan, with 20). The high concentration of patent applications in a few jurisdictions indicates that the use of the knowledge contained in them is not widespread, despite the urgency of the situation (Figure 4).

The picture is even more dramatic when examining the residence of vaccine patent applicants. While filing jurisdiction tends to reflect the markets in which patented knowledge will be commercialized,

[2] Note: We use the European Patent Office as a jurisdiction here rather than separating into individual European jurisdictions. The EPO has a mechanism by which inventors can file an application in multiple European jurisdictions with a single application, so it is treated by many as their "home" jurisdiction (Foster-McGregor et al., 2019).

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

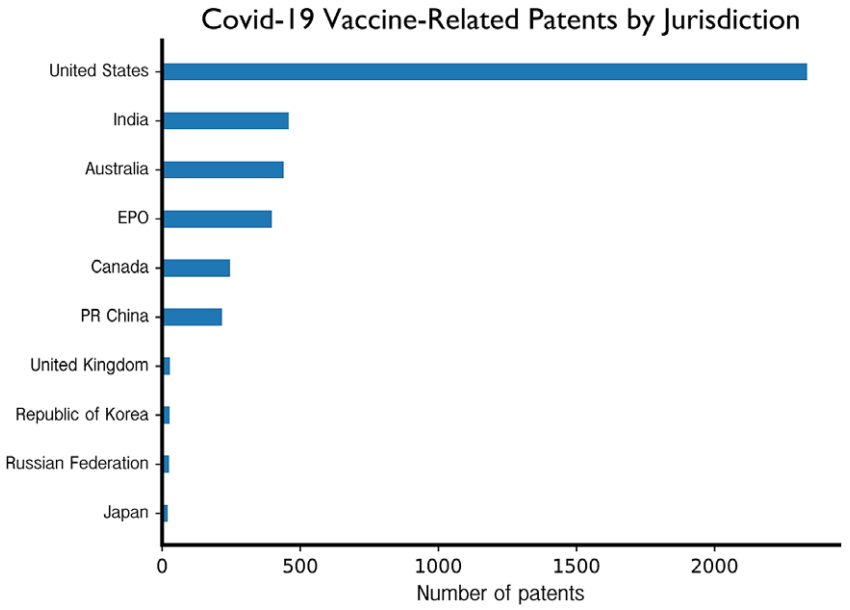

Figure 4. *COVID-19 vaccine-related patents by jurisdiction. We used the WIPO PATENTSCOPE database to do a field combination search for the keywords "COVID-19" or "sars-cov-2" and the keyword "vaccin*." We then identified the 10 countries with the most patents using the CTR keyword, which most closely corresponds with the jurisdiction in which the patent was filed.* Source*: World Intellectual Property Organization (WIPO) (2022).*

applicant residence data shows where the innovations originate (Foster-McGregor et al., 2019). Clearly, the US is overwhelmingly dominant in the field of COVID-19 vaccine patents, with almost 13 times the number of patents of the second-place country (Figure 5). This factor has undoubtedly contributed to its ability to procure enough doses to vaccinate its population. From an analysis standpoint, the discrepancy between the jurisdiction and applicant residence data justifies our prior use of applicant residence when attributing triadic patents to different countries.

While COVID-19 vaccines have been developed at record speed in an impressive feat of modern technology, it is mostly rich countries that have been able to access them and widely inoculate their populations (see Figure 6; Gebrekidan and Apuzzo, 2021).

The World Health Organization, UNICEF, the Global Vaccine Alliance, and the Coalition for Epidemic Preparedness Initiatives spearheaded the COVAX initiative early in the pandemic, with the aim of supplying vaccine doses to countries that could not afford to procure them otherwise. The sibling initiative ACT-A (Access to COVID-19 Tools Accelerator) sought to facilitate the spread of COVID-related IPR. However, these efforts largely served to illustrate that voluntary contributions of intellectual property access, funds, and vaccine doses are insufficient. COVAX was underfunded, and wealthy countries took their allotted doses from it even when they had purchased more than enough from suppliers (Institute of New Economic Thinking (INET) Commission on Global Economic Transformation, 2021). Likewise, representatives of developing countries reported that ACT-A failed to live up to their expectations of it and felt that their input went unheeded when the initiative was developed (Mandaviya, 2023). Thus, efforts to bolster equitable access to vaccines have flagged the role of IP (intellectual property) restrictions. While globally there is enough capacity to produce enough vaccine supply, this is hamstrung by tight control of IPR by a few pharmaceutical giants in wealthy countries. The efforts to get vaccines to all developing countries have been closely tied with arguments to relax the rules

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

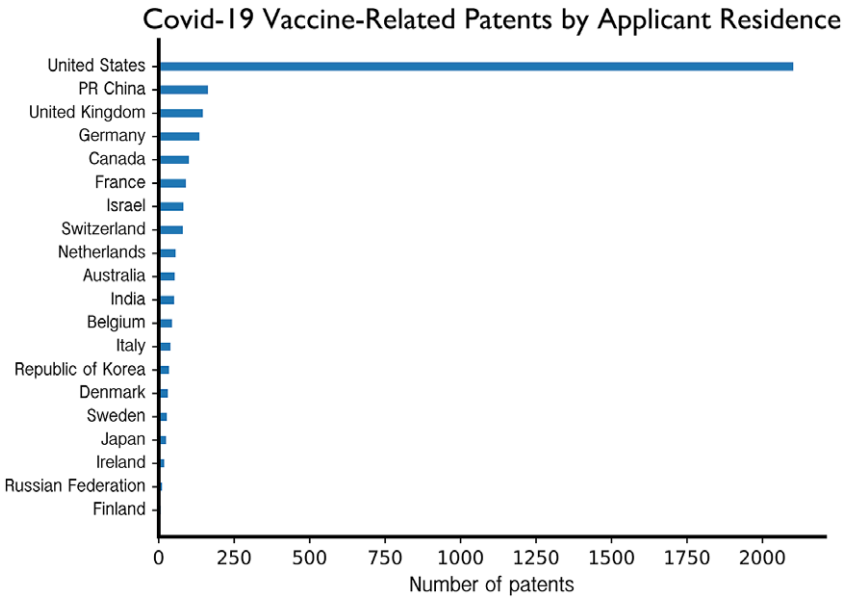

Figure 5. *COVID-19 vaccine-related patents by applicant residence. We used the WIPO PATENTSCOPE database to do a field combination search for the keywords "COVID-19" or "sars-cov-2" and the keyword "vaccin*." Because it is not possible to download applicant residence data as a spreadsheet and therefore easily rank them based on the number of patents by residents, we performed a search using these keywords and the ARE (applicant residence) field. We searched for all countries in the previous figure, as well as the top 10 countries identified in the triadic patent analysis, with a few additional countries that were dominant in certain sectors for triadic patents but did not make the top 10.* Source*: World Intellectual Property Organization (WIPO) (2022).*

of the IPR regime and a global move for suspension of intellectual property rights (Spence et al., 2021). This is required not just for vaccines but for a whole host of treatments, tests, and products related to the pandemic.

