

Invention and Global Diffusion of Technologies for Climate Change Adaptation: A Patent Analysis

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Table of Contents

Acknowledgments	5
Abbreviations	5
Key Insights	6
1. Introduction	8
2. Data Issues	10
3. Invention of Technologies for Climate Change Adaptation	18
4. International Technology Transfer	22
5. Patenting Activity in Relation to Climate Hazards	29
6. Conclusion and Policy Implications	34
Appendix A: Supplementary Tables and Figures	36
Appendix B: Regressions	49
Appendix C: Construction of the Five Hazard Indicators	51
Endnotes	52
References	53
Figures	
Figure 2.1 Country-Specific Climate Hazard and Adaptive Capacity Levels, 1995–2015.....	13
Figure 3.1 Climate Adaptation Innovation, as Measured by High-Value Patents, 1995–2015 ..	18
Figure 3.2 Innovation for Climate Change Adaptation, as a Share of Total Innovation, 1995–2015.....	20
Figure 4.1 Technology Transfer Rates, by Invention Type, 2010–15	22
Figure 4.2 Trends in Climate Adaptation Technology Transfer as a Share of Invented Adaptation Technologies, 1995–2015.....	24
Figure 4.3 Transfer Rates of Climate Change Adaptation Technology, by Field, 2010–15.....	25
Figure 4.4 Number of FDI Deals in Climate Change Adaptation Technologies, 2000–15.....	27
Figure 5.1 Relationship between Adaptation Technology Invention and Climate Hazards in High- and Middle-Income Countries, 2010–15.....	29
Figure 5.2 Relationship between Climate Hazards and Adaptation Technology Inventions (as a Share of All Technology) in High- and Middle-Income Countries, 2010–15.....	30
Figure 5.3 Relationship between Climate Hazards and Imports of Climate Change Adaptation Technologies in High- and Middle-Income Countries, 2010–15.....	31
Figure 5.4 Correlation between Availability of Adaptation Technologies and Climate Hazard Levels in High- and Middle-Income Countries 2010–15	33
Figure A.1 Climate Change Mitigation Innovation, as a Share of Total Innovation, 1995–2015	37

Figure A.2	Relationship between Climate Adaptation Technology Invention and Climate Hazards, Middle-Income Countries, 2010–15 Annual Average	40
Figure A.3	Relationship between Climate Adaptation Technology Imports and Climate Hazards, Middle-Income Countries, 2010–15 Annual Average	41
Figure A.4	Correlation between Number of Adaptation Inventions and Climate Hazard Levels in High- and Middle-Income Countries, 2010–15	42
Figure A.5	Correlation between Number of Imported Adaptation Inventions and Climate Hazard Levels in High- and Middle-Income Countries, 2010–15	43

Tables

Table 2.1	Technology Fields of Y02A Patents included in the Study.....	13
Table 2.2	Definitions and Data Sources of the Five Hazard Indicators	16
Table 3.1	Average Annual Growth of Innovation in Different Fields, as Measured by High-Value Patents, 1995–2015	19
Table 3.2	Top 10 Inventor Countries in Climate Change Adaptation Technologies, 2010–15...	21
Table 4.1	Average Number of Patent Offices Where Internationally Patented Inventions Are Filed, by Technology Type, 2010–15.....	23
Table 4.2	Distribution between Country Income Groups of Patented Inventions of Technologies for Climate Change Adaptation, 2010–15.....	26
Table 4.3	Flow of FDI Deals in Climate Change Adaptation Technologies between Country Income Groups, 2010–15	27
Table 4.4	Top Acquirers and Importers of Climate Adaptation Technologies among Low- or Middle-Income Countries, 1995–2015	28
Table A.1	Top 10 Inventor Countries in Climate Change Mitigation Technologies, 2010–15 ...	36
Table A.2	Top 10 Inventor Countries in Climate Change Adaptation Technologies, by Sector, 2010–15	37
Table A.3	Transfer between Country Income Groups of Patented Technologies for Climate Change Adaptation and Mitigation, 2010–15.....	38
Table A.4	Top 10 Importing Countries of Climate Change Adaptation Technologies, 1995–2015.....	38
Table A.5	Top 15 Acquirer Countries in FDI Deals Related to Climate Change Adaptation Technologies 1995–2015.....	39
Table A.6	Economies and Income Groups Included in the Study	44
Table B.1	Relationship between Domestic Innovation and Climate Hazard Levels, Population, and Stock of Patented Inventions	50
Table B.2	Relationship between Technology Imports and Climate Hazard levels, Population, Stock of Patented Inventions, and Trade Barriers.....	50

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Abbreviations

EPO	European Patent Office
FDI	foreign direct investment
IP	intellectual property
IPCC	Intergovernmental Panel on Climate Change
PATSTAT	World Patent Statistical Database (EPO)
R&D	research and development
Y02A	technologies for adaptation to climate change (PATSTAT classification)

Key Insights

Many people will adapt to climate change by changing their behavior, perhaps by moving to a new location or changing their occupation. They will also rely on technologies that increase resilience to climate risks and extremes, such as new irrigation systems, advanced weather forecasting tools, and more-resilient crop varieties. The extent to which such technologies are developed and globally available will significantly shape the “new normal” of life—if not sheer survival, for millions—in adapting to climate change. To better grasp the current state and future needs within this sphere, this report relies on patent data to describe and analyze innovation activity in technologies for climate change adaptation.

The analysis looks at the pace of innovation; identifies which countries lead and how technologies for climate change adaptation diffuse across countries (international technology transfer); compares trends in adaptation innovation with those in other technology fields; and relates these trends to adaptation needs. Importantly, the reliance on patent data restricts the scope of the analysis to solutions for adaptation that are at the technological frontier and ignores the role of nontechnological forms of innovation and low-tech options.

The main findings of the report, summarized below, not only provide the first global snapshot of climate-adaptive technological innovation but also point toward the policy implications of current weaknesses in technology transfer.

Invention for adaptation relative to mitigation.

Globally, the number of patented inventions in technologies for climate change adaptation increased steadily between 1995 and 2015. However, this increase in absolute terms does not correspond to a *proportional* rise in innovation for climate adaptation. When considering the total number of inventions across all technologies in all fields, the share of climate adaptation inventions in 2015 was roughly the same as in 1995. This stagnation of research and development (R&D) efforts toward *adaptation* stands in sharp contrast to the trend for climate change *mitigation* technologies, whose share in total innovation (including non-climate-related) nearly doubled during the same period.

Concentration of innovation in climate change adaptation.

Technological innovation to adapt to climate change is concentrated within a limited number of countries. China, Germany, Japan, the Republic of Korea, and the United States together account for nearly two-thirds of all high-value inventions (inventions seeking patents in more than one country) filed globally between 2010 and 2015.

International diffusion of patented inventions.

This concentration of innovation activity could in principle be compensated by international technology transfer from the innovating countries. However, the data reveal limited international technology diffusion through the patent system. Few adaptation inventions are transferred across borders relative to climate change mitigation technologies and non-climate-related innovations. The international diffusion of adaptation technologies related to agriculture and coastal and river protection is particularly low. Whether this pattern reveals that technologies for adaptation are less applicable outside the innovating country than other technologies or that higher barriers exist to their international diffusion is an open question.

Cross-border transfers.

Cross-border transfers of patented inventions for climate change adaptation predominantly occur between a small group of countries consisting of high-income economies and China (85 percent of global technological flows).

Knowledge transfer to low-income countries.

There is virtually no transfer of patented knowledge to low-income countries. If any, access to technologies for climate change adaptation occurs outside the patent system. However, this situation is not specific to adaptation technologies. The innovation literature has shown that these countries mainly rely on low-tech solutions and organizational innovations.

Mismatch between countries' adaptation needs and technological capacity.

Innovation and technology diffusion do not seem to be driven by adaptation needs but by the level of recipient countries' technological absorptive capacities. This could be bad news for adaptation to climate change because countries with strong technological capacities typically face lower adaptation needs at present. The mismatch between adaptation needs and technology availability is particularly serious concerning technologies for mitigating temperature increases.

Ability of market forces to meet local adaptation needs.

Economic forces thus seem currently unable to transform local adaptation needs into market demand for patented adaptation technologies. Solving this problem and creating the right incentives for adaptation technologies to spread where they are urgently needed requires a better understanding of the market failures that hinder demand, which is a precondition for designing demand-pull policies in this domain.

1 Introduction

The Earth's climate has already begun to change and will inevitably continue to do so. Even if the targets set in the Paris Agreement are met—to keep the global surface temperature increase below 2 degrees Celsius relative to preindustrial levels—many regions will still suffer severely from the consequences of climate change. They will have more frequent extreme weather events, changes in precipitation patterns, rising sea levels, temperature increases, and many other related effects (IPCC 2018).

In this context, technology is certainly a major tool to increase societies' ability to adapt to the adverse effects of climate change (Klein and Tol 1997; Miao 2017; GCA 2019). International technology transfer hence becomes particularly important because a large fraction of the innovation activity in today's knowledge-based economy takes place in the Global North, while technologies for climate change adaptation are urgently needed in low- and middle-income countries, which are particularly vulnerable to climate shocks (Fankhauser and McDermott 2014)

Increasing the availability of technology in vulnerable countries requires knowledge of the current geography of innovation. To that end, this report uses patent data to describe and quantify the invention and global diffusion of technologies for climate change adaptation over recent decades based on a global patent database. Importantly, relying on patent data restricts the scope of the analysis to solutions for adaptation that are at the technological frontier and excludes the role of nontechnological forms of innovation and low-tech options. A particular emphasis is put on the case of low- and middle-income countries, which combine high vulnerability to climate change with low technological resources.

The analysis relies on patent data from the World Patent Statistical Database (PATSTAT), maintained by the European Patent Office (EPO), which covers the population of patents filed worldwide. We use the EPO's new "YO2A" category to identify all patents in PATSTAT pertaining to "technologies for adaptation to climate change." The classification was released in April 2018 and has so far never been used in empirical analyses. Although innovation scholars and analysts widely use patent data to map technology fields, such data do have some drawbacks, as the report discusses. The patent data are thus complemented with data on foreign direct investment (FDI), which allow us to test the robustness of the results on technology transfer.

The literature on the economics of climate-related innovation has focused on mitigation technologies.¹ In contrast, few papers so far have analyzed innovation in technologies for *adaptation* to climate change with an empirical approach (Popp 2019). As in this report, Conway et al. (2015) use a global patent dataset to describe innovation activity and international technology. However, those authors deal only with water-related technologies, while we consider a much larger set of countries and technology fields.

Other papers adopt a different perspective by examining drivers of innovation. Miao and Popp (2014) empirically estimate the impact of historical extreme events (earthquakes, floods, and droughts) on innovation activity in three corresponding risk-mitigating technologies (quakeproof buildings, flood control, and drought-resistant crops). They use patent data from up to 28 countries and find evidence that natural disasters increase risk-mitigating innovations, with a magnitude that differs across types of disaster and technology. Using a similar approach, Hongxiu (2017) and Hu et al. (2018) also observe that past extreme climatic events induced an increase in the number of risk-mitigating technological innovations.

The rest of this report proceeds as follows:

- *Section 2, "Data Issues,"* describes our dataset and essential data issues, emphasizing the strengths and weaknesses of patent data to measure innovation and technology diffusion.
- *Section 3, "Invention of Technologies for Climate Change Adaptation,"* presents a first set of results showing how global innovative activity in technologies for climate change adaptation has developed over time and space.
- *Section 4, "International Technology Transfer,"* covers the international transfer of adaptation technologies. The latter two subsections relate our findings to results from studies using similar data that have looked at innovation and transfer of climate change mitigation technologies (for example, Dechezleprêtre et al. 2011).
- *Section 5, "Patenting Activity in Relation to Climate Hazards,"* examines the relationship between technology and adaptation needs.
- *Section 6, "Conclusion and Policy Implications,"* summarizes the findings and three important policy implications that follow from them.

2 Data Issues

Patents as Indicators of Innovation and Technology Transfer

Patents are commonly used to measure technological innovation and diffusion. For instance, Dechezleprêtre et al. (2011) adopt a similar approach to examine climate change mitigation technologies.

To understand the indicators used below, it is useful to briefly describe how the patent system works. When an individual or organization discovers a new technology, they decide where to market this invention and how to deter imitation by potential competitors. Patenting is a legal way to achieve this, because a patent in a particular country confers the exclusive right to make, use, and sell the protected invention in that country for a maximum period of 20 years. Accordingly, an inventor who plans to market an invention in a particular jurisdiction will patent it there. A set of patents protecting the same invention is called a patent “family.” Most patent families include only one country (often the home country of the inventor, particularly for large countries).

A wealth of information is available on patent documents and therefore in the global PATSTAT database. The present study mostly exploits information on the country where the inventor is located, the set of countries in which each invention is patented, the date of the first patent filing within a patent family, and the invention’s technological area. The level of inventive activity is measured by the number of patent families; in other words, the set of countries in which each invention is patented indicates technology transfer from the inventor’s home country to foreign countries. Many articles use this approach to infer innovative activity and international technology diffusion from patent data (Dechezleprêtre et al. 2011; Eaton and Kortum 1996).

