Report

Innovation *in* Green Technologies

An opportunity for businesses in low and middle income countries?

JULY 2025

IFC International Finance Corporation
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Cover photo: Devkanya Pandey drives electric auto in the city of Indore, Madhya Pradesh, India.

Innovation *in* Green Technologies:

An opportunity for businesses in low and middle income countries?

Acknowledgments

This report was prepared under the guidance of Susan Lund, International Finance Corporation (IFC) vice president for Economics and Private Sector Development, and Paolo Mauro, director of IFC's Economic and Market Research Department.

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Peer reviewers include Robin Burgess, Richard Damania, Bronwyn Hall, Denis Medvedev, Pablo Andres Salas Bravo, and Reinhilde Veugelers. Jamie Fergusson, Carolyn Fischer, and Roumeen Islam provided additional feedback on the overall approach and specific analyses. Mark Dutz gave technical and editorial advice.

We thank Erik Churchill and Chris Vellacott from IFC's Communications Department for their editorial contributions. Irina Sarchenko was the graphic designer and Bruce Ross-Larson edited the report.

This report is a product of IFC's Economics and Private Sector Development Vice Presidency.

Key Takeaways

Over the past 15 years, the markets for new energy and production technologies—that conserve energy or natural resources, or mitigate greenhouse gases—have **outpaced** other economic sectors. There is also rising demand for products and processes that make economies more resilient to the consequences of climate change.

Drivers for this "green" market space include more widespread climate and environmental policies as well as technological breakthroughs that make greener alternatives **cheaper or more convenient**.

Although this market remains dominated by firms from high income countries, businesses in low and middle income countries are also **increasingly** active in the green market space.

They have a **comparative advantage** in science and commercial innovation in green technologies, and this could ultimately lead to stronger economic growth and job creation.

Emerging evidence points to lower market **entry barriers** for green technologies. Developing economies also face more drastic consequences of climate change, which leads them to delve into adaptation technologies.

Even so, investment in green innovation in low and middle income countries is **below optimal levels**. Strong knowledge spillovers and financial constraints imply that individual investors have insufficient means or incentives to invest in green innovation.

So, **supportive** policies or investment strategies can help.

Innovation in green technologies by firms in low and middle income countries also generates **value spillovers** for firms in higher income countries.

Different countries have strengths in **different** segments or technologies in the broad green category. Online tools accompanying this report provide further granular indicators for individual countries, technology classes, and market segments.

Abbreviations

AI	Artificial Intelligence
BACI	Base de Données sur le Commerce International (International Trade Database)
DFI	Development Finance Institution
EV	Electric Vehicle
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HIC	High Income Country
ICT	Information and Communication Technology
IFC	International Finance Corporation
LIC	Low-Income Country
LMIC	Lower and Middle Income Country
MIC	Middle-Income Country
MDB	Multilateral Development Bank
OECD	Organisation for Economic Co-operation and Development
PATSTAT	Patent Statistical Database
PV	Photovoltaic
R&D	Research and Development
RAA	Revealed Academic Advantage
RBA	Revealed Brand Advantage
RCA	Revealed Comparative Advantage
RIA	Revealed Investment Advantage
RTA	Revealed Technological Advantage

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Foreword

Demand for cleaner, more efficient technologies is transforming global markets and with it, the geography of innovation. Over the last 15 years, markets for new energy technologies and climate resilience have outpaced growth in other sectors by over 30 percent compared to exports overall. Green products now account for at least 10 percent of global goods exports with related value chains adding a further 20 percent. This growth—driven by dramatic cost declines in renewables, energy storage technologies, and rising adaptation needs due to increasingly extreme weather conditions—is leading to a wave of economic creative destruction where legacy business models and supply chains are being replaced. This provides a surge of economic opportunities for new market entrants and innovative firms.

This report explores whether such opportunities extend to businesses in low- and middle-income countries (LMICs). The findings are cautiously optimistic. While high-income countries still dominate green exports, LMICs have been improving their comparative advantage over the past two decades. LMICs also hold a comparative advantage in what this report calls the upstream segments of a knowledge economy value chain: in scientific research and patented innovations. That is, while there are generally fewer innovations originating in LMICs, a larger fraction is in green technology areas. Over 12 percent of innovations in LMICs (excluding China) are green compared to 8.5 percent in high-income countries.