At the World Trade Organization (WTO), developed country governments have until recently repeatedly blocked attempts by India, South Africa, and other developing countries for suspension of patents for the COVID-19 vaccines and related treatment (Prabhala et al., 2020). TRIPS specifically allows for compulsory licensing, and the Doha Declaration on TRIPS and Public Health explicitly mentions public health emergencies as adequate cause to issue compulsory licenses that would allow other countries to produce essential drugs (Institute of New Economic Thinking (INET) Commission on Global Economic Transformation, 2021). Despite this, it has taken more than 2 years since the pandemic was declared for any agreement to be reached, during which time many people have died preventable deaths.

Recently, "the Quad" (composed of the US, EU, India, and South Africa) has put forward an agreement, signed in June 2022, to suspend certain TRIPS provisions for the purpose of expanding access to COVID-19 vaccine intellectual property (Monicken, 2022). However, this agreement falls short of what developing countries had hoped for (Green, 2022). It is unclear whether developing countries will have the latitude to access multiple patents with a single authorization or whether the process will be hindered by bureaucracy, and WTO will only decide whether to extend the waiver to desperately needed therapeutics and diagnostics 6 months after it goes into effect (Monicken, 2022). Furthermore, the technical know-how and trade secrets that are necessary for effectively harnessing patented knowledge are excluded from the deal (Krishnan, 2022).

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

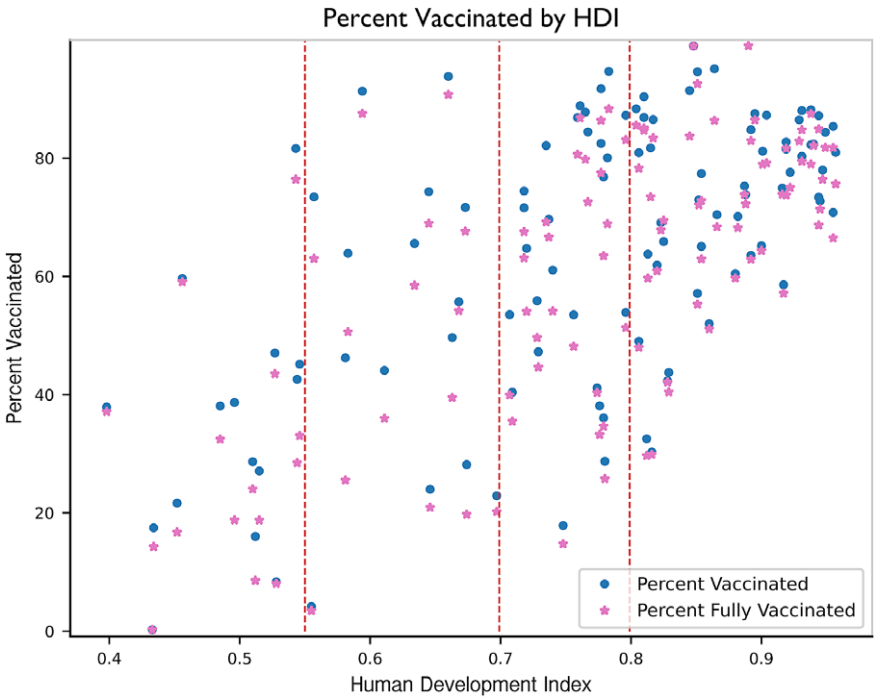

Figure 6. *Access to COVID-19 vaccines is inequitable. Countries were sorted into HDI groups using the same method as in Figure 2. Data were obtained from the UNDP COVID-19 Vaccine Equity Dashboard.* Source*: UNDP COVID-19 Vaccine Equity Dashboard 2023; generated using most recent data available as of February 27, 2023. "Vaccinated" refers to those who have received at least one dose of a two-dose regimen, or one dose of a one-dose regimen, while "fully vaccinated" refers to those who have at least received the last dose of the primary regimen.*

4. Patents and the Fourth Industrial Revolution

Are the latest advances in science and technology harnessed for sustainable development in a globally equitable manner? What role do patent protections play in achieving or alternately disrupting the advance and spread of technologies? First, we examine the question, does stronger IP protection lead to more sustained, system-wide innovation? Note that even if there is a positive relationship and stronger IP protection resulted in more innovation, from society's point of view, we could still have underprovision of innovation when the benefits to society are unaccounted for.

4.1. Patents and innovation

Empirically, there is scant evidence that the strengthening of patent laws leads to more R&D spending at the country level (see Challu, 1995; Scherer and Weisburst, 1995; Lanjouw and Cockburn, 2001; Sakakibara and Branstetter, 2001; Bessen and Hunt, 2007). In many industries, in recent decades, the patent system has resulted in weak or even negative support for innovation.[3] This is especially true in developing countries (Allred and Park, 2007), though evidence for the effect of patenting on innovation in developed countries is mixed (Allred and Park, 2007; Sweet and Maggio, 2015).

For one, the current patent system limits efficient diffusion of technology (Baker et al., 2017). Inefficient diffusion of technology can in turn inhibit further innovation. Feedback from first adopters

[3] For a recent rich discussion, see Cheng and Parra-Lancourt (2020).

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

and "user-driven" innovation is important in the lifecycle of more mature technologies (Jaffe and Stavins, 1995).

The effects of IP on innovation also vary from industry to industry. Empirical studies have shown that patents have a net positive impact on innovation in the chemical and pharmaceutical industries (Bessen and Meurer, 2009). The differentiating factor, for this sector, is the well-defined boundaries around patents on chemical compounds and pharmaceuticals. It is easier to demonstrate the novelty of a specific molecule, have clear assessment standards, and detect whether there is infringement (Levin et al., 1987). Their novelty, non-obviousness, and usefulness can be more clearly assessed as well (Cheng and Parra-Lancourt, 2020). Policymakers and regulators may want to reconsider uniform treatment of innovations from all industries (Roin, 2005). For example, boundaries around software patents are typically vague. Each product tends to include multiple technological ideas (Menell, 1994; Cockburn and MacGarvie, 2011; Bessen and Meurer, 2012; Chien, 2012).