Using patent data to measure innovation is useful for several reasons:

- First, compared with other frequently used proxies, patent data measure the *output* of the innovation process, while alternative indicators (such as R&D expenditure or the number of researchers employed) measure *inputs* into this process.
- Second, patent data provide not only detailed, disaggregated information on the technology itself but also on many characteristics of its development, such as place of invention, date of filing, names of the inventor and applicant, and sector.
- Third, to be considered for patent protection, an invention needs to be marketable—that is, it should potentially have an industrial application. Thus, a patent indicates that an inventor expects some economic benefits from the invention.

Because filing a patent is costly (around €30,000 for a European patent), we can safely assume that patents are filed only in places (countries) where inventors see a significant probability that the technology will generate some economic returns. A large fraction of the most economically

significant innovations in recent years have been patented (Aghion et al. 2016). In a study focusing on Sweden, Svensson (2012) showed that about 61 percent of all patents filed were for commercialized patented technologies. Morgan, Kruytbosch, and Kannankutty (2001) and Griliches (1990) found that, respectively, 47 percent and 55 percent of all patented technologies are commercialized in the United States.

However, using patent-related data to measure innovation and technology transfer also features several drawbacks. To start with, inventors may employ alternative methods to protect their innovation—in particular, industrial secrecy or lead-time advantages (Cohen, Nelson, and Walsh 2000). As a result, patents are filed only in countries where intellectual property (IP) protection is sufficiently strong. Otherwise, the inventor may prefer to rely on industrial secrecy or simply to market the innovation without legal protection.

These alternative strategies are especially relevant in the context of technology transfer between countries. This is a potentially important limitation for this study because many of the most vulnerable countries also weakly enforce IP rights. The data show few patents in low-income countries. Whether this indicates a measurement problem or low availability of technology is difficult to establish solely with patent data. However, other indicators clearly plead in favor of the second hypothesis. For instance, the median enrollment ratios for tertiary education—a proxy for scientific (and technology) knowledge production—are 6 percent, 28 percent, and 60 percent in the low-income, middle-income, and high-income country groups, respectively (UN DESA 2018). Bernardes and Albuquerque (2003) point out that low-income countries produce far fewer scientific publications than other country income groups. We also test the robustness of the findings with FDI statistics, which show patterns of lower FDI in low-income countries.

Another difficulty is that the propensity to patent differs between sectors, depending on the nature of the technology (Cohen, Nelson, and Walsh 2000). We mitigate these issues by looking primarily at the share of a country's total patent filings that concern technologies for climate change adaptation. This thus accounts for differences in the local enforcement of IP rights and in the propensity to patent across countries, which should apply equally to patents in all technology fields, including adaptation technologies. We also concentrate on time trends, which are immune to this problem if heterogeneities in patenting propensity vary weakly over time.

The value of individual patents is also heterogeneous, including across patent offices. For example, inventions filed at the Chinese Patent Office are known to have a lower unit value than inventions filed at the EPO or at the United States Patent and Trademark Office (Boeing and Mueller 2015, 2016). This leads us to restrict parts of our analysis to high-value patented inventions, defined as inventions for which protection has been sought in more than one country.² Although this is a common solution to the problem of heterogeneity, an alternative option could be to track patent renewal, or the number of times a patent is cited by subsequent patents. However, the geographical scope of the analysis prevents the use of these indicators. Moreover, no global data are available to apply this solution. In particular, there are nearly no data on patent offices in low- and middle-income countries.

The Y02A Classification

As noted earlier, we use PATSTAT as the main database for our analysis. The data, issued biannually by the EPO, include more than 66 million patents that have been filed in 169 national or regional patent offices.

In April 2018, the EPO introduced a new classification for patents related to “technologies for adaptation to climate change” (Y02A). Patents classified in this category protect “technologies that allow adapting to the adverse effects of climate change in human, industrial (including agriculture and livestock) and economic activities”,³ which corresponds closely to the UNFCCC (2005) definition of adaptation technologies. Importantly, this classification covers all patent offices included in PATSTAT and was applied retrospectively to all patent applications (not only to new patent filings), ensuring full coverage across space and time.

Adaptation patents are divided into six subcategories, covering the main fields of innovation in technologies for climate change adaptation (table 2.1):

- *Coastal and river protection* covers “technologies for adaptation to climate change at coastal zones and river basins,” including technologies for devices that protect homes from flooding, as well as early warning systems.
- *Water management* consists of technologies concerned with “water conservation, efficient water supply, and efficient water use.”
- *Infrastructure* covers technologies that aim at “adapting or protecting infrastructure (e.g., transport and energy systems) or their operation.”
- *Agriculture* includes “adaptation technologies in agriculture, forestry, livestock, or agroalimentary production.”
- *Health* subsumes all technologies concerned with the “adaptation to climate change in human health protection.”
- *Indirect adaptation* refers to “technologies having an indirect contribution to adaptation to climate change” such as climate simulation tools, weather forecasting, and weather surveillance systems.

Notably, the technology categories are structured by the economic sector affected, not by climatic threat. Each category is further divided into multiple items. As an illustration, the “coastal and river protection” subcategory includes 36 items. This classification focuses on highly relevant adaptation technologies. However, keep in mind that adaptation also relies on technologies that are not adaptation-specific, such as basic water treatment.

Table 2.1 Technology Fields of Y02A Patents included in the Study

Category	Description	Examples
Coastal and river protection	Technologies for adaptation to climate change at coastal zones and river basins	Dikes; dams; artificial reefs; groynes; real-time flood forecasting
Water management	Technologies related to water conservation, efficient water supply, and efficient water use	Water desalination methods; saltwater intrusion barriers; water filtration systems
Infrastructure	Technologies for adapting or protecting infrastructure or their operation	Floating houses; thermal insulation technologies; passive air cooling
Agriculture	Technologies for adaption to climate change in agriculture, forestry, livestock or agroalimentary production	Windbreaks; greenhouse technologies; irrigation systems; plants tolerant to drought, heat, salinity
Health	Technologies for adaptation to climate change in human health protection	Malaria medical treatment; catalytic converters to control pollutant emission controls
Indirect adaptation	Technologies making an indirect contribution to climate change adaptation	Climate simulation; radar-based weather surveillance; real-time meteorological measurement

Source: “Technologies for Adaptation to Climate Change,” Cooperative Patent Classification Subclass Y02A, European Patent Office (EPO).

Note: Y02A is a patent classification within the EPO’s [World Patent Statistical Database \(PATSTAT\)](https://worldwide.espacenet.com/classification?locale=en_EP#!/CPC=Y02A) for technologies enabling adaptation to climate change. For the full classification, see https://worldwide.espacenet.com/classification?locale=en_EP#!/CPC=Y02A.

In evaluating the quality of the Y02A classification, we looked at both inclusion and exclusion errors. First, we checked that all technologies for climate change adaptation listed in a major report on the topic by the United Nations Framework Convention on Climate Change (UNFCCC 2006) were also present in the Y02A classification. Second, to determine whether irrelevant patents had been classified as adaptation technologies, we selected a random sample of 100 patents. For each of these patents, we examined the complete description of the technology, its title, and abstract in PATSTAT. We then checked the relevance of this technology as an “adaptation to climate change” technology by comparing it with the descriptions of technologies listed in UNFCCC (2006). We found that a high number of patents in this random sample (89 percent) were indisputably related to adaptation to climate change as described by the UNFCCC, providing reassurance as to the quality of the Y02A tagging scheme.

The fact remains that the boundary between adaptation and nonadaptation technologies is blurry. Most of the solutions that promote economic development also facilitate adaptation to climate shocks. Our solution here was to rely on lists by well-established institutions.

The full PATSTAT dataset includes all patents filed from 1995 to 2015. This includes 19 million inventions, of which more than 121,000 deal with adaptation. Adaptation inventions thus represent 0.6 percent of all patented inventions in the sample.

As a benchmark, we also considered the patents for climate change mitigation technologies, which are covered by another classification.⁴ The mitigation category is considerably larger (960,187 patents). Note that a patented invention can be classified simultaneously as adaptation and mitigation technology. This is the case for 28 percent (29,019) of all adaptation patents in our sample. An example is a coastal protection system equipped with a wind turbine to pump seawater and store energy and that also includes a desalination station.

To compare developments in climate change adaptation technologies with general trends in patented inventions, we built a benchmark for each technology field. We first selected all International Patent Classification (IPC) codes corresponding to adaptation patents, by technology field. Next, we extracted the first four characters of each IPC code, and those with the largest number of observations, until we covered at least 70 percent of the patents in that field and retained all patents with four matching characters in their IPC codes.

Foreign Direct Investment Data

To challenge the patent-based results, we extracted information on FDI deals for the period 1995–2015 from the Zephyr database provided by Brussels-based business publisher Bureau Van Dijk.⁵ The objective was to identify foreign investments that could lead to adaptation technology transfers. To identify these deals, we adapted the methodology used in Dussaux, Dechezleprêtre, and Glachant (2018) and foreign direct investments (FDI) and applied it to adaptation technologies, as follows:

1. We first selected acquiring firms that have patented at least one adaptation patent in the country where the target firm is located. Using the Y02A PATSTAT classification, we could identify every firm that filed an adaptation patent in a country. We extracted all observations with pairs (applicant firm, application country) specific to adaptation patents and matched these adaptation pairs with the Zephyr database. By doing so, we only retained deals where the acquiring firm had filed at least one adaptation patent in the target country.
2. Second, we used information on target firms' industrial activity. Using the NACE Rev. 2 classification,⁶ we identified activities with a potential link to adaptation technologies. We matched the selection of NACE codes linked with technologies for climate change adaptation with the industrial activity NACE code of the target firm to only retain target firms in adaptation-related sectors. To identify transfers across countries, we restricted our database to foreign deals, defined as deals where the acquirer and the target country are different.

Measuring Climate Risks

To relate the patterns of innovation and technology transfer to the level of climate risk, we needed country-level indicators that measure climate threat. Measuring a country's vulnerability to climate change is not straightforward owing to both conceptual reasons and data constraints. Before presenting the indicators that we developed, it is first necessary to clarify the concepts used to qualify climate change impacts. The Intergovernmental Panel on Climate Change (IPCC) defines climate change "risk" as "[the] probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur" (IPCC 2014). Risk results from the interaction of three factors:

- *Natural hazards* refer to the possible future occurrence of extreme and nonextreme weather and climate events that may have adverse effects on vulnerable and exposed elements.
- *Exposure* refers to the inventory of elements in an area where hazard events may occur: presence of people; livelihoods; infrastructure; or economic, social, or cultural assets in places that could be adversely affected.
- *Vulnerability* refers to the propensity of exposed elements (such as human beings, their livelihoods, and assets) to suffer adverse impacts from hazard events. One of the main vulnerability components is adaptive capacity: "the ability of society and its supporting sectors to adjust to reduce potential damage and to respond to the negative consequences of climate events" (Chen et al. 2015). Access to technology and knowledge is an important component of adaptive capacity. Others are institutional quality, availability of capital, and so on.

For both data and conceptual reasons, the analysis below relies on natural hazard indicators, which are the only unambiguously exogenous factors of climate risk. The degree of vulnerability is influenced by technological capabilities, potentially leading to tautological results: as the size of the losses is influenced by adaptation capacities that include the local availability of technologies, a negative (positive) correlation may simply signal that more (less) innovation increases adaptation capacities. The level of exposure also raises endogeneity concerns (for example, technologies may help people to relocate away from the most-exposed areas) and data availability problems. In contrast, hazards can be measured by physical indicators generated by climate models.

No ready-to-use set of indicators quantifies the level of different hazard types at the country level. We therefore combined multiple data sources. We first chose a typology of hazards similar to that of IPCC (2014). We then slightly amended this typology to facilitate the correspondence with the patent classification.⁷ It includes five threats: sea level rise, temperature extremes, floods, droughts, and storms. (Table 2.2 provides the definition of the corresponding indicators and data sources. Details are provided in appendix C.)

Almost all indexes were computed on projections of future climatic threats, based on the idea that innovation prepares for the future. The only exception is storm risk mitigation, which is based on historical events for data availability reasons. This probably did not affect the results, because historic shocks are strongly positively correlated with future ones.