LMICs' advantage is particularly apparent in fields like adaptation and green energy, possibly building on local needs, resource endowments, and less entrenched legacy systems. The report also finds evidence for lower costs associated with innovation steps in green technologies which might make these technologies more accessible to more financially constrained LMIC inventors. Moreover, green innovations from LMICs are, on average, of high quality, as evidenced by elevated numbers of direct and indirect patent citations even exceeding average levels found in high income countries. However, numerous citations also indicate significant knowledge spillovers, which imply that individual inventors are underinvesting in green R&D as a large part of the benefits will accrue to other firms. The report also finds evidence that green innovation in LMICs is affected by financial constraints. Both factors suggest that there is a strong case for further investments in green innovation in LMICs as a strategy for impact investors and via supporting policies such as climate or industrial policies. The evidence provided in the report shows that this will increase the flow of knowledge spillovers within LMICs thereby leading to more innovation and thus economic growth. Interestingly, the results show that innovation from LMICs, especially in green technology, flows to high-income countries, adding further value to its production.

Often the challenge of economic development is framed as one of technology adoption: LMICs are encouraged to adopt technologies that have been developed in high income countries. Innovation efforts are viewed as a waste of resources. However, successful adoption often requires additional, adaptative innovations. Long-term, transformative economic growth is ultimately driven by innovation, as illustrated by recent development success stories such as the Republic of Korea or China. A central message from this report is that many LMICs have outstanding innovators, especially in green technologies. Supporting them can increase economic growth in both LMICs and HICs. This support could come in the form of accelerator programs, venture investment or direct grants. The report additionally highlights the importance of academic and scientific knowledge for commercial innovation which is no less important in LMICs than in high income countries (HIC). However, the report also finds that academic institutions in LMICs lag far behind their HIC counterparts in translating academic output into commercial value. Hence, strengthening higher education and academic research could be an important avenue for boosting LMIC innovation.

A final message of the report is that one size does not fit all: not all LMICs will have capabilities in green innovation areas and those that do will not all have capabilities in all or the same green technology areas. Hence, we will release online tools alongside this report that we hope will help investors, governments, and development partners to identify where the most promising opportunities lie on a country by country and technology basis.

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In Brief

A growth market

Over the last 15 years, a market has emerged for new energy and production technologies that reduce local pollution, conserve scarce natural resources, reduce greenhouse gas emissions, and improve resilience to extreme weather. Trade in related products—often labeled collectively as "green"—has outstripped overall trade. Beyond climate policies, these developments have been driven by progress in technologies such as solar and wind power generation, or energy storage including more efficient batteries. Such progress has led to an impressive decline in costs for such technologies. More frequent extreme weather events have also boosted the demand for products supporting adaptation to the consequences of climate change.

An opportunity for new entrants and innovation by existing firms

The adoption and improvement of these new technologies will likely continue to usher in a wave of creative destruction, allowing firms to leapfrog legacy technologies and supply green products and services. This report explores whether such economic transformation provides opportunities to create jobs and foster economic growth, focusing its analysis on low and middle income countries (LMICs).

Market participation

Although trade in green products remains largely dominated by high income country (HIC) firms, LMIC-based firms have increased their participation over the last 20 years. China's export share has expanded, consistent with its rapid economic growth. But several other LMICs have improved their export shares in green goods even more, suggesting the development of specific capabilities in green markets.

Comparative advantage

Academic output and commercial innovation can be thought of as the upstream segments of a knowledge economy value chain with entrepreneurial ventures, branding, and trademarks forming the downstream segments. This report finds that LMICs have a comparative advantage in scientific output related to green technologies—LMICs have a greater share of innovation in green technologies than HICs. They do not generally have an absolute advantage, which would mean a larger number of innovations in green technologies than for HICs. Comparative advantage in those upstream segments could be turned into commercial advantage in the future.

Shades of green

This latent comparative advantage is more pronounced in fields such as adaptation to climate change or green energy technologies, but not in green automotive technologies (except for China). The results suggest that LMIC firms may focus on technologies that are simpler and less costly to develop. Additional drivers include climate legislation and LMIC country citizens' increasing concern about the need to adapt to climate change.

The quality of LMIC innovation

Quantitative and qualitative indicators suggest that innovation in LMICs in green technologies is valuable both commercially and for broader spillovers. And for LMICs as a group, estimated spillovers are greater for green than for other innovations. So, prioritizing green technologies would also be growth-enhancing. Spillovers from R&D in LMIC firms also bring significant benefits to high income countries.

An opportunity for growth

With lower costs for some forms of energy (such as solar) and technological advances underway in several areas, low and middle income countries may gain additional shares of various green markets going forward under a current policies scenario. The evidence suggests, however, that measures by policymakers and investors can accelerate this process, thus fostering economic development and job creation.

No one size fits all

Not all countries are equally well suited to have a thriving private sector focused on green products. Nor should all countries focus on the same products. To facilitate more granular analysis, dedicated tools will be released to accompany this report.

Photo: The Cibuk 1 wind farm in Serbia ©IFC

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Context—
The Green Transition As A Growth Market

KEY TAKEAWAYS