In the previous section, it was shown that patent activity is distributed very unequally across country groups. When it comes to registering patents, developed regions are ahead, by many multiples. This divide is aggravated when it comes to 4IR technologies due to the rapid pace of innovation and the way these technologies have ingrained themselves into daily life. Given the extent of this inequality, it is instructive to ask if the current IPR regime does anything to help developing countries converge with the developed world. Or, on the contrary, does it lead to even greater divergence?

4.2. Patents and the 4IR

We find that the patent regime is particularly unsuited to efficient development trajectories for the latest *frontier* technologies. This is due to some characteristic features of the latest technologies. The patent regime is also further concentrating market power for global Big Tech firms that largely originate in wealthy countries and exacerbating the detrimental effects of that asymmetry, including on innovation. Taken together, this does not bode well for the optimal deployment of modern technologies for achieving widespread and inclusive sustainable development.

Though patent protections are intended to spur innovation by allowing for sufficient return on investment, in practice, they may also stifle follow-on innovation that builds on previous technological advances. This effect has become more pronounced in recent decades, with modern technologies, for a number of reasons.

For one, the pace of technological innovation has increased. Typical patent protections last for 20 years and this length may be increased using a variety of means (Henry and Stiglitz, 2010). For reference, Apple's first iPhone came out just 16 years ago (HISTORY, 2007). Cutting-edge 4IR technology changes on a much shorter timescale than the duration of patent protections, so the protected information is often outdated by the time the patent expires and the information is broadly available for commercial use (Roin, 2013).

This is exacerbated by the ripple effect of holding the rights to important patents. Firms will often barter for access to each other's intellectual property, leading to a vicious cycle in which those who are at the technological frontier tend to be the ones pushing it ahead. Such a system disadvantages developing countries, latecomer firms, and smaller firms and individuals who do not have large patent portfolios. Likewise, public sector researchers may be at a disadvantage since their research is sometimes freely accessible, rather than sequestered behind patent protection (United Nations Development Programme (UNDP), 2001). Even when publicly funded research is patent-protected, its role in the development of important technologies is not always properly acknowledged. For example, the American National Institutes of Health is still grappling with the pharmaceutical giant Moderna to obtain payments for a key technique that it licensed to the company. The technique was integral to the production of Moderna's COVID-19 vaccine, which earned the company massive profits (Mueller, 2023). Recent reports have pointed to the importance of public sector research as a basis for patent activity in the US (Flaherty, 2019) and have found that such research disproportionately leads to high-value patents (Hourihan, 2020). Given

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

the amount of value generated by follow-on innovation from publicly available research, it clearly plays an important role in domestic technology development.

Second, the nature of the product that is patented has changed, with implications for the effectiveness of patents. The evidence from recent decades shows that the patent system has not played a supportive role to innovation when it comes to most industries, except for the chemical and pharmaceutical industries. It is difficult to isolate specific inventive steps within the complicated codes that underlie many 4IR technologies, so patent boundaries are unclear (Gratton, 2002; Goldman, 2013). That a cancer treatment and the slide to unlock feature in smartphones receive the same 20-year patent protection, is hard to justify (Cheng and Parra-Lancourt, 2020). This is an additional reason for a rethink of the patents system, specifically the optimal stringency for a particular industry and if these should be differentiated by industry.[4]

Third, there is a trend toward a more complex technological landscape than before. There is more convergence of technologies from areas that were distinct before. This increased interdependence exacerbates any negative impacts on follow-on innovation (Cheng and Parra-Lancourt, 2020). New products and technologies tend to be built upon patented knowledge from disparate fields, making it even more important for firms to already hold patents rights that they can use to barter with firms from other sectors (United Nations Development Programme (UNDP), 2001).

4.3. Impacts on competition

The Fourth Industrial Revolution has been marked by a high degree of market concentration (United Nations Development Programme (UNDP), 2019). The domination of Big Tech is being flagged and increasingly in the sights of regulators. The IP system tends to also limit competition. This is another channel that goes on to inhibit further innovation.

Firms have been adopting strategies that harm competition. The growing use of a number of strategic patenting tactics has resulted in patent thickets. Patent thickets arise when individual products draw on hundreds or even thousands of patents, often with fuzzy boundaries (Hall et al., 2015). To commercialize a new technology, an innovator must navigate through a dense web of overlapping IPR. The increased transaction costs associated with thickets reduce incentives to innovate. In areas featuring complex technologies, increases in patent thicket density have led to greater increases in patent applications by owners of large patent portfolios, relative to smaller ones (von Graevenitz et al., 2013).

As technologies in the Fourth Industrial Revolution become more complex, patent thickets will lead to further market concentration and pose more barriers to entry to potential competitors (Cheng and Parra-Lancourt, 2020). Additionally, firms sometimes file patents solely to block competitors, with no intention to commercially use the patented knowledge. Such "strategic non-use" patents lock away knowledge with no benefit to society (Torrisi et al., 2016). The intention behind these often is to threaten or retaliate against competitors via litigation, a process which diverts resources from innovation and can intimidate innovators into avoiding the development of products that could be perceived as similar (Chang, 2002).

Companies may introduce small updates to their technologies when filing new patents to add to a thicket; these patents keep knowledge out of the hands of other potential inventors just as much as a truly novel patent, but without the benefit that a novel patent would bring. One recent example is the drug Humira, which treats conditions like arthritis. AbbVie, the company that holds the patent, has used patent thicketing and lawsuits to delay the entry of competitors into the market. By suing competitors and then settling with them to delay their entry in the market by years or decades, the firm is able to maintain its outsize profits. The patents that AbbVie has added to create the thicket have occasionally included minor improvements, but mainly have just expanded on the existing patent (Robbins, 2023). Thus, the drug has existed for more than two decades with only minor improvements, but because of loopholes in the patent

[4] For a discussion on the shortcomings of uniform patents in all industries, see Roin (2013).

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

system, its price has continued to rise. Follow-on innovation from the initial patent has been stifled by this technically legal and commonplace practice, a clear indicator that the current IPR system is not achieving its goals of promoting and incentivizing innovation. Though this example reveals weaknesses in the American system of regulating IPR, it is much the same globally.

5. Global Level Reforms and Challenges

5.1. TRIPS hinders developing countries' ability to catch up

The experience with the COVID-19 vaccine and its unequal distribution is an illustration of the broader issue of affordable access to lifesaving medicine under current international arrangements (United Nations Development Programme (UNDP), 2001). TRIPS, in particular, is a major barrier to technological diffusion and access. During their earlier development, today's economic powers had the freedom to protect infant industries and limit IP protections in order to disseminate knowledge that could stimulate innovation (David, 2010; Moser, 2013; Peng, 2017). Foreign inventions were often poorly protected, if at all, allowing domestic innovators to freely access and build upon those technologies (Kotabe, 1992; Nicholas, 2011; Peng, 2017). Except in limited and vaguely defined cases, developing countries today cannot engage in these same practices without running afoul of TRIPS.