Table 2.2 Definitions and Data Sources of the Five Hazard Indicators

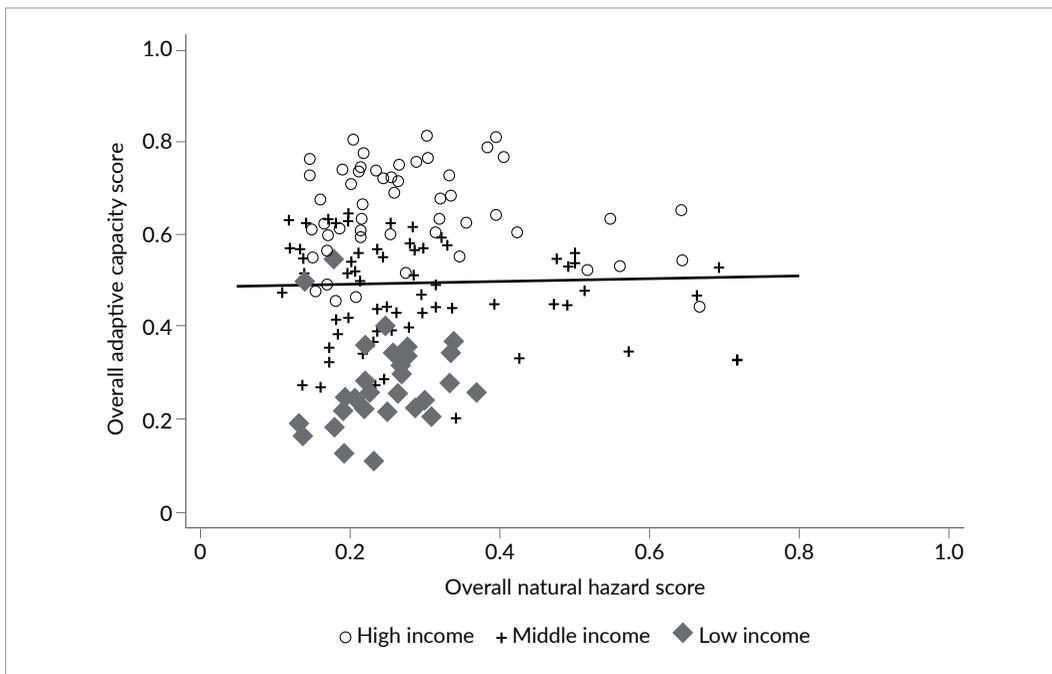
Indicator	Definition	Source
Sea level rise	Proportion of land areas, adjacent to the ocean, that are lower than the sea level rise and the average height of storm surge projected by the end of the century	ND-GAIN
Temperature extremes	Warm spell duration index (WSDI): periods of excessive warmth using a percentile-based threshold calculated for a five-day calendar window; projected for 2040–70 under the RCP4.5 scenario ^a	Climdex
Floods	RX5DAY: monthly maximum precipitation over five consecutive days (mean per year); projected for 2040–70 under the RCP4.5 scenario ^a	Climdex
Drought	Change in annual runoff from the baseline projection to the future projection; projected for 2020–40 under the RCP4.5 emission scenario ^a	Aqueduct
Storms	Historical number of storms per capita for the period 1900–2015	EM-DAT

Note: For details on construction of the five hazard indicators, see appendix C. For the indicators' correlation coefficients, see appendix A, figures A.4 and A.5. Aqueduct = <https://www.wri.org/aqueduct> of the World Resources Institute. Climdex = <https://www.climdex.org/>. EM-DAT = Emergency Events Database of the Centre for Research on the Epidemiology of Disasters. ND-GAIN = University of Notre Dame Global Adaptation Index.

a. RCP4.5 = Representative Concentration Pathway, scenario 4.5, of the Intergovernmental Panel on Climate Change, which refers to a greenhouse gas concentration trajectory for a stabilization scenario (stabilizing radiative forcing at 4.5 W m⁻² in the year 2100 without ever exceeding that value) assuming the imposition of emissions mitigation policies.

In Sections 3 and 4, we relate these indicators to one dimension of a country's adaptive capacity: technology access. To provide an initial, more general view, figure 2.1 plots the average hazard level versus overall adaptive capacity (technology included, but not exclusively) for 177 countries, using data extracted from the University of Notre Dame Global Adaptation Index (ND-GAIN) database.⁸ The hazard index features the arithmetic mean values of the five indicators listed in table 2.2, each being normalized so that they range from 0 to 1.⁹ The graph shows no clear correlation between adaptation capacity and needs, as indicated by a flat regression line. It also splits the countries into three income groups and confirms the observation that low-income countries are highly exposed to projected natural hazards and have low capacities to adapt. This adaptation gap has been frequently reported in the adaptation literature (Barbier and Hochard 2018; Fankhauser and McDermott 2014; Tol 2018).

Figure 2.1 Country-Specific Climate Hazard and Adaptive Capacity Levels, 1995–2015



Sources: University of Notre Dame Global Adaptation Index (ND-GAIN) for the overall adaptive capacity score; and calculations of natural hazards based on the following databases: ND-GAIN; Climdex (<https://www.climdex.org/>); Aqueduct water risk data, World Resources Institute; and the Emergency Events Database (EM-DAT) of the Centre for Research on the Epidemiology of Disasters.

Note: Each point describes an individual country. Country income categories use World Bank-defined classifications. The adaptive capacity index ranges from 0 (low capacity) to 6 (high capacity). The hazard index is the arithmetic means of the five hazard indicators listed in table 2.2, each being normalized so that they range from 0 to 1.

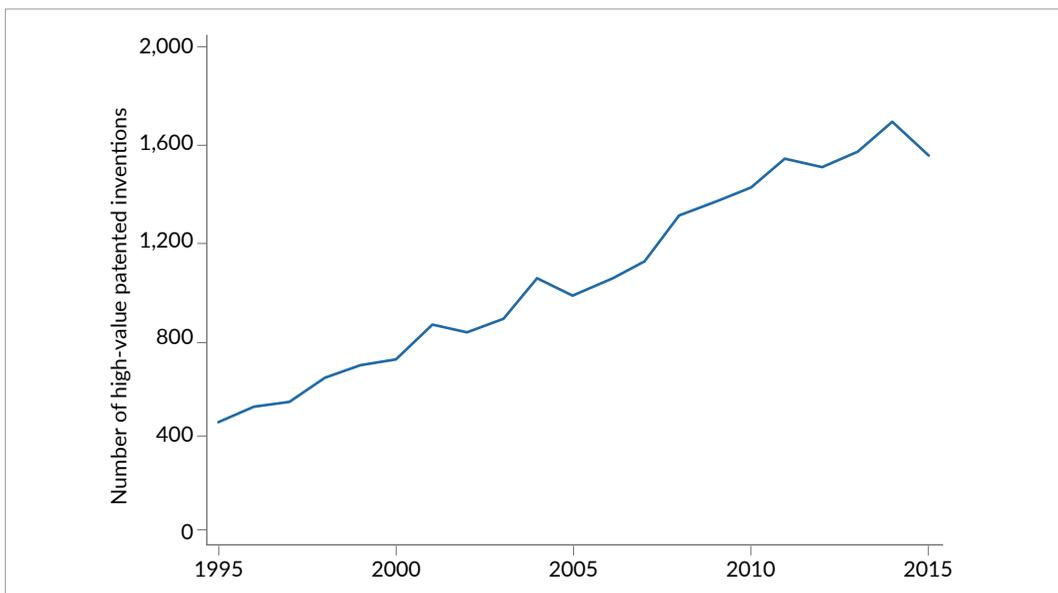
3 Invention of Technologies for Climate Change Adaptation

This section presents the global development and distribution of inventions in climate change technologies for climate change adaptation over the past 20 years.

Growth of Climate Adaptation Innovation

A first look at the data shows a boom in the number of high-value patented inventions (those patented in at least two countries)—a fourfold increase since 1995 (figure 3.1), which corresponds to an impressive 6.7 percent average annual growth rate (table 3.1). Technologies related to flood protection have experienced the highest growth rates by far. However, these numbers must be put in perspective: they are comparable to the average growth rate for all technologies (5.6 percent) but much lower than the 10.9 percent observed for climate change mitigation technologies over the same period (table 3.1).

Figure 3.1 Climate Adaptation Innovation, as Measured by High-Value Patents, 1995–2015



Source: Calculations based on World Patent Statistical Database (PATSTAT) data, European Patent Office.

Note: “High-value” patented inventions are filed in at least two patent offices.

Table 3.1 Average Annual Growth of Innovation in Different Fields, as Measured by High-Value Patents, 1995–2015

Technology field	Average annual growth (%)
All climate change adaptation	6.7
Coastal and river protection	17.0
Water management	8.0
Infrastructure	8.0
Agriculture	5.6
Health	7.6
Indirect adaptation	12.1
All technologies in all fields	5.6
All climate change mitigation	10.9

Source: Calculations based on World Patent Statistical Database (PATSTAT) data, European Patent Office.

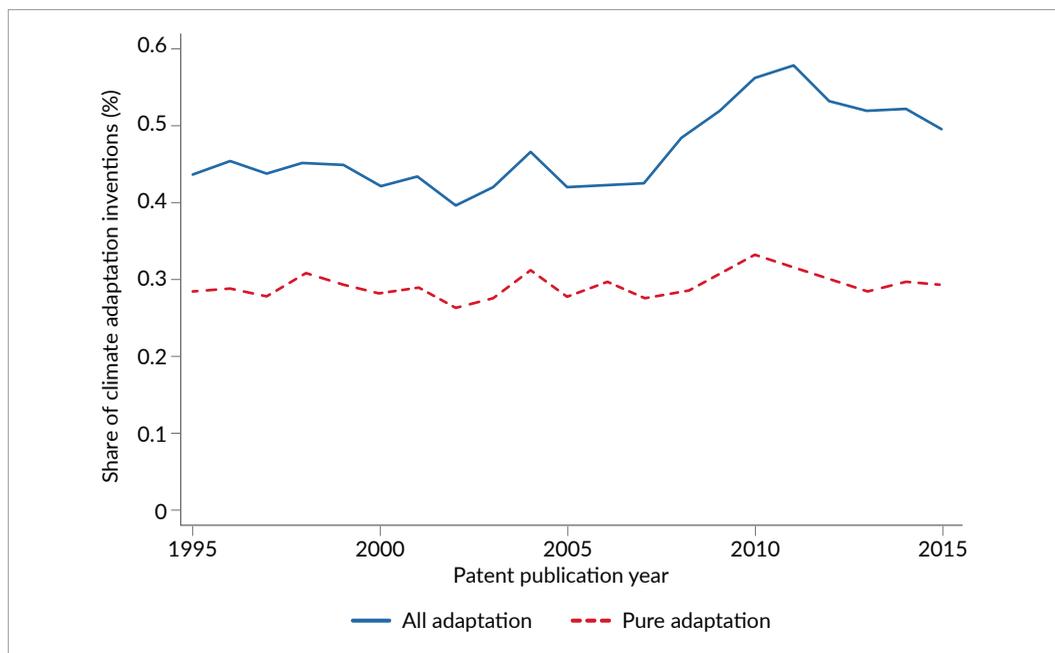
Note: “High-value” patented inventions are filed in at least two patent offices.

It is common knowledge among patent experts that such upward trends are partly driven by an increase in patenting propensity rather than by a genuine increase in innovation. To control for this factor, and to measure the proportion of R&D efforts directed toward climate-adaptation technologies, figure 3.2 shows the share of patented climate adaptation inventions in total patented innovation. Adaptation inventions, represented by the blue line on the graph, averaged around 0.5 percent of global patenting activity annually during 1995–2015, which is arguably low given the challenges associated with future climate change. In particular, it is considerably lower than the share of climate change mitigation patents over 1995–2015, which averaged 5.7 percent of global inventions annually (see appendix A, figure A.1).

More strikingly, this latter percentage has gone down since its peak of about 9 percent in 2012, despite the emerging impact of climate change in many countries. When looking deeper into the data, this reduction appears to mostly concern technology subcategories that facilitate both adaptation to climate change and mitigation of carbon emissions. As noted earlier, more than a quarter of the patents fall into this category. Removing these patents produces a stable percentage (around 0.3 percent of global inventions) throughout the study period (shown by the red line in figure 3.2). This rise and fall in innovation in climate change mitigation technologies over the recent period has been documented in previous studies and has been linked to the evolution of oil prices (Dechezleprêtre et al. 2011).

In sum, we observe a constant rate of innovation activity in pure climate change adaptation technologies since 1995. This is bad news because technological progress does not crowd out other forms of innovation. The growing relevance of climate adaptation technologies has seemingly not led to an increase in the proportion of global innovation efforts to develop patented technologies in that field.

Figure 3.2 Innovation for Climate Change Adaptation, as a Share of Total Innovation, 1995–2015



Source: Calculations, based on World Patent Statistical Database (PATSTAT) data, European Patent Office.

Note: “Pure adaptation” refers to technologies for climate change adaptation that are not simultaneously classified as mitigation technologies.

Geographic Concentration of Climate Adaptation Innovation

Turning next to the geographic distribution, innovation appears highly concentrated: the top five inventor countries (China, Germany, Japan, the Republic of Korea, and the United States) account for more than 60 percent of the world’s innovation activity. The United States is by far the world leader, with nearly one-quarter of all high-value adaptation inventions developed between 2010 and 2015 (table 3.2). However, the rapid growth of innovation in China and Korea is notable. These two countries together produced less than 4 percent of all adaptation inventions in 1995 and increased their shares to 8.9 percent and 7.8 percent, respectively, in 2015.

Such a high geographic concentration is not specific to this technological area. The same top five countries represent 86.5 percent of the world’s total patented inventions in all technologies and 75.8 percent of high-value climate mitigation innovation (appendix A, table A.1).

The fourth column of table 3.2 helps us understand whether these top inventors are “specialized” in adaptation inventions, as defined by the specialization index—the ratio between the share of global adaptation inventions produced by a country and the share of all global inventions produced by that country. The specialization index indicates that the top 10 adaptation technology

inventors are not relatively specialized in inventing adaptation technologies. Nonetheless, it is worth emphasizing that France, the Netherlands, and Sweden are specialized to some extent in adaptation technologies.

The case of China deserves more explanation. We discuss here the number of *high-value* inventions, which excludes inventions patented in a single country. If we consider all inventions, including those filed in a single country, China becomes by far the most active inventor in the field, filing more than 48 percent of all adaptation patents in the world, because most of its inventions are only filed at home. It is well established that China's patenting behavior is an outlier in that inventors there file patents of much lower quality than in other countries (Boeing and Mueller 2019; Prud'homme and Zhang 2017).

Table 3.2 Top 10 Inventor Countries in Climate Change Adaptation Technologies, 2010–15

Rank	Country	Average share of world's high-value adaptation inventions (%) ^a	Specialization index ^b	Country's top three technology fields
1	United States	23.6	1.02	Health, agriculture, indirect adaptation
2	Japan	15.8	0.67	Health, agriculture, water management
3	Germany	10.8	1.01	Health, infrastructure, agriculture
4	Korea, Rep.	7.0	0.88	Health, agriculture, water management
5	China	6.5	0.74	Agriculture, health, water management
6	France	5.8	1.59	Health, agriculture, infrastructure
7	United Kingdom	3.8	1.31	Health, water management, agriculture
8	Sweden	2.1	2.05	Agriculture, health, infrastructure
9	Canada	2.1	1.23	Agriculture, water management, health
10	Netherlands	2.1	1.78	Agriculture, health, infrastructure

Source: Calculations based on World Patent Statistical Database (PATSTAT) data, European Patent Office.

a. "High-value" patented inventions are defined as patents filed in more than one patent office.

b. The "specialization index" is the ratio between the share of global adaptation inventions made by a country and the share of global overall inventions made by that country. A specialization index above 1 indicates that the country represents a higher share of worldwide adaptation inventions than overall inventions and is thus more specialized in adaptation inventions.

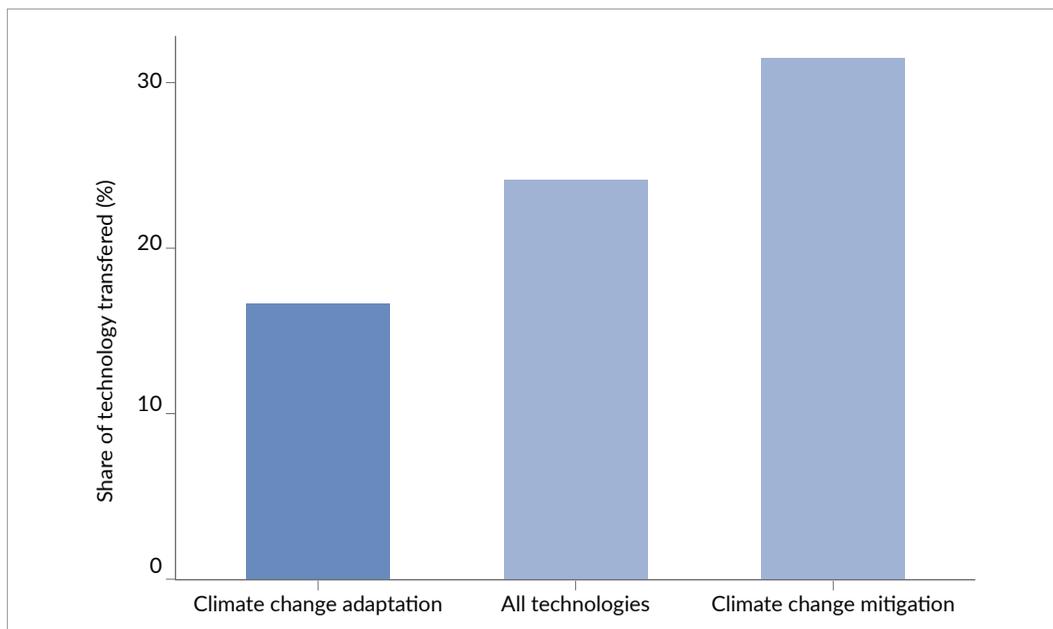
4 International Technology Transfer

Given the high geographic concentration of innovation in adaptation technologies, it is of utmost importance to examine whether such technologies diffuse across borders, in particular toward countries with the highest adaptation needs. What ultimately matters for countries is to access technology, whether or not that technology has been developed in the country. This section describes international diffusion patterns. The next section then considers the correlation between patent activity and climate hazard levels.

Extent of Cross-Border Technology Transfers

A first indicator for measuring international diffusion is the share of patented inventions that are filed in at least two different offices.¹⁰ Figure 4.1 compares these shares for three technology groups: climate change adaptation, climate change mitigation, and all technologies. Only 17 percent of adaptation inventions cross at least one border, which is significantly below the average for all technologies (24 percent) and about half that of mitigation technologies (31 percent).

Figure 4.1 Technology Transfer Rates, by Invention Type, 2010–15



Source: Calculations based on World Patent Statistical Database (PATSTAT) data, European Patent Office.

Note: The technology transfer rate is the share of a country's technology patents that are also filed in at least one other country.

However, those inventions that do cross at least one border are patented in around five patent offices on average, a figure broadly similar to the rates for climate change mitigation technologies and for technology overall (table 4.1). Although this finding should be interpreted with caution, it suggests that the geographical applicability of climate adaptation inventions is not fundamentally different from that of other technologies. It is also in line with the argument that barriers to technology imports (such as trade barriers and stringent local IP rights) in recipient countries are not specific to adaptation technologies. How, then, can we explain the low transfer rate in figure 4.1? A consistent explanation would be that the *average* value of individual adaptation patents is low in relative terms, thereby being less likely to warrant foreign patenting.

Table 4.1 Average Number of Patent Offices Where Internationally Patented Inventions Are Filed, by Technology Type, 2010–15

Technology field	Average number of patent offices ^a
All climate change adaptation	4.88
Coastal and river protection	4.50
Water management	4.54
Infrastructure	4.05
Agriculture	5.46
Health	4.80
Indirect adaptation	5.15
All technologies	4.46
All climate change mitigation	4.51

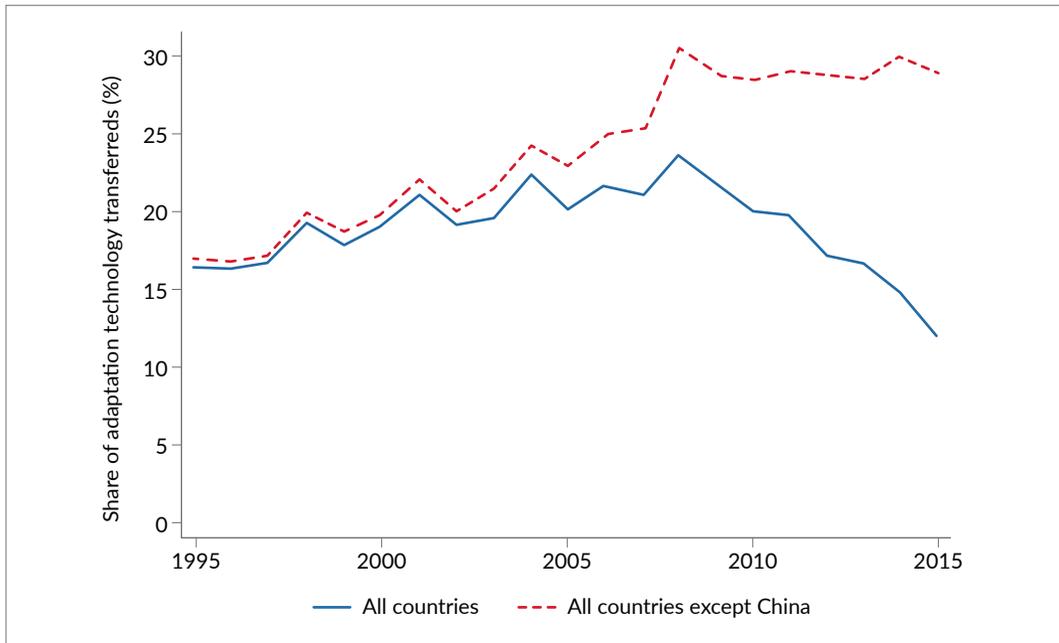
Source: Calculations based on World Patent Statistical Database (PATSTAT) data, European Patent Office.

Note: The table includes only inventions patented in at least two countries.

a. The number of patent offices is the number of offices where an international patent (a patent filed in at least one foreign country) is filed.

The international transfer rate (the share of inventions patented in at least two offices) decreased by half between 2008 and 2015 (figure 4.2). This drastic reduction corresponds to the Chinese patenting boom, which accounts for most domestic patents. However, this too should be interpreted with caution because the boom pertains to all technologies and can thus be observed in all fields. As shown by the dashed line, figure 4.2 indicates no decrease once China is excluded.

Figure 4.2 Trends in Climate Adaptation Technology Transfer as a Share of All Adaptation Technology Inventions, 1995–2015

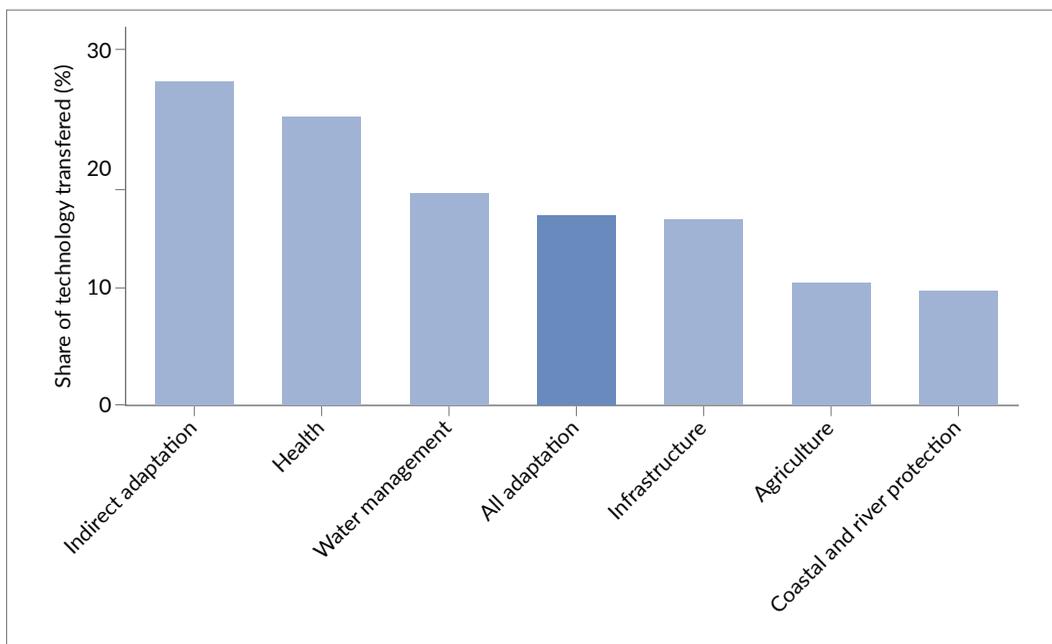


Source: Calculations based on World Patent Statistical Database (PATSTAT) data, European Patent Office.

Note: Technology transfer refers to the share of technology patents filed in more than one country.

This low diffusion rate may be explained by two sets of nonexclusive factors: (a) high barriers to technology transfer (such as tariffs, lax IP enforcement, and limited technological capabilities in potential recipient countries); and (b) lower applicability in the sense that individual innovations are tailored to specific contexts. We return to the interpretation of this result below.

Looking at figure 4.3, we find relatively large differences across sectors. Climate adaptation technologies related to agriculture (10.4 percent) and coastal and river protection (9.7 percent) are transferred less often than the average adaptation technology (16 percent). In contrast, indirect adaptation and health adaptation patents are transferred more regularly, each with more than 24 percent of patented inventions filed in more than one country.

Figure 4.3 Transfer Rates of Climate Change Adaptation Technology, by Field, 2010–15

Source: Calculations based on World Patent Statistical Database (PATSTAT) data, European Patent Office.

Note: The technology transfer rate is the percentage of patents filed in more than one country. “Indirect adaptation” refers to technologies that contribute indirectly to climate change adaptation, such as climate simulation tools, weather forecasting, and weather surveillance systems.

Technology Transfers by Country Income Group

Table 4.2 gives a more detailed view of international technology flows by considering transfers between different income country groups. It also displays the average score for overall technology transfers as a benchmark (within parentheses).

A first notable fact is the overwhelming importance of high-income countries: 93 percent of all exported technologies for climate change adaptation originate from these countries, which also receive 71 percent of all exported inventions. In contrast, low-income countries receive no foreign-patented technologies. As mentioned previously, it could be that foreign inventors protect their technologies transferred toward low-income countries through secrecy (or do not protect them at all).

As for middle-income countries, they receive 28 percent of all adaptation transfers, the vast majority of which come from high-income countries, with China accounting for half of these inward transfers. These flows have sharply increased recently: their share was only 7 percent in 1995. Recall, however, that although China and other middle-income countries have become significant recipients, they export few of their patented technologies.