The two main flexibilities included in TRIPS are compulsory licensing and parallel imports. The compulsory licensing provision allows governments to license out patented information without the patent holder's consent. This practice is allowed in certain urgent situations and has especially been used for pharmaceuticals. However, the bureaucratic hurdles involved limit the use of this practice in developing countries (Zaman, 2013; Baker et al., 2017). This issue has been revitalized in the context of the COVID-19 pandemic. Some states have invoked the compulsory licensing option to produce vaccines and treatments, but the fear of retaliation that would jeopardize bilateral trade agreements has made others reluctant to take this step (Institute of New Economic Thinking (INET) Commission on Global Economic Transformation, 2021). Additionally, many developing countries lack the necessary capacity to produce vaccines and treatments even if they invoke compulsory licensing, again leaving them dependent on imports from developed countries, which have been limited due to vaccine nationalism (Gruszczynski and Wu, 2021; McMahon, 2021). Non-patented intellectual property including trade secrets, clinical trial data, and technical know-how also remain out of reach, since compulsory licensing only covers patents (Institute of New Economic Thinking (INET) Commission on Global Economic Transformation, 2021).

Parallel imports, in which a product is imported from another country where it is less expensive, are also allowed through TRIPS. As with compulsory licensing, this process is not always straightforward. For example, the publishing industry has successfully lobbied to limit parallel imports of educational materials (Baker et al., 2017).

Besides the option for compulsory licensing and parallel imports under certain conditions, the only corrective measure included in TRIPS is the technology transfer clause for least developed countries in Article 66.2. This is a discretionary mechanism and evidence shows that it is rarely used and poorly monitored (United Nations Development Programme (UNDP), 2001; Moon, 2008; Moon, 2011; Zaman, 2013). Given the unevenness with which TRIPS treats the needs and interests of developed and developing countries, it is little wonder that this system has cemented global inequalities. This effect is clearly visible in our analysis; across a variety of technological fields, the dominance of the top 10 countries in triadic patents has mostly held steady or even increased since 2005, 10 years after TRIPS came into effect. Evidently, the TRIPS conditions do not stimulate innovation and investment in all countries.

TRIPS has existed for the entirety of the 4IR, meaning that the most recent technological revolution has been characterized by inequality. Most countries do not even have the building blocks of these technologies, which hinders their ability to catch up. However, global inequities in pandemic recovery illustrate the most striking and immediately concerning effects of TRIPS. Even the "flexibilities" of TRIPS are insufficient; the terms of the compulsory licensing and parallel import provisions are vague and

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

developing countries fear the repercussions if they inadvertently violate the rules. Power imbalances on the global stage prevent these flexibilities from being truly useful to developing countries.

5.2. Global level reforms

Given the challenges of TRIPS, it is clear that global level reforms are necessary to give developing countries more flexibility in handling IPR protections. For example, Zaman (2013) argues that countries should be given more latitude to use compulsory licensing and parallel imports for green technologies because combating climate change is an urgent necessity for all countries (Zaman, 2013). This is not merely a problem of uneven patent ownership distribution. Rather, deeply ingrained power imbalances serve to reinforce and even widen the gap in innovation capacity between rich and poor countries, which contributes to global inequalities. These challenges reflect the persistent structural problem with the global IPR regime.

TRIPS embodies this spirit through its insistence on uniformity in IPR protections. Enforcing the same level of patent protection for developed and developing countries leads to higher proportional costs for developing countries to innovate using existing intellectual property since they own less of it (Chang, 2011). The incentives offered by IPR are also less effective in developing countries since there are fewer actors capable of taking advantage of them. Thus, innovation is not necessarily hindered by lack of IPR but by lack of access to capital, education, infrastructure, technical know-how, trade secrets, clinical trial data, and other necessary tangible and intangible goods (Sweet and Maggio, 2015; Sanders et al., 2018; Institute of New Economic Thinking (INET) Commission on Global Economic Transformation, 2021). In addition, TRIPS conditions impose an institutional cost. A functioning IPR system requires substantial institutional and educational resources, including trained officers, lawyers, courts, and inspectors (Chang, 2011). This presents a challenge for already-strained developing country budgets. The necessity of accessing protected intellectual property leads to monetary flows from developing to developed countries in the form of royalties and licensing fees, which exacerbates existing between-country inequalities (Kumar, 2003).

Given the crucial role played by technology in development, it is especially important to ensure access to those technologies that are most useful for development goals, many of which are 4IR technologies. It would be reasonable to designate such technologies as global public goods, backed by public funding and openly accessible. One way to improve access would be to allow developing country governments and other actors to freely adopt and adapt such technologies to suit their needs, delaying royalty and licensing payments until these actors profit commercially from the technology (UNDESA, 2011). This may involve a multistakeholder discussion to determine which technologies should be considered global public goods, such as vaccines and climate change mitigation/reversal technologies (Sanders et al., 2018). Following such a discussion, TRIPS and related agreements would need to be updated to reflect the exemption of technologies labeled as global public goods from the usual IPR protections.

Pharmaceutical advances tend to be more well defined than advances in other industries, say algorithms in information technology, and consequently patents in pharmaceuticals are seen as more efficient than most other industries. The COVID-19 pandemic, however, gives pause. The extraordinary rapid spread of the virus across the globe, the staggering extent of deaths and illness around the world, and the eventual development of vaccines and therapies, shows that addressing COVID-19 needs global solidarity and action. We cannot go by standard efficiency arguments for protecting the intellectual property for the companies that developed the vaccines and the treatments. There is a strong moral argument to make these available broadly to all countries. More than that, addressing COVID-19 is a global public good. The populations that did not receive vaccination become hosts for the development of new variants of the virus that in turn lead to new waves, more illness and death, rendering even vaccinated and rich countries helpless. This is yet another externality that is not accounted for. The argument for sharing of IP information in the case of COVID-19 and similar global challenges is irrefutable. Clearly, the existing IPR needs reform.

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

The United Nations has multiple technology transfer initiatives in place already, focused especially on sustainable development. Both the Technology Facilitation Mechanism (TFM) and the United Nations Framework Convention on Climate Change (UNFCCC) Technology Mechanism aim to help countries combat climate change and achieve the SDGs by improving access to cutting-edge technologies. Though the inclusion of technology transfer in high-level discussions about the SDGs is an encouraging step, so far it seems to have been insufficient. The aforementioned failure of ACT-A to galvanize widespread sharing of COVID-19 mitigation technologies is a clear example of this (Haugen, 2021). However, part of the TFM is the online 2030 Connect system, which aims to create a pool of openly accessible information as well as to connect growing businesses with support systems (Brougham, n.d.). This is a long-term initiative, so it is too early to judge its effectiveness. Over time, such efforts may help to change the global culture around IPR.