Table 4.2 Distribution between Country Income Groups of Patented Inventions of Technologies for Climate Change Adaptation, 2010–15 (Percent)

Origin country	Destination country		
	High income	Middle income	Low income
High income	66 (69)	27 (24)	0 (0)
Middle income	5 (7)	1 (<1)	0 (0)
Low income	<0.1 (<0.1)	<0.01 (<0.01)	0 (0)

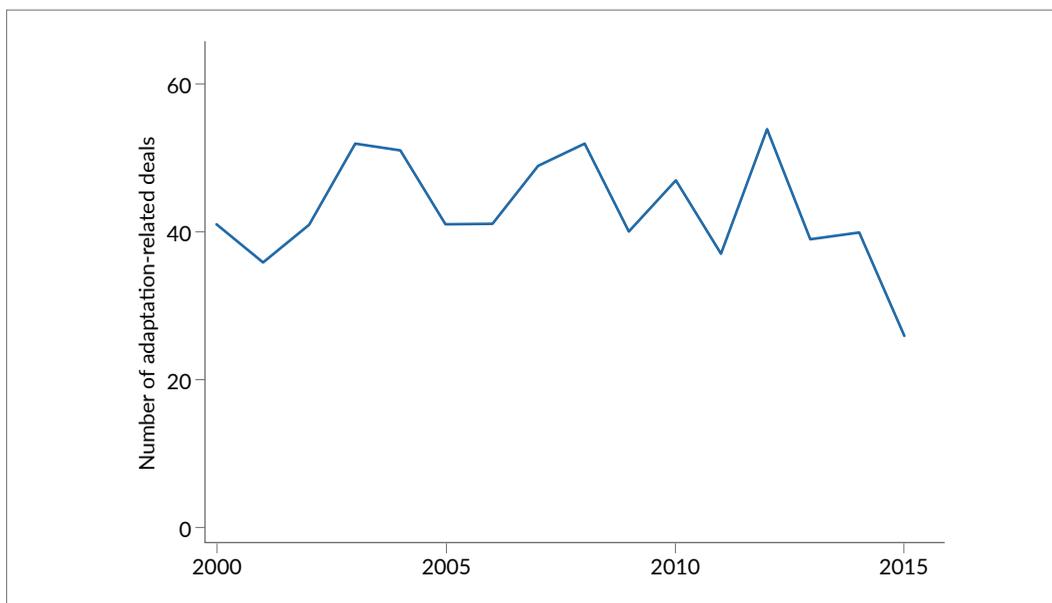
Source: Calculations based on World Patent Statistical Database (PATSTAT) data, European Patent Office.

Note: Distributions are the percentages of patents filed in both an origin country and at least one destination country. Results for all technologies appear in parentheses.

These numbers are comparable with the distribution averages for all technologies (shown within parentheses), except for the slightly higher role of middle-income countries as technology recipients, which is mostly due to China's particularly high rate as a destination for adaptation patents. A comparison between adaptation and mitigation technologies (appendix A, table A.3) shows that they are equally transferred to middle-income countries (28 percent versus 26 percent).

Using FDI Data to Measure Cross-Border Transfers

As explained earlier, the analysis of FDI data provides another approach to quantify cross-country technology flows. The data on adaptation-related FDI deals (described in section 2) confirm the picture drawn from patent statistics. The number of deals varies between 26 and 54 per year (figure 4.4) and shows a high variability, probably driven by the small size of the sample (687 deals). The overall trend, however, is not fundamentally different from that displayed in figure 4.2, which shows the evolution of foreign patenting over the same period.

Figure 4.4 Number of FDI Deals in Climate Change Adaptation Technologies, 2000–15


Sources: Calculations based on Zephyr database, Bureau Van Dijk, Brussels.

Note: N = 687 deals. FDI = foreign direct investment.

Table 4.3 compares the share of FDI adaptation deals with the share of international adaptation patent flows (within parentheses) between different country income groups. Nearly all deals originate from firms based in high-income countries. The concentration of FDI deals is thus even stronger than that indicated by patents.

Table 4.3 Flow of FDI Deals in Climate Change Adaptation Technologies between Country Income Groups, 2010–15 (Percent)

Origin country	Destination country		
	High income	Middle income	Low income
High income	73 (66)	27 (27)	0 (<0.01)
Middle income	0 (5)	0 (1)	0 (0)
Low income	0 (<0.1)	0 (<0.01)	0 (0)

Sources: Calculations based on data from Zephyr database (Bureau Van Dijk, Brussels) and World Patent Statistical Database (PATSTAT) (European Patent Office).

Note: Results for cross-border transfers of climate change adaptation patents appear in parentheses. N = 243 deals. FDI = foreign direct investment.

Finally, table 4.4 displays the nine largest middle-income countries in terms of inward FDI flows for climate change adaptation, compared with their shares of foreign patents in adaptation technologies. Again, the overall picture is the same for both indicators for most countries, except for China, which attracts a higher share of foreign investments than foreign patents.

The case of India deserves particular attention. The absence of Indian patent data in PATSTAT (the only major patent office missing from the database) makes it impossible to measure the contribution of this country to international transfers with this indicator, although FDI data are readily available. Table 4.4 suggests that the country is poorly connected to international technology flows.

Table 4.4 Top Acquirers and Importers of Climate Adaptation Technologies among Middle-Income Countries, 1995–2015

FDI rank	Target country	Share of world adaptation deals received (%)	Share of world adaptation patents imported (%)	Patent rank
1	China	18.8	9.40	1
2	Brazil	2.6	2.89	2
3	India	1.0	—	—
4	South Africa	0.9	1.33	5
5	Turkey	0.6	0.70	6
6	Russian Federation	0.4	1.87	4
7	Peru	0.1	0.18	13
8	Indonesia	0.1	0.11	17
9	Mexico	0.1	2.51	3

Sources: Calculations based on data from Zephyr database (Bureau Van Dijk, Brussels) and World Patent Statistical Database (PATSTAT) (European Patent Office).

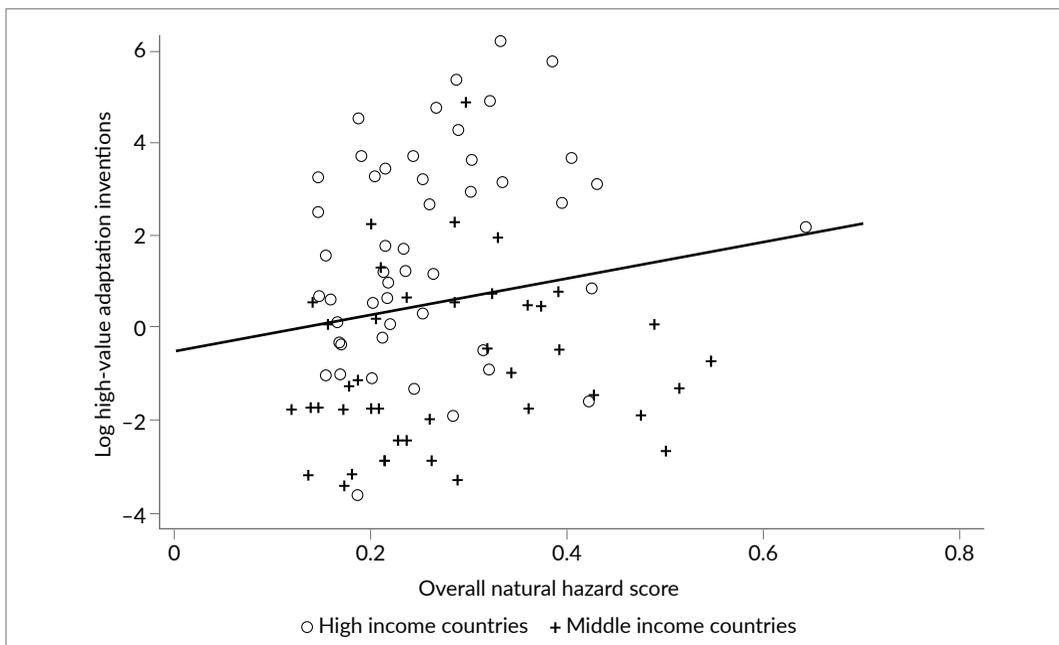
Note: — = not available. FDI = foreign direct investment.

Patenting Activity in Relation to Climate Hazards

5

How do the above patterns of innovation and technological diffusion correspond to countries' needs for climate change adaptation technology? Figure 5.1 shows the relationship between a country's level of patented invention (y-axis) and the average hazard index (x-axis). No clear positive correlation is observed. Focusing on the countries with the highest hazard scores, unsurprisingly, we see that almost all middle-income countries in this group produce little innovation (they are below the regression line), in contrast with highly exposed, high-income countries such as Australia, Japan, Korea, Singapore, and the United States.

Figure 5.1 Relationship between Adaptation Technology Invention and Climate Hazards in High- and Middle-Income Countries, 2010–15



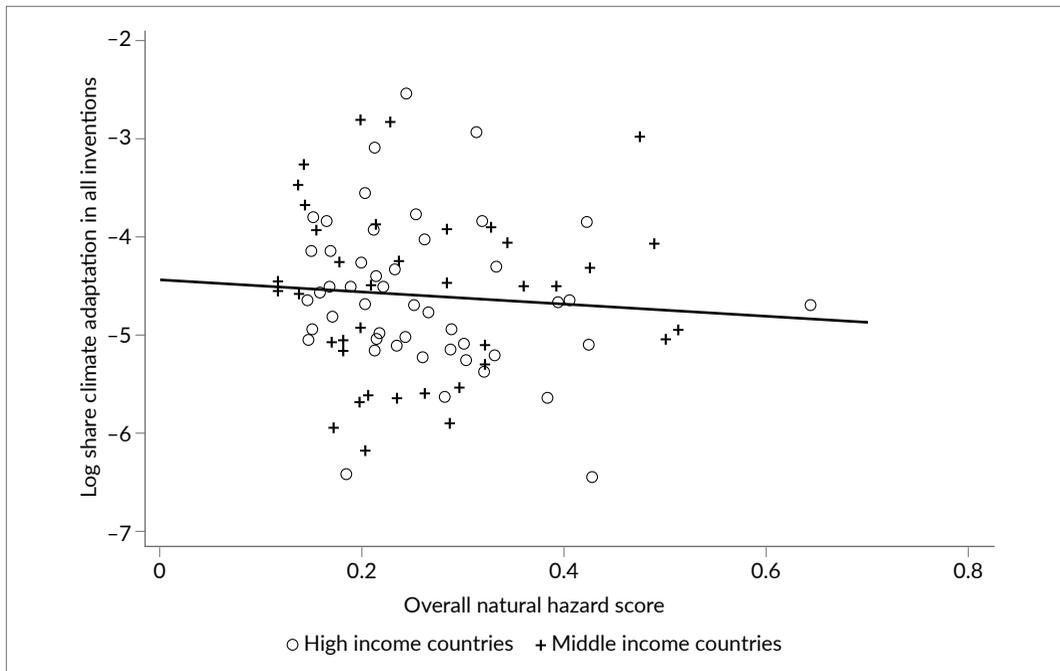
Sources: Calculations based on World Patent Statistical Database (PATSTAT), European Patent Office; University of Notre Dame Global Adaptation Index (ND-GAIN); Climdex indexes (<https://www.climdex.org/>); Aqueduct water risk data, World Resources Institute; and Emergency Events Database (EM-DAT), Centre for Research on the Epidemiology of Disasters.

Note: Each point describes an individual country. Country income categories use World Bank-defined classifications. Low-income countries are excluded for lack of sufficient patent data. The log number of inventions is the 2010–15 annual average. The hazard index is the arithmetic mean of the five hazard indicators listed in table 2.2, each being normalized to range from 0 to 1.

Availability of Adaptation Technology, by Country Income Level

What drives this gap between middle-income and high-income countries? It could simply reflect the differences in general innovative capacity. Figure 5.2 supports this statement, as the gap disappears as soon as innovation for adaptation is expressed as a share of total patents. A quasi-flat regression line however provides no evidence of R&D directed toward adaptation.

Figure 5.2 Relationship between Climate Hazards and Adaptation Technology Inventions (as a Share of All Technology) in High- and Middle-Income Countries, 2010–15

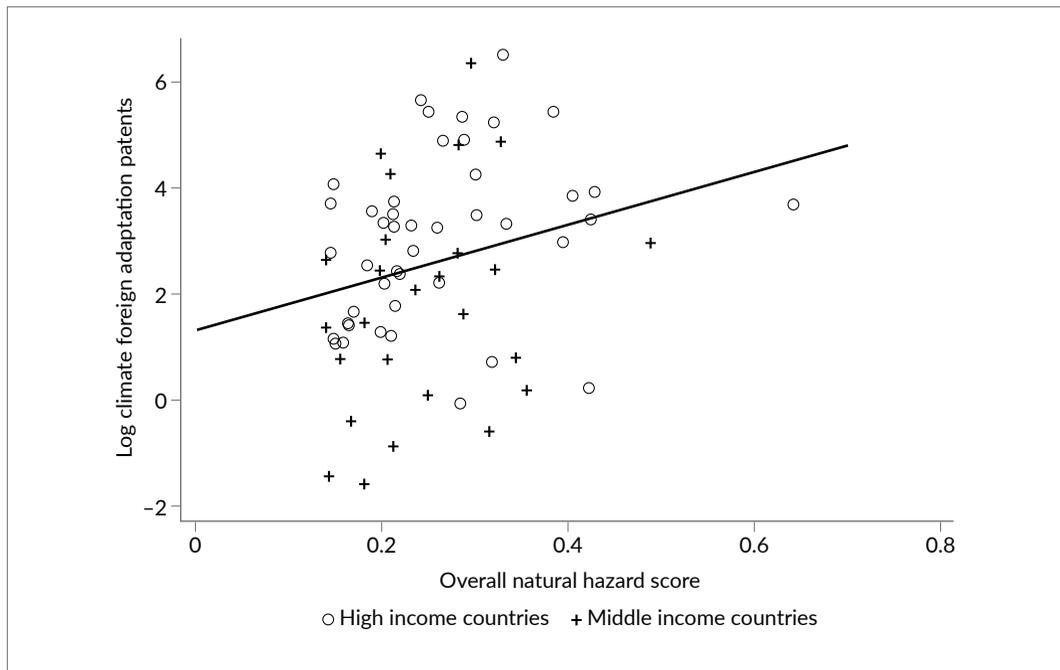


Source: Calculations based on World Patent Statistical Database (PATSTAT), European Patent Office; University of Notre Dame Global Adaptation Index (ND-GAIN); Climdex indexes (<https://www.climdex.org/>); Aqueduct water risk data, World Resources Institute; and Emergency Events Database (EM-DAT), Centre for Research on the Epidemiology of Disasters.

Note: Each point describes an individual country. Country income categories use World Bank-defined classifications. Low-income countries are excluded for lack of sufficient patent data. The vertical axis shows the number of adaptation inventions made in the country as a share of all technology inventions made in this country (2010–15 annual average). The hazard index is the arithmetic means of the five hazard indicators listed in table 2.2, each being normalized so that they range from 0 to 1.

The availability of technologies for adaptation to climate change is not only a matter of domestic innovation. Countries may also benefit from imports of technologies invented abroad. Do inward flows of foreign technologies compensate for this domestic innovation deficit? Probably not. As shown in figure 5.3, the slope of the regression line is not fundamentally steeper than in figure 5.1, but most middle-income countries again remain below the line.¹¹ Importantly, this technology gap is not specific to adaptation technologies: the average share of a country's adaptation inventions in its total number of inventions is roughly the same in high-income countries (0.98 percent) as in middle-income ones (0.92 percent).

Figure 5.3 Relationship between Climate Hazards and Imports of Climate Change Adaptation Technologies in High- and Middle-Income Countries, 2010–15



Sources: Calculations based on World Patent Statistical Database (PATSTAT), European Patent Office; University of Notre Dame Global Adaptation Index (ND-GAIN); Climdex indexes (<https://www.climdex.org/>); Aqueduct water risk data, World Resources Institute; and Emergency Events Database (EM-DAT), Centre for Research on the Epidemiology of Disasters.

Note: Each point describes an individual country. Country income categories use World Bank-defined classifications. Low-income countries are excluded for lack of sufficient patent data. The vertical axis shows the log number of foreign climate change adaptation inventions patented in the country (2010–15 annual average). The hazard index is the arithmetic means of the five hazard indicators listed in table 2.2, each being normalized so that they range from 0 to 1.

Availability of Adaptation Technology, by Climate Hazard Type

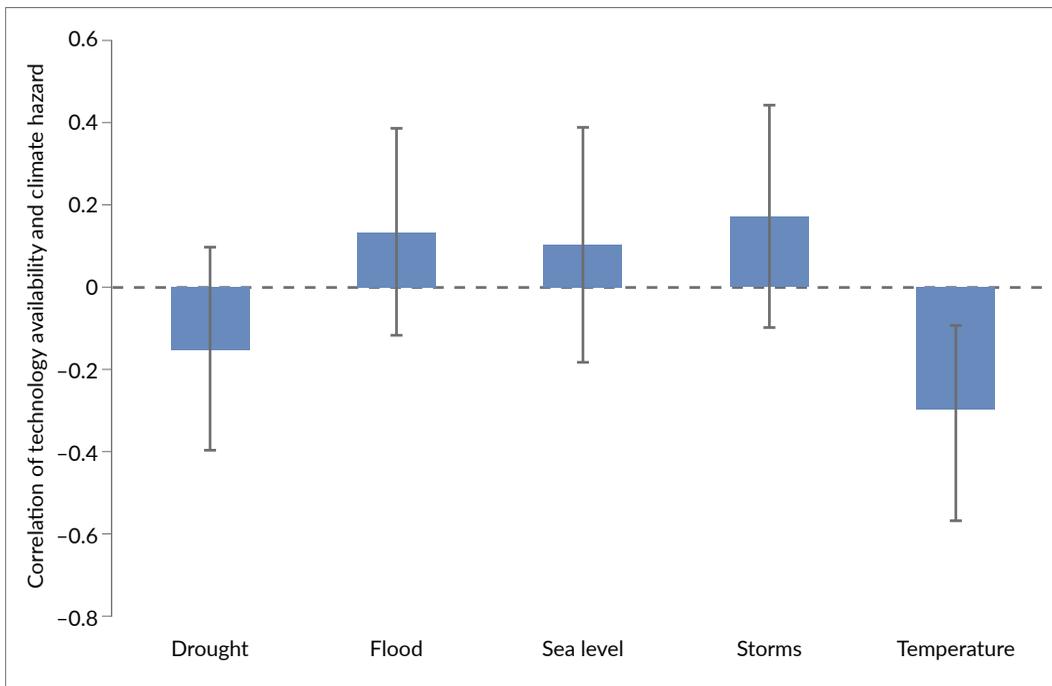
Beyond this general view, the data also allow us to identify the types of hazard with the widest gaps between the need for and access to climate adaptation technology. For each of the five hazard types, figure 5.4 displays the correlation coefficient between technology availability (the sum of high-value domestic inventions and imported patented inventions) and hazard levels in high- and middle-income countries.¹² Recall that a correlation is -1 in case of perfect negative correlation and $+1$ in case of perfect positive correlation.

One hazard type shows significant negative correlation: mitigating impacts from temperature extremes. This mostly concerns pollution reduction technologies, greenhouse technologies, plant varieties adapted to hot environments, aquaculture, and air conditioning technologies. Other correlation coefficients are nonsignificantly different from zero.

These patterns could reflect the influence not only of adaptation needs but also other factors such as a country's technological capabilities. In particular, countries with strong technological capabilities (like China, Japan, western European countries, and the United States) are less exposed to heat waves than countries such as Costa Rica, Ecuador, and Peru, which have low technological capabilities. The access to technologies that mitigate climate change impacts may be driven by the existence of a local demand for these technologies or by the availability of technological capabilities to develop them. The local demand for adaptation technologies can be increased, for instance, by international climate adaptation funding. Because financial issues are the principal barrier to accessing technology in low- and middle-income countries (UNFCCC 2018), these funds are intended to create demand for adaptation solutions in the receiving country.

The OECD climate-related development finance data allow us to access bilateral climate funding dedicated to adaptation projects for the period 2009–15.¹³ However, the geographical distribution of this support cannot explain the differences we observe across sectors. We have also tried to disentangle these factors using a regression approach. However, the data are too limited to obtain robust results. (See appendix B for preliminary results of two simple Poisson regressions).

Figure 5.4 Correlation between Availability of Adaptation Technologies and Climate Hazard Levels in High- and Middle-Income Countries, 2010–15



Sources: Calculations based on World Patent Statistical Database (PATSTAT), European Patent Office; University of Notre Dame Global Adaptation Index (ND-GAIN) indicators; Emergency Events Database (EM-DAT), Centre for Research on the Epidemiology of Disasters; Climdex indexes (<https://www.climdex.org/>); and Aqueduct water risk data, World Resources Institute.

Note: The technology variables are averages for the period 2010–15. “Technology availability” is the sum of high-value adaptation inventions (that is, with patents filed in at least two countries) made by a given country and the patents imported by that country. For details on construction of the five hazard indicators, see appendix C. Vertical black lines represent confidence intervals at the 95 percent level.

6 Conclusion and Policy Implications

This report is the first global analysis of innovation and the international diffusion of technologies for adaptation to climate change to rely on patent data. It draws a clear picture of a technology gap between low- and middle-income countries and high-income countries. With the exception of China, low- and middle-income countries show low patented innovation outcomes and limited access to foreign-protected technologies for adaptation to climate change.

Although the report does not include causal evidence, its analysis suggests that the main driver of this disparity is the weakness of technological capabilities in the developing world—a weakness not specific to adaptation-related technologies. Results also indicate that technological availability and adaptation needs are poorly aligned, particularly regarding technologies for adaptation to temperature increases.

The observed low innovation and technology transfer activity in adaptation technologies toward middle-income countries—and all the more toward low-income countries—falls below that of climate change mitigation technologies. This is both puzzling and problematic.

It is puzzling because, from an economic point of view, climate change mitigation is a pure public good in the sense that it generates benefits for all. In contrast, adaptation benefits are partly private. Hence, from a general economic point of view, it is not obvious that there could be less of a business case for the latter.

It is problematic when it comes to low-income countries because they are already highly exposed to climate change impacts, yet transferring climate mitigation solutions toward these countries is less urgent for the time being because they have low emissions so far. It is true that low-income countries may have a greater need for simple, nontechnological solutions given their current technological capacity. Nevertheless, unless such solutions crowd out other forms of innovation, better technologies can only facilitate adaptation and build up technology-absorptive capacities that will be crucial for their future.

From these observations follow three important policy implications:

- First, technological capacity building is an essential ingredient to narrow the gap. This message is not at all specific to technologies for adaptation to climate change.
- Second, economic forces seem unable to transform local adaptation needs into demand for adaptation technology on the markets. Solving this problem requires a better understanding of the market failures that hinder demand, a precondition for designing demand-pull policies in the relevant sectors (with public investments, subsidies, and other policy tools).
- Third, perhaps less importantly, the data do not suggest that the applicability of individual adaptation inventions to specific national contexts is lower than in other sectors. It follows that relying on foreign technologies is not less relevant than domestic innovation. The promotion of technology transfer should thus be a pillar of the policies implemented in this area.

This work also suggests several avenues for future research. The first and most important one is to conduct sector-specific studies to identify the factors that hinder the functioning of the markets for these patented technologies. This is the level of analysis required to derive sound policy recommendations. The second is to examine the contribution of these technologies to climate change adaptation in the Global South. How crucial are they? How do they relate to low-tech solutions and other forms of innovation? How do economic incentives shape technology adoption? Third, the data used in this study include very disaggregated information that could be exploited to better identify which patents are relevant in a given sector or national context. Combined with country-level technology needs assessments, it could be exploited to prioritize the transfer of the most useful patents. These are the initial elements of a research agenda to increase the contribution of technical progress to climate change adaptation. •

A Appendix A | Supplementary Tables and Figures

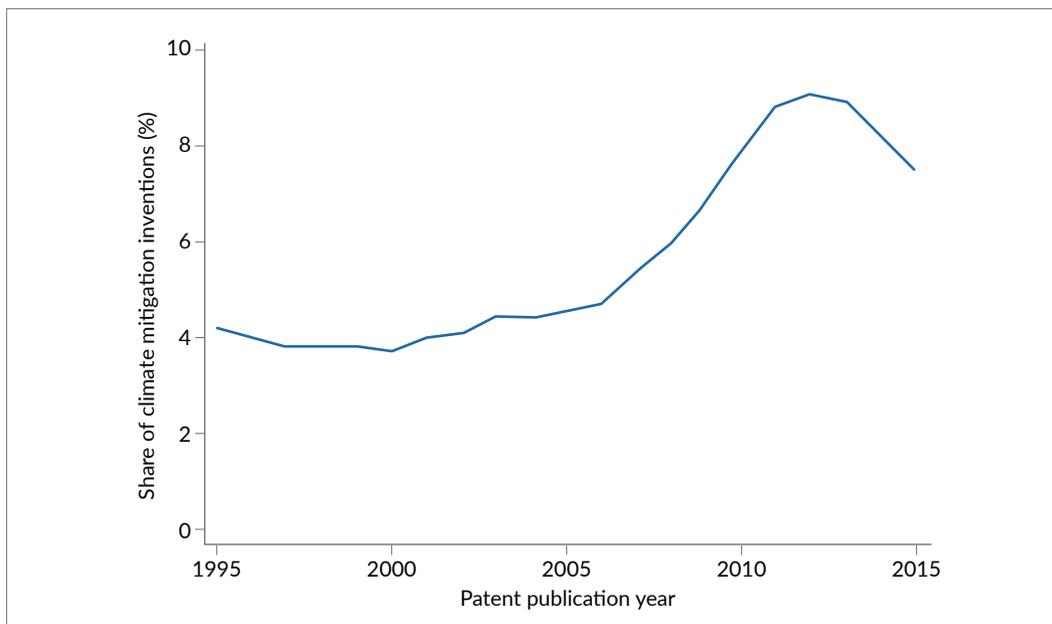
Table A.1 Top 10 Inventor Countries in Climate Change Mitigation Technologies, 2010–15

Rank	Country	Average share of world high-value mitigation inventions (%) ^a	Average share of all world mitigation inventions (%)
1	Japan	25.8	22.9
2	United States	23.0	11.4
3	Germany	12.2	6.6
4	Korea, Rep.	8.4	12.5
5	China	6.4	33.1
6	France	4.7	2.2
7	United Kingdom	3.1	1.3
8	Italy	1.7	0.9
9	Canada	1.6	0.8
10	Sweden	1.2	0.5

Source: Calculations based on World Patent Statistical Database (PATSTAT) data, European Patent Office.

a. “High-value” patented inventions are filed in at least two patent offices.

Figure A.1 Climate Change Mitigation Innovation, as a Share of Total Innovation, 1995–2015



Source: Calculations based on World Patent Statistical Database (PATSTAT) data, European Patent Office.

Table A.2 Top 10 Inventor Countries in Climate Change Adaptation Technologies, by Sector, 2010–15

Rank	Country	Coastal protection	Water management	Infrastructure	Agriculture	Health	Indirect adaptation
1	United States	1	13	11	29	30	17
2	Japan	2	17	15	17	45	5
3	Germany	1	10	18	14	55	3
4	Korea, Rep.	5	18	14	29	30	5
5	China	3	19	18	36	21	4
6	France	1	9	16	22	45	9
7	United Kingdom	1	22	15	23	31	9
8	Sweden	0	9	13	12	60	7
9	Canada	3	21	9	38	20	10
10	Netherlands	2	10	17	51	21	2

Source: Calculations based on World Patent Statistical Database (PATSTAT) data, European Patent Office.