Technology transfer is important, especially for urgent matters such as climate change. However, long-term, developing country actors must be involved directly in research and development. Merely opening access to intellectual property is insufficient without building up domestic capacity to adopt and adapt technologies (Chang, 2011; Archibugi and Filippetti, 2015). Encouraging and funding domestic innovation systems to put in place the necessary physical and institutional infrastructure would give developing countries the chance to act more independently and reduce their reliance on foreign technology in the long run (Sanders et al., 2018).

This is especially important given that research funded by developed countries often does not prioritize developing country needs. For example, internationally funded health research generally neglects tropical diseases that primarily affect developing countries (United Nations Development Programme (UNDP), 2001; Baker et al., 2017). Likewise, little research is devoted to vaccines for malaria and tuberculosis, despite their prevalence. Firms do not see much profit potential in their development due to the relative poverty of the countries most affected by these diseases (Archibugi and Filippetti, 2015). This all suggests the need for a fundamental *cultural* shift at the global level. Rather than granting supremacy to IPR as the sole motivator of innovation, we must instead reframe knowledge production and dissemination as an important development tool and prioritize its usage for the promotion of human wellbeing.

6. National- and Regional-Level Patent Reforms

Though international agreements influence the way patenting is handled, patents are ultimately processed through national and regional offices. Recognizing the limitations of patent systems, some alternative forms of compensation have been suggested for national and regional policymakers to consider. A more centralized system by which people can sell patent rights would allow them to profit off of their intellectual property and makes it easier for firms and other inventors to access new ideas and technologies that could lead to future innovation (United Nations Development Programme (UNDP), 2001; Hagiu and Yoffie, 2013).

Governments could also consider direct financing for future research or tax credits as means of compensation for innovation that do not require monopolies (Baker et al., 2017; Cheng and Parra-Lancourt, 2020). Recognizing the outsize returns to society, governments already fund research at public institutions and subsidize private research. With such funding, the understanding must be that the resulting knowledge stays in the public domain. This is especially pertinent in light of the role of intellectual property protections in restricting COVID-19 vaccine access. Much of the research that produced the vaccines was publicly funded, but pharmaceutical companies have still been allowed to hoard that knowledge, allegedly to allow them to recoup development costs (Institute of New Economic Thinking (INET) Commission on Global Economic Transformation, 2021). They have thus been doubly rewarded, first via advance purchase commitments and public funding, then via profits from later sales (Oxfam International, 2021).

There are many examples where cutting edge knowledge stays in the public domain. A major contributor to the rise of the digital economy has been the availability of open source platforms for software applications (such as Apache Hadoop, Nginx, and Github), accessed by digital and non-digital firms at zero cost. For example, Github, an open source repository of software, application programs and

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

tools, allows firms or developers to access and customize programs and tools without substantial investment of time and money (International Labor Organization, 2021). These mechanisms accelerate innovation (Gawer, 2014).

Many leading IT companies collaborate with open source platforms. This allows them to improve their public relations, gain legitimacy, and to learn and align with the latest innovations in their field (Lerner and Tirole, 2005). Microsoft collaborates with the Apache Software Foundation and makes products and innovations available through this volunteer community of developers. Google opened up its Android patents, Tesla announced that it will not initiate patent lawsuits against anyone who in good faith wants to use its technology, and the National Aeronautics and Space Administration has made hundreds of patents available (Hard, 2014; Buck, 2015; Lunden, 2015). "Knowledge commons" systems are similar, promoting the free sharing of ideas under the principle that knowledge is a common good. Under this system, there are less tangible incentives that motivate people to innovate and share their work beyond direct monetary compensation, such as increased opportunity for collaboration and demonstrating skill sets that may be useful for obtaining employment (Benkler, 2010; Baker et al., 2017).

Another way to improve the system of patents is to tighten and streamline regulations, making them fit for purpose for current times. National and regional patent offices can raise the standards of originality and practical utility, which would decrease the number of patents overall, awarding them only to those innovations that genuinely merit a temporary monopoly (Bessen and Meurer, 2009). This would require proper funding and staffing for patent offices, which has dwindled or simply is not available in many jurisdictions. It would also be prudent to solicit input from experts in the field to help patent officers assess the merits of complex innovations (Henry and Stiglitz, 2010). This can prevent overly broad patents, which keep vital technologies out of reach of developing countries.

Given the diversity in type and scale of patentable innovations, another option is to base the length of patent protection on the complexity of the concept or technology being patented, rather than using a default 20-year timeline (Lester and Zhu, 2018). This reform could use time-to-market as a proxy for the costs and risks involved in development (Roin, 2013; Cheng and Parra-Lancourt, 2020). This would help to ensure that the patent system serves its intended purpose of rewarding initial investments in research and development without resorting to excessively long timelines that concentrate wealth and technical knowledge within a few firms and countries (Cheng and Parra-Lancourt, 2020). Compensatory liability is another system which ensures that patent holders are adequately compensated without restricting access to innovations. Under such a system, patent holders receive monetary compensation when others use their intellectual property but are not allowed to prevent follow-on innovation from that knowledge (Baker et al., 2017).

The reforms proposed in this section are important for combatting rampant anti-competitive practices and promoting the emergence of new firms in frontier technology sectors. However, on their own, they would mainly impact those countries that already produce large numbers of patents. Reforms such as those proposed in the previous section, along with investments in domestic innovation systems as called for by the SDGs, are necessary in order to address global-level inequalities. Enhancing access is important, but this must be paired with efforts to remove other barriers to innovation, such as funding and education.

7. Beyond Patent Reform

Given the complexity of innovation systems, patent reforms are a necessary but insufficient solution. The very structure of the global economy is inequitable, with some countries routinely relegated to exporting raw materials and importing goods and services. We continue to see the devastating effects of this system as COVID-19 rages across the developing world. This should serve as a cautionary tale for the 4IR. Rather than treating access to knowledge as a zero-sum game, we must change the global culture of technological development to promote knowledge sharing, follow-on innovation, and the fostering of domestic capacity. This should not only entail easier access to patentable knowledge, but also to related know-how, clinical trial data, and trade secrets. Reforms should be forward-looking and aim to facilitate the production of knowledge within developing countries.

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

8. Conclusion

Technological inequality is a rising cause of concern for people as they reflect on the insecurity in their lives. Ensuring access to the latest technologies, including the COVID-19 vaccine, will require concerted effort by international organizations and national governments, and significant outreach efforts. Fair and equitable access is not a given, as discussed. Beyond access, it is important to bridge the global divide in technological progress where some countries are pushing the frontier, while others are not participating in any significant way.

Acknowledgments. The authors would like to thank Hoi Wai Jackie Cheng for his insightful comments on this article, and Serge Kapto for his suggestion of *Data & Policy* as a journal to which we could submit this work. The views expressed herein are those of the author and do not necessarily reflect the views of the United Nations.

Funding statement. This research received no specific grant from any funding agency, commercial or not-for-profit sectors.

Competing interest. The authors declare no competing interests exist.

Author contribution. A.B.: Data collection and analysis, writing about data sources, global and national policy, and editing. S.N.: Conceptualization, writing about patent alternatives and critiques from the literature, and editing.

Data availability statement. The data that support the findings of this study are openly available from the following sources: WIPO PATENTSCOPE Database (https://patentscope.wipo.int/search/en/structuredSearch.jsf); World Bank DataBank (https://databank.worldbank.org/source/world-development-indicators/preview/on); and OECD Data Warehouse (https://www.oecd-ilibrary.org/science-and-technology/data/oecd-patent-statistics/patents-by-main-technology-and-by-international-patent-classification-ipc_data-00508-en).

References

Alimkhan A, **Makhambayev A and Ukaegbu IA** (2019) The Fourth Industrial Revolution: Towards energy 4.0 in Kazakhstan. In *2019 21st International Conference on Advanced Communication Technology (ICACT)*, February 17–20, 2019. PyeongChang, Korea (South): IEEE.

Allred BB and Park WG (2007) Patent rights and innovative activity: Evidence from national and firm-level data. *Journal of International Business Studies 38*(6), 878–900.

Archibugi D and Filippetti A (2015) Knowledge as global public good. In Archibugi D and Filippetti A (eds), *The Handbook of Global Science, Technology and Innovation*. Oxford: Wiley, pp. 479–503.

Baker D, **Jayadev A and Stiglitz J** (2017) Innovation, intellectual property, and development: A better set of approaches for the 21st century. CEPR. Available at https://cepr.net/report/innovation-intellectual-property-and-development-a-better-set-of-approaches-for-the-21st-century/ (accessed 08 August 2022).

Benkler Y (2010) The idea of access to knowledge and the information commons: Long-term trends and basic elements. In Kapczynski A and Krikorian G (eds), *Access to Knowledge in the Age of Intellectual Property.* New York: Zone Books, pp. 217–236.

Bessen J and Hunt RM (2007) An empirical look at software patents. *Journal of Economics & Management Strategy 16*(1), 157–189.

Bessen J and Meurer MJ (2009) *Patent Failure: How Judges, Bureaucrats, and Lawyers Put Innovators at Risk*. Princeton: Princeton University Press.

Bessen JE and Meurer MJ (2012) The direct costs from NPE disputes. *Cornell Law Review 99*(2), 387–424.

Brougham J (n.d.) Research shines a light on "under the radar" innovation in low income countries. Social Sciences Division. Available at https://www.socsci.ox.ac.uk/research-shines-a-light-on-under-the-radar-innovation-in-low-income-countries (accessed 16 February 2023).

Buck J (2015) NASA offers licenses of patented technologies to start-up companies. NASA. Available at https://www.nasa.gov/press-release/nasa-offers-licenses-of-patented-technologies-to-start-up-companies (accessed 08 August 2022).

Challu PM (1995) Effects of the monopolistic patenting of medicine in Italy since 1978. *International Journal of Technology Management 10*(2/3), 237–251.

Chang H-J (2002) *Kicking Away the Ladder: Development Strategy in Historical Perspective*. London: Anthem.

Chang H-J (2011) Institutions and economic development: Theory, policy and history. *Journal of Institutional Economics 7*(4), 473–498.

Cheng HWJ and Parra-Lancourt M (2020) The Fourth Industrial Revolution, development and intellectual property: The world economic and social survey 2018 and beyond. In Heath C, Moerland A and Sanders AK (eds), *Intellectual Property Law and the Fourth Industrial Revolution*. Wolters Kluwer.

Chien CV (2012) Reforming software patents. *Houston Law Review 50*(2), 325–390.

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

Cockburn IM and MacGarvie MJ (2011) Entry and patenting in the software industry. *Management Science 57*(5), 915–933.

Cox FD (2017) *Democracy and Inequality: A Resource Guide*. Stockholm: International IDEA.

David PA (2010) Koyaanisqatsi in cyberspace: The economics of an "out-of-balance" regime of private property rights in data and information. In Reichman JH and Maskus KE (eds), *International Public Goods and Transfer of Technology under a Globalized Intellectual Property Regime*, 79–120. Cambridge: Cambridge University Press.

Flaherty B (2019) Federally funded research drives nearly one-third of U.S. patents, report finds. *STAT News.* Available at https://www.statnews.com/2019/06/20/federal-finding-research-patents/ (accessed 08 August 2022).

Foster-McGregor N, **Nomaler Ö and Verspagen B** (2019) Measuring the creation and adoption of new technologies using trade and patent data. United Nations Industrial Development Organization (UNIDO). Available at https://www.unido.org/publications/measuring-creation-and-adoption-new-technologies-using-trade-and-patent-data (accessed 08 August 2022).

Freedom House (2019) Democracy in retreat. Freedom House. Available at https://freedomhouse.org/report/freedom-world/2019/democracy-retreat (accessed 08 August 2022).

Fu X, **Pietrobelli C and Soete L** (2011) The role of foreign technology and indigenous innovation in the emerging economies: Technological change and catching-up. *World Development 39*(7), 1204–1212.

Gawer A (2014) Bridging differing perspectives on technological platforms: Toward an integrative framework. *Research Policy 43* (7), 1239–1249.

Gebrekidan S and Apuzzo M (2021) Rich countries signed away a chance to vaccinate the world. *The New York Times*, March 21, 2021. Available at https://www.nytimes.com/2021/03/21/world/vaccine-patents-us-eu.html (accessed 08 August 2022).

Goedhart NS, **Broerse JE**, **Kattow R and Dedding C** (2019) 'Just having a computer doesn't make sense': The digital divide from the perspective of mothers with a low socio-economic position. *New Media & Society 21*(11–12), 2347–2365.

Goldman E (2013) Fixing software patents. Santa Clara Law Digital Commons. Available at https://digitalcommons.law.scu.edu/cgi/viewcontent.cgi?article=1597&context=facpubs (accessed 08 August 2022).

Gratton É (2002) Should patent protection be considered for computer software-related innovations? *Computer Law Review and Technology Journal 7*, 223.

Green A (2022) Can a 'watered-down' TRIPS waiver still matter? *Devex*, May 25, 2022. Available at https://www.devex.com/news/can-a-watered-down-trips-waiver-still-matter-103334 (accessed 08 August 2022).

Gruszczynski L and Wu C-h (2021) Between the high ideals and reality: Managing COVID-19 vaccine nationalism. *European Journal of Risk Regulation 12*, 1–9.

Hagiu A and Yoffie DB (2013) The new patent intermediaries: Platforms, defensive aggregators, and super-aggregators. *Journal of Economic Perspectives 27*(1), 45–66.

Hall BH, **Helmers C and von Graevenitz G** (2015) Technology entry in the presence of patent thickets. *National Bureau of Economic Research Working Paper 21455.* https://doi.org/10.3386/w21455.

Hard A (2014) Tesla opens up technology patents. Digital Trends. Available at https://www.digitaltrends.com/cars/good-guy-elon-musk-opens-teslas-patents-gives-free-access-technology/ (accessed 08 August 2022).

Haugen HM (2021) Does TRIPS (agreement on trade-related aspects of intellectual property rights) prevent COVID-19 vaccines as a global public good? *Journal of World Intellectual Property 24*(3–4), 195–220. https://doi.org/10.1111/jwip.12187.

Henry C and Stiglitz JE (2010) Intellectual property, dissemination of innovation and sustainable development. *Global Policy 1* (3), 237–251.

HISTORY (2007) Steve Jobs debuts the iPhone. HISTORY. Available at https://www.history.com/this-day-in-history/steve-jobs-debuts-the-iphone (accessed 08 August 2022).

Hourihan M (2020) Public research investments and patenting: An evidence review. American Association for the Advancement of Science. Available at https://www.aaas.org/sites/default/files/2020-05/AAAS%20Public%20Research%20and%20Patenting%20FINAL.pdf (accessed 08 August 2022).

Institute of New Economic Thinking (INET) Commission on Global Economic Transformation (2021) The pandemic and the economic crisis: A global agenda for urgent action. Available at https://www.ineteconomics.org/research/research-papers/the-pandemic-and-the-economic-crisis-a-global-agenda-for-urgent-action.

International Labor Organization (2021) World employment and social outlook: The role of digital labour platforms in transforming the world of work. International Labor Organization. Available at https://www.ilo.org/wcmsp5/groups/public/—dgreports/—dcomm/—publ/documents/publication/wcms_771749.pdf (accessed 08 August 2022).

Jaffe AB and Stavins RN (1995) Dynamic incentives of environmental regulations: The effects of alternative policy instruments on technology diffusion. *Journal of Environmental Economics and Management 29*, S-43–S-63.

Kotabe M (1992) A comparative study of US and Japanese patent systems. *Journal of International Business Studies 23*(1), 147–168.

Krishnan V (2022) The power imbalance undermining global health. *The Atlantic*, July 18, 2022. Available at https://www.theatlantic.com/international/archive/2022/07/covid-trips-agreement-vaccines-global-health/670551/ (accessed 08 August 2022).

Kumar N (2003) Intellectual property rights, technology and economic development: Experiences of Asian countries. *Economic and Political Weekly 38*, 209–226.

Lanjouw JO and Cockburn IM (2001) New pills for poor people? Empirical evidence after GATT. *World Development 29*(2), 265–289.

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

Lerner J and Tirole J (2005) The economics of technology sharing: Open source and beyond. *Journal of Economic Perspectives 19*(2), 99–120.

Lester S and Zhu H (2018) Rethinking the length of patent terms. *American University International Law Review 34*, 787.

Levin RC, **Klevorick AK**, **Nelson RR and Winter SG** (1987) Appropriating the returns from industrial research and development. Brookings Papers on Economic Activity. Available at https://www.brookings.edu/wp-content/uploads/1987/12/1987c_bpea_levin_klevorick_nelson_winter_gilbert_griliches.pdf.

Lunden I (2015) Google offers to give away patents to startups in its push against patent trolls. TechCrunch. Available at https://techcrunch.com/2015/07/23/google-offers-to-sell-patents-to-startups-to-boost-its-wider-cross-licensing-initiative/ (accessed 08 August 2022).

Mandaviya M (2023) India plans to use its G20 presidency to build consensus on global health resilience. The World Economic Forum. Available at https://www.weforum.org/agenda/2023/02/india-g20-presidency-consensus-global-health-resilience/ (accessed 08 August 2022).

Mann L and Berry M (2016) Understanding the political motivations that shape Rwanda's emergent developmental state. *New Political Economy 21*(1), 119–144.

McMahon A (2021) Global equitable access to vaccines, medicines and diagnostics for COVID-19: The role of patents as private governance. *Journal of Medical Ethics 47*(3), 142–148.

Menell PS (1994) The challenges of reforming intellectual property protection for computer software. *Columbia Law Review 94*(8), 2644–2654.

Monicken H (2022) TRIPS waiver compromise delivered to WTO members ahead of MC12. *Inside U.S. Trade*, May 3, 2022. Available at https://insidetrade.com/daily-news/trips-waiver-compromise-delivered-wto-members-ahead-mc12 (accessed 08 August 2022).

Moon S (2008) "Does TRIPS Art. 66.2 encourage technology transfer to LDCs?" An analysis of country submissions to the TRIPS council (1999–2007). UNCTAD-ICTSD Policy Brief. Geneva. Available at: https://unctad.org/system/files/official-document/iprs_pb20092_en.pdf.

Moon S (2011) Meaningful technology transfer to the LDCs: A proposal for a monitoring mechanism for TRIPS article 66.2 ICTSD. Available at https://www.files.ethz.ch/isn/138434/technology-transfer-to-the-ldcs.pdf (accessed 08 August 2022).

Moser P (2013) Patents and innovation: Evidence from economic history. *Journal of Economic Perspectives 27*(1), 23–44.

Mueller B (2023) After long delay, Moderna pays N.I.H. for covid vaccine technique. *The New York Times*, February 23, 2023. Available at https://www.nytimes.com/2023/02/23/science/moderna-covid-vaccine-patent-nih.html (accessed 08 August 2022).

Nicholas T (2011) Independent invention during the rise of the corporate economy in Britain and Japan 1. *Economic History Review 64*(3), 995–1023.

OECD (2009) *Patents as statistical indicators of science and technology, In OECD Patent Statistics Manual*, OECD Publishing, Paris. https://doi.org/10.1787/9789264056442-3-en.

OECD (2021) OECD.Stat. Available at https://stats.oecd.org/viewhtml.aspx?datasetcode=PATS_IPC&lang=en# (accessed 08 August 2022).

Oxfam International (2021) Pfizer, BioNTech and Moderna making $1,000 profit every second while world's poorest countries remain largely unvaccinated. Oxfam International. November 16, 2021. Available at https://www.oxfam.org/en/press-releases/pfizer-biontech-and-moderna-making-1000-profit-every-second-while-worlds-poorest (accessed 08 August 2022).

Peng MW (2017) An institution-based view of global IPR history. *Journal of International Business Studies 48*(7), 893–907.

Prabhala A, **Jayadev A and Baker D** (2020) Opinion | Want vaccines fast? Suspend intellectual property rights. *The New York Times*, December 7, 2020. Available at https://www.nytimes.com/2020/12/07/opinion/covid-vaccines-patents.html (accessed 08 August 2022).

Robbins R (2023) How a drug company made $114 billion by gaming the U.S. patent system. *The New York Times*, January 28, 2023. Available at https://www.nytimes.com/2023/01/28/business/humira-abbvie-monopoly.html?searchResultPosition=2 (accessed 08 August 2022).

Robinson L, **Schulz J**, **Blank G**, **Ragnedda M**, **Ono H**, **Hogan B**, **Mesch G**, **Cotten SR**, **Kretchmer SB and Hale TM** (2020) Digital inequalities 2.0: Legacy inequalities in the information age. *First Monday 27*(7).

Roin BN (2005) The disclosure function of the patent system (or lack thereof). *Harvard Law Review.*

Roin BN (2013) The case for tailoring patent awards based on time-to-market. *UCLA Law Review 61*, 672.

Sakakibara M and Branstetter L (2001) Do stronger patents induce more innovation? Evidence from the 1988 Japanese patent law reforms. *RAND Journal of Economics 32*(1), 77–100.

Sanders K, **Anselm TF**, **Haider A**, **Jambeck J**, **LaPointe C**, **Vickers C and Ziebarth N** (2018) World economic and social survey 2018: Frontier technologies for sustainable development. Available at https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/WESS2018_full_web.pdf.

Scherer FM and Weisburst S (1995) Strengthening the patent protection in Italy. Ph.D. thesis, Harvard University.

Spence M, **Stiglitz JE and Ghosh J** (2021) Avoiding a K-shaped global recovery by Michael Spence, Joseph E. Stiglitz and Jayati Ghosh. Project Syndicate. Available at https://www.project-syndicate.org/commentary/global-economy-avoiding-k-shaped-recovery-by-michael-spence-et-al-2021-03 (accessed 08 August 2022).

Sweet CM and Maggio DSE (2015) Do stronger intellectual property rights increase innovation? *World Development 66*, 665–677.

Torrisi S, **Gambardella A**, **Giuri P**, **Harhoff D**, **Hoisl K and Mariani M** (2016) Used, blocking and sleeping patents: Empirical evidence from a large-scale inventor survey. *Research Policy 45*(7), 1374–1385.

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press

UNCTAD (2021) Catching technological waves: Innovation with equity. Technology and Innovation Report 2021. New York. Available at https://unctad.org/publication/technology-and-innovation-report-2021.

UNDESA (2011) The great green technological transformation. World economic and social Survey 2011.

United Nations Development Programme (UNDP) (2001) Human development report 2001: Making new technologies work for human development. Available at https://hdr.undp.org/content/human-development-report-2001.

United Nations Development Programme (UNDP) (2019) Human development report 2019: Beyond income, beyond averages, beyond today: Inequalities in human development in the 21st century. Available at https://hdr.undp.org/content/human-development-report-2019. (accessed 08 August 2022).

United Nations Development Programme (UNDP) (2022) The SDGs in action. Available at https://www.undp.org/sustainable-development-goals?gclid=Cj0KCQiAorKfBhC0ARIsAHDzsltxJJg7RKnTmhMuXwYBJlObicjYjyLurWA2MwEHcjv2wp9e9LZmjVcaAm3tEALw_wcB (accessed 08 August 2022).

United Nations Economist Network (2020) Shaping the trends of our time: Report of the UN Economist Network for the UN 75th anniversary. New York. Available at https://digitallibrary.un.org/record/3884187?ln=en.

von Graevenitz G, **Wagner S and Harhoff D** (2013) Incidence and growth of patent thickets: The impact of technological opportunities and complexity. *Journal of Industrial Economics 61*(3), 521–563.

World Intellectual Property Organization (WIPO) (2022) Global Innovation Index 2022: What is the future of innovation driven growth? Available at https://www.wipo.int/edocs/pubdocs/en/wipo-pub-2000-2022-en-main-report-global-innovation-index-2022-15th-edition.pdf (accessed 08 August 2022).

Zaman K (2013) The TRIPS patent protection provisions and their effects on transferring climate change technologies to LDCs and poor developing countries: A critical appraisal. *Asian Journal of International Law 3*(1), 137–161.

Appendix

Data sources

There are numerous resources for data on patent applications. National and regional offices such as the United States Patent and Trademark Office (USPTO) and European Patent Office (EPO) have their own databases with different information on patent applications and grants. There are also international databases that bring together information about patents filed at national and regional offices and through the Patent Cooperation Treaty (PCT) process. We focused mainly on the World Intellectual Property Organization (WIPO) PATENTSCOPE database, the World Bank DataBank, and the Organization for Economic Co-operation and Development (OECD) OECD.Stat Data Warehouse.

The PATENTSCOPE database includes detailed information about patents filed via PCT as well as those filed at select national and regional offices. This database allows for sophisticated searches by keyword, applicant characteristics, IPC code, and date, among other fields. The World Bank's World Development Indicators, accessed via the organization's DataBank, includes the number of patent applications by residents of each country over several decades. This information comes from WIPO's Intellectual Property Statistics Data Center and employs an "equivalent counts" method, in which patents that have multiple applicants from the same country are counted more than once (one count for each resident on the patent application). The data are not disaggregated along any axis other than the year of the patent application. Finally, the OECD Data Warehouse includes the number of triadic patents (defined as those filed at the USPTO, EPO, and Japanese Patent Office (JPO)) for the last several decades. These data are drawn from the EPO's PATSTAT database. Users can filter data by applicant or inventor country of residence, type of technology or IPC code, and year.

Note that due to a combination of administrative processing time, backlogs, and lags in data availability, reliable patent data are not immediately available (OECD, 2009). According to OECD, the data for triadic patents by technology are only complete through 2016 (OECD, 2021). Given that the dataset starts in the year 2005, we opted to divide the data into three equal time chunks of 2005–2008, 2009–2012, and 2013–2016.

Cite this article: Bostrom A and Nayyar S (2023). Fit for purpose? The patents regime, the Fourth Industrial Revolution, and sustainable development. *Data & Policy*, 5: e18. doi:10.1017/dap.2023.17

https://doi.org/10.1017/dap.2023.17 Published online by Cambridge University Press