Note: For definitions of each sector, see table 2.1.

Table A.3 Transfer between Country Income Groups of Patented Technologies for Climate Change Adaptation and Mitigation, 2010–15

Origin country	Destination country		
	High income	Middle income	Low income
High income	66 (68)	27 (26)	0 (0)
Middle income	5 (5)	1 (1)	0 (0)
Low income	<0.1 (<0.1)	<0.01 (<0.1)	0 (0)

Source: Calculations based on World Patent Statistical Database (PATSTAT) data, European Patent Office.

Note: Distributions are the percentages of patents filed in both an origin country and at least one destination country. Results for climate change mitigation technologies appear in parentheses.

Table A.4 Top 10 Importing Countries of Climate Change Adaptation Technologies, 1995–2015

Rank	Country	Average share of world received patents (%)
1	United States	13.3
2	China	9.4
3	Australia	8.0
4	Canada	6.9
5	Japan	5.9
6	Germany	5.0
7	United Kingdom	4.6
8	France	4.5
9	Korea, Rep.	3.8
10	Brazil	2.9

Source: Calculations based on World Patent Statistical Database (PATSTAT) data, European Patent Office.

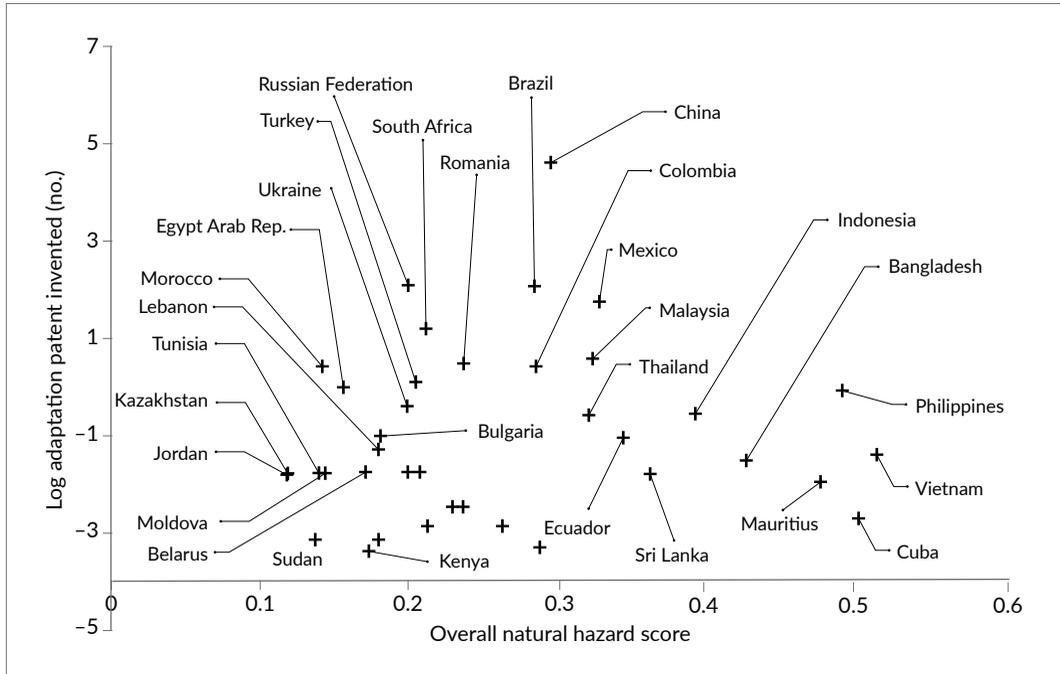
Table A.5 Top 15 Acquirer Countries in FDI Deals Related to Climate Change Adaptation Technologies 1995–2015

Rank	Acquirer country	Number of deals	Share of worldwide deals made (%)
1	United States	187	24.0
2	Japan	180	23.1
3	Germany	135	17.4
4	France	54	6.9
5	Netherlands	45	5.8
6	Denmark	42	5.4
7	Finland	38	4.9
8	Switzerland	26	3.3
9	Korea, Rep.	18	2.3
10	United Kingdom	12	1.5
11	Norway	10	1.3
12	Taiwan	8	1.0
13	Sweden	7	0.9
14	New Zealand	4	0.5
15	India	3	0.4

Source: Calculations based on Zephyr database, Bureau Van Dijk, Brussels.

Note: N = 778 deals. FDI = foreign direct investment.

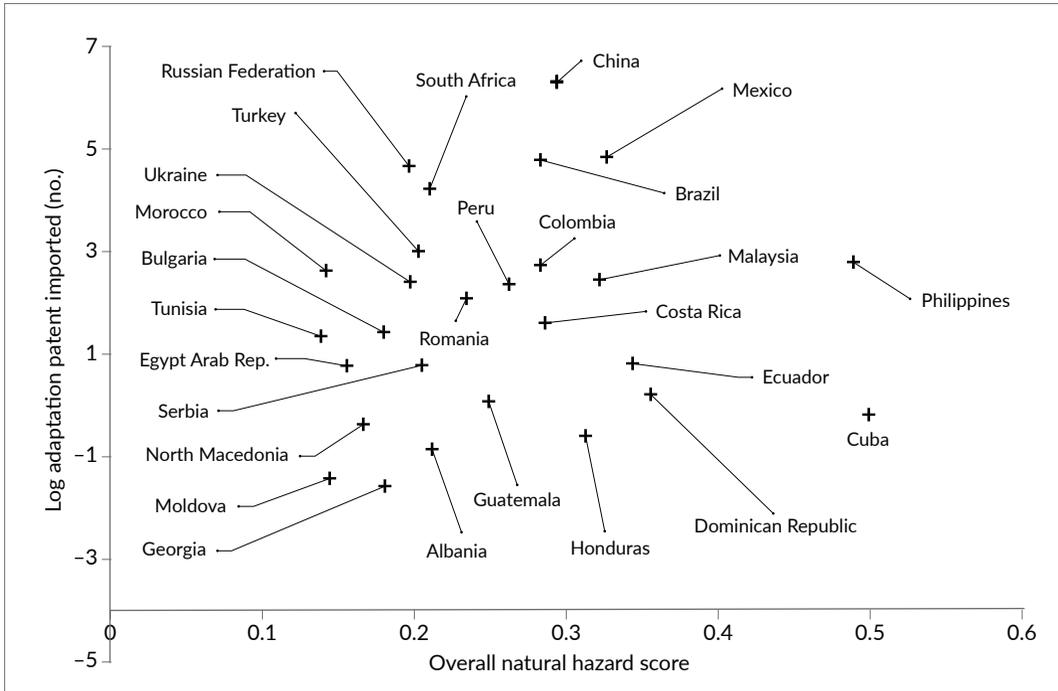
Figure A.2 Relationship between Climate Adaptation Technology Invention and Climate Hazards, Middle-Income Countries, 2010–15 Annual Average



Source: Calculations based on World Patent Statistical Database (PATSTAT), European Patent Office; University of Notre Dame Global Adaptation Index (ND-GAIN) indicators; Climdex indexes (<https://www.climdex.org/>); Aqueduct water risk data, World Resources Institute; and Emergency Events Database (EM-DAT), Centre for Research on the Epidemiology of Disasters.

Note: Each point describes an individual country. “Middle-income countries” are defined by World Bank classifications. The log numbers of inventions are the 2010–15 annual averages. The hazard index is the arithmetic means of the five hazard indicators listed in table 2.2, each being normalized so that they range from 0 to 1.

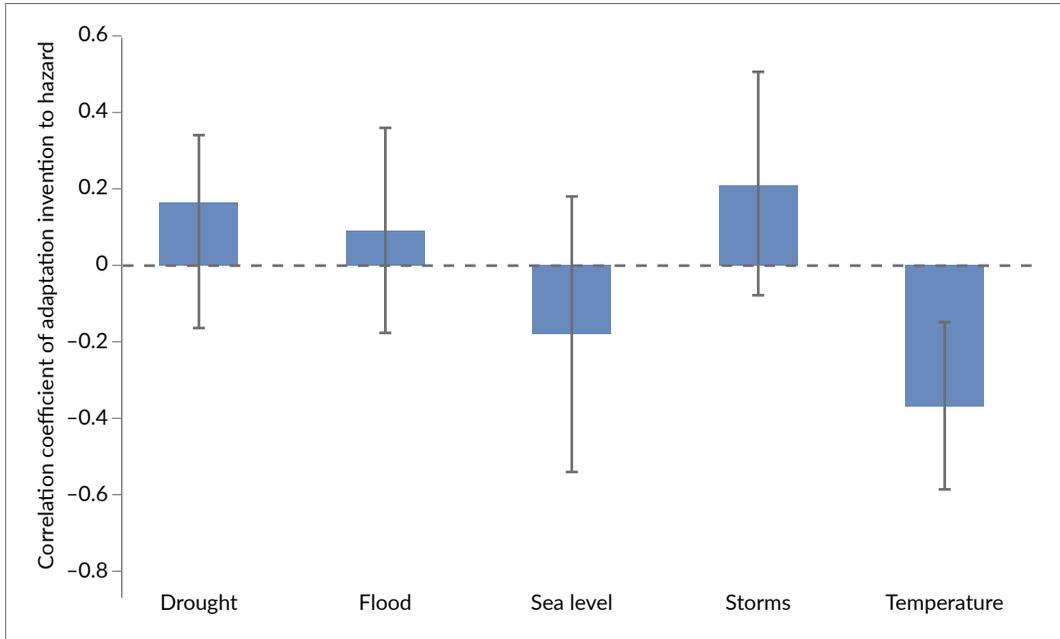
Figure A.3 Relationship between Climate Adaptation Technology Imports and Climate Hazards, Middle-Income Countries, 2010–15 Annual Average



Source: Calculations based on World Patent Statistical Database (PATSTAT), European Patent Office; University of Notre Dame Global Adaptation Index (ND-GAIN) indicators; Climdex indexes (<https://www.climdex.org/>); Aqueduct water risk data, World Resources Institute; and Emergency Events Database (EM-DAT), Centre for Research on the Epidemiology of Disasters.

Note: Each point describes an individual country. “Middle-income countries” are defined by World Bank classifications. The log number of imports are the 2010–15 annual averages. The hazard index is the arithmetic means of the five hazard indicators listed in table 2.2, each being normalized so that they range from 0 to 1.

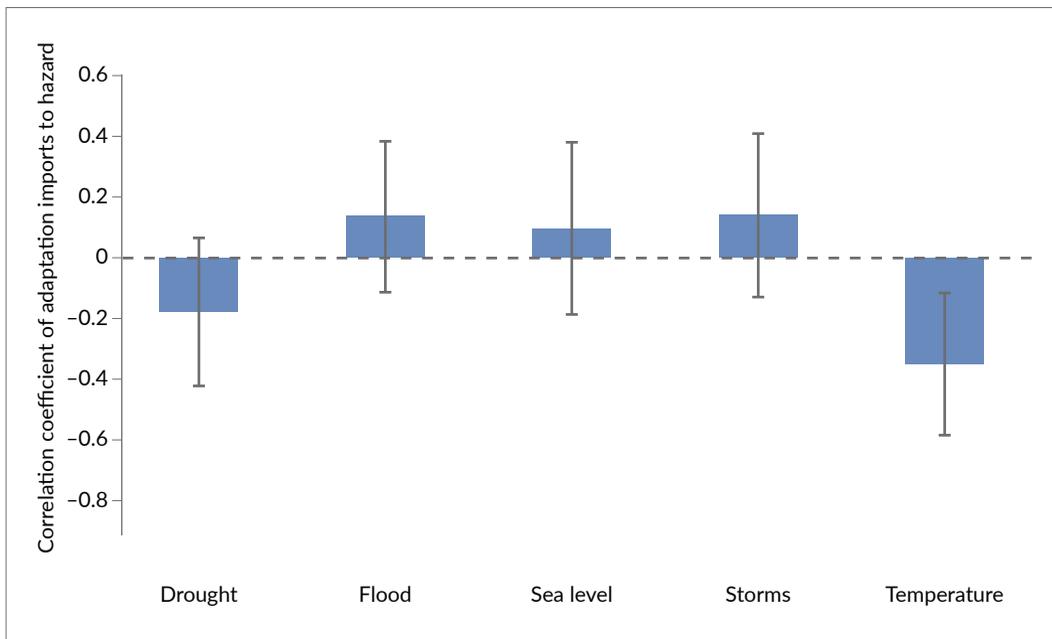
Figure A.4 Correlation between Number of Adaptation Inventions and Climate Hazard Levels in High- and Middle-Income Countries, 2010–15



Source: Calculations based on World Patent Statistical Database (PATSTAT), European Patent Office; University of Notre Dame Global Adaptation Index (ND-GAIN) indicators; Climdex indexes (<https://www.climdex.org/>); Aqueduct water risk data, World Resources Institute; and Emergency Events Database (EM-DAT), Centre for Research on the Epidemiology of Disasters.

Note: The technology variables are averages for the period 2010–15. For details on construction of the five hazard indicators, see appendix C. Vertical black lines represent confidence intervals at 95 percent level. “Invention” in this figure represents the number of high-value adaptation inventions (patents filed in at least two countries) made by a given country

Figure A.5 Correlation between Number of Imported Adaptation Inventions and Climate Hazard Levels in High- and Middle-Income Countries, 2010–15



Source: Calculations based on World Patent Statistical Database (PATSTAT), European Patent Office; University of Notre Dame Global Adaptation Index (ND-GAIN) indicators; Climdex indexes (<https://www.climdex.org/>); Aqueduct water risk data, World Resources Institute; and Emergency Events Database (EM-DAT), Centre for Research on the Epidemiology of Disasters.

Note: The technology variables are averages for the period 2010–15. For details on construction of the five hazard indicators, see appendix C. Vertical black lines represent confidence intervals at 95 percent level. “Imports” in this figure represent the number of foreign adaptation patents (invented by a foreign country) filed in a given country

Table A.6 Economies and Income Groups Included in the Study

Economy	High income	Middle income	Low income
Afghanistan			■
Albania		■	
Algeria		■	
Angola		■	
Antigua and Barbuda	■		
Argentina	■		
Armenia		■	
Australia	■		
Austria	■		
Azerbaijan		■	
Bahamas, The	■		
Bahrain	■		
Bangladesh		■	
Barbados	■		
Belarus		■	
Belgium	■		
Belize		■	
Benin			■
Bhutan		■	
Bolivia		■	
Bosnia and Herzegovina		■	
Botswana		■	
Brazil		■	
Brunei Darussalam	■		
Bulgaria		■	
Burkina Faso			■
Burundi			■
Cambodia		■	
Cameroon		■	
Canada	■		
Central African Republic			■
Chad			■
Chile	■		
China		■	
Colombia		■	

Table A.6 (Cont.)

Economy	High income	Middle income	Low income
Comoros			■
Congo, Dem. Rep.			■
Congo, Rep.		■	
Costa Rica		■	
Côte d'Ivoire		■	
Croatia	■		
Cuba		■	
Cyprus	■		
Czech Republic	■		
Denmark	■		
Djibouti		■	
Dominica		■	
Dominican Republic		■	
Ecuador		■	
Egypt, Arab Rep.		■	
El Salvador		■	
Equatorial Guinea		■	
Eritrea			■
Estonia	■		
Eswatini		■	
Ethiopia			■
Fiji		■	
Finland	■		
France	■		
Gabon		■	
Gambia, The			■
Georgia		■	
Germany	■		
Ghana		■	
Greece	■		
Grenada		■	
Guatemala		■	
Guinea			■
Guyana		■	
Haiti			■

Table A.6 (Cont.)

Economy	High income	Middle income	Low income
Honduras		■	
Hungary	■		
Iceland	■		
Indonesia		■	
Iran, Islamic Rep.		■	
Iraq		■	
Ireland	■		
Israel	■		
Italy	■		
Jamaica		■	
Japan	■		
Jordan		■	
Kazakhstan		■	
Kenya		■	
Korea, Rep.	■		
Kuwait	■		
Kyrgyz Republic		■	
Lao PDR		■	
Latvia	■		
Lebanon		■	
Lesotho		■	
Liberia			■
Libya		■	
Lithuania	■		
Luxembourg	■		
Madagascar			■
Malawi			■
Malaysia		■	
Maldives		■	
Mali			■
Malta	■		
Mauritania		■	
Mauritius		■	
Mexico		■	
Moldova		■	
Mongolia		■	
Montenegro		■	

Table A.6 (Cont.)

Economy	High income	Middle income	Low income
Morocco		■	
Mozambique			■
Myanmar		■	
Namibia		■	
Nepal			■
Netherlands	■		
New Zealand	■		
Nicaragua		■	
Niger			■
Nigeria		■	
North Macedonia		■	
Norway	■		
Oman	■		
Pakistan		■	
Panama	■		
Papua New Guinea		■	
Paraguay		■	
Peru		■	
Philippines		■	
Poland	■		
Portugal	■		
Qatar	■		
Romania		■	
Russian Federation		■	
Rwanda			■
Samoa		■	
São Tomé and Príncipe		■	
Saudi Arabia	■		
Senegal			■
Serbia		■	
Seychelles	■		
Sierra Leone			■
Singapore	■		
Slovak Republic	■		
Slovenia	■		
Solomon Islands		■	
Somalia			■

Table A.6 (Cont.)

Economy	High income	Middle income	Low income
South Africa		■	
Spain	■		
Sri Lanka		■	
St. Kitts and Nevis	■		
St. Lucia		■	
St. Vincent and the Grenadines		■	
Sudan		■	
Suriname		■	
Sweden	■		
Switzerland	■		
Syrian Arab Republic			■
Tajikistan			■
Tanzania			■
Thailand		■	
Togo			■
Tonga		■	
Trinidad and Tobago	■		
Tunisia		■	
Turkey		■	
Turkmenistan		■	
Uganda			■
Ukraine		■	
United Arab Emirates	■		
United Kingdom	■		
United States	■		
Uruguay	■		
Uzbekistan		■	
Vanuatu		■	
Venezuela, RB		■	
Vietnam		■	
Yemen, Rep.			■
Zambia		■	
Zimbabwe			■

Note: Country income categories are based on World Bank-defined classifications.

Appendix B | Regressions

B

We provide the results of two simple Poisson regressions in tables B.1 and B.2. The dependent variables are $invention_i$ (the number of patented inventions of technologies for climate change adaptation invented in country i), and (the number of foreign inventions of technologies for climate change adaptation patented in country i in the period 2005–10). More specifically, we estimate the following count models:

$$invention_i = \exp(\alpha_1 hazard_i + \beta_1 invention_stock_i + \gamma_1 population_i + \varepsilon_{1i}) \text{ and} \quad (B.1)$$

$$imports_i = \exp(\alpha_1 hazard_i + \beta_2 invention_stock_i + \gamma_2 population_i + \varepsilon_{2i}) \text{ and} \quad (B.2)$$

which include three explanatory factors:

- $hazard_i$, which captures the local demand measured by the country's hazard level in country
- $invention_stock_i$, which captures the level of technological capabilities proxied by the (discounted) stock of patented inventions in all technologies filed in the country
- $population_i$, which represents the country size proxied by its population.

ε_{1i} and ε_{2i} are two error terms.

The results confirm that country's technological capability is a strong predictor of innovation and technology imports in all fields, as is the country's size. The influence of local demand is difficult to analyze. Some corresponding coefficients are negative (floods for innovation, droughts and floods for imports) in these two regressions. When we change or add control variables, the signification of the hazard-related coefficient is modified among hazards, but the puzzle remains as we still get a negative coefficient for some categories. No theory can explain a significant and negative coefficient relative to the hazard variable, indicating that we have not found an appropriate model.

Table B.1 Relationship between Domestic Innovation and Climate Hazard Levels, Population, and Stock of Patented Inventions

Dependent variable	All	Droughts	Floods	Sea level rise	Storms	Temperature extremes
Hazard	-1.519* (0.813)	0.235 (0.744)	-1.393*** (0.442)	-0.584 (0.675)	-0.571 (0.780)	-0.755 (1.390)
Population	0.135*** (0.040)	0.186* (0.100)	0.140* (0.076)	0.185 (0.162)	0.209** (0.104)	0.111 (0.088)
Stock of patented inventions	0.763*** (0.026)	0.651*** (0.051)	0.648*** (0.040)	0.581*** (0.080)	0.687*** (0.056)	0.787*** (0.057)
# observations	118	95	99	87	91	104

Note: The dependent variable is the number of patented inventions of technologies for climate change adaptation invented in the country in the period 2005–10. The coefficients are estimated from a Poisson regression. Robust standard errors in parentheses.

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$ **Table B.2 Relationship between Technology Imports and Climate Hazard levels, Population, Stock of Patented Inventions, and Trade Barriers**

Dependent variable	All	Droughts	Floods	Sea-level rise	Storms	Temperature extreme
Hazard	-0.389 (0.798)	-1.741*** (0.507)	-1.277** (0.640)	-0.634 (0.514)	0.548*** (0.209)	-0.606 (0.649)
Population	0.450*** (0.077)	0.451*** (0.117)	0.451*** (0.075)	0.279*** (0.086)	0.374*** (0.077)	0.459*** (0.069)
Stock of patented inventions	0.356*** (0.050)	0.329*** (0.071)	0.335*** (0.048)	0.334*** (0.049)	0.338*** (0.054)	0.382*** (0.045)
Trade barriers	0.009 (0.156)	0.103 (0.195)	0.264* (0.136)	0.150 (0.174)	0.159 (0.140)	-0.101 (0.105)
# observations	72	65	66	59	62	68

Note: The dependent variable is the number of foreign inventions of technologies for climate change adaptation patented in the country in the period 2005–10. The coefficients are estimated from a Poisson regression. Robust standard errors in parentheses.

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$

Appendix C | Construction of the Five Hazard Indicators

The sea level rise indicator is the original University of Notre Dame Global Adaptation Index (ND-GAIN) indicator whose definition is provided in table 2.2. Importantly, it corresponds to projections by the end of the century.

Temperature and flood indicators rely on [Climdex](https://www.climdex.org/) (<https://www.climdex.org/>) simulations for the period 2040–70 under the IPCC's RCP4.5 scenario.¹⁴ The final score for both indicators is the average of the resulting indicator computed in 20 climate models as part of the CMIP5 program.¹⁵

The drought indicator is the projected change in annual runoff under the RCP4.5 scenario from the [Aqueduct water stress database of the World Resources Institute](#). For each country, we compute the mean of the basin level's score for the water supply indicator under the RCP4.5 scenario for the years 2020, 2030, and 2040.

We then average these four indicators at the country level.

Last, the storms indicator only includes past events because we could not find any relevant projections. It is the country's average annual number of storms per capita for the period 1900–2015. The historical number of storms per country for the period 1900–2015 is extracted from the Centre for Research on the Epidemiology of Disasters (CRED) Emergency Events Database ([EM-DAT](#)). The assumption here is that past events are strongly positively correlated with future threats.

Endnotes

- ¹ For a recent survey of the research, see Popp (2019).
- ² A commonly used alternative control for differences between patent offices would be to include only triadic patents in our sample (for example, patents filed at US, European, and Japanese patent offices). However, because we are specifically addressing technology transfer between countries, this selection would make a meaningful global analysis impossible.
- ³ “Technologies for Adaptation to Climate Change,” Cooperative Patent Classification (CPC) Subclass Y02A, Espacenet website, European Patent Office: https://worldwide.espacenet.com/classification?locale=en_EP#/CPC=Y02A.
- ⁴ Specifically, all the mitigation technologies are classified as Y02B, Y02C, Y02D, Y02E, Y02P, Y02T, or Y02W.
- ⁵ For more information on the Zephyr database, see the Bureau Van Dijck website: <https://www.bvdinfo.com/en-gb/our-products/data/specialist/zephyr>.
- ⁶ “NACE Rev. 2” refers to Statistical Classification of Economic Activities in the European Community (NACE, for the French “*nomenclature statistique des activités économiques dans la Communauté européenne*”). It is the [industry standard classification system](#) used in the European Union. The current version is revision 2.
- ⁷ We have excluded ocean acidification because the IPCC does not mention any technology mitigating this problem.
- ⁸ Note that the IPCC concepts of “risk” and “hazard” are referred to, respectively, as “vulnerability” and “exposure” in ND-GAIN. The present report exclusively relies on IPCC definitions.
- ⁹ Choosing an arithmetic mean is conventional. Using a more sophisticated weighting rule would require more data and be less transparent. Moreover, we do not think that it would modify the overall messages conveyed by figures 5.1–5.3 (in section 5). Note that the most important figure, figure 5.4, presents hazard-specific results.
- ¹⁰ The structure of the patent data distinguishes between the inventing (home) and receiving (foreign) countries of a patented invention. The transfer rate is then calculated as the share of a country’s inventions that are also filed in at least one foreign country.
- ¹¹ In appendix A, figure A.2 and figure A.3 are variants of figure 5.1 and figure 5.3, restricted to middle-income countries and displaying country names for readers interested in particular cases.
- ¹² In appendix A, two graphs (figure A.4 and figure A.5) give these correlation coefficients, distinguishing between domestic and imported adaptation technology innovations
- ¹³ For these data, see the Excel files for “Climate-related development finance at the activity level, recipient perspective” on the OECD web page, “Climate Change: OECD DAC External Development Finance Statistics”: <http://www.oecd.org/dac/financing-sustainable-development/development-finance-topics/climate-change.htm>.
- ¹⁴ A Representative Concentration Pathway (RCP) scenario refers to a greenhouse gas concentration trajectory adopted by the IPCC. Four pathways were used for climate modeling and research for the IPCC Fifth Assessment Report in 2014. RCP4.5 is a stabilization scenario (stabilizing radiative forcing at 4.5 W m⁻² in the year 2100 without ever exceeding that value) that assumes the imposition of emissions mitigation policies.
- ¹⁵ The Climate Model Intercomparison Project, Phase 5 (CMIP5) refers to a standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models (AOGCMs). It includes 35 climate model experiments to evaluate the relevance of such models in simulating the recent past climate, to produce projections of future climate conditions, and to analyze the factors leading to differences among the models’ projections. For more information about CMIP5, see the Program for Climate Model Diagnosis & Intercomparison website: <https://pcmdi.llnl.gov/mips/cmip5/>.

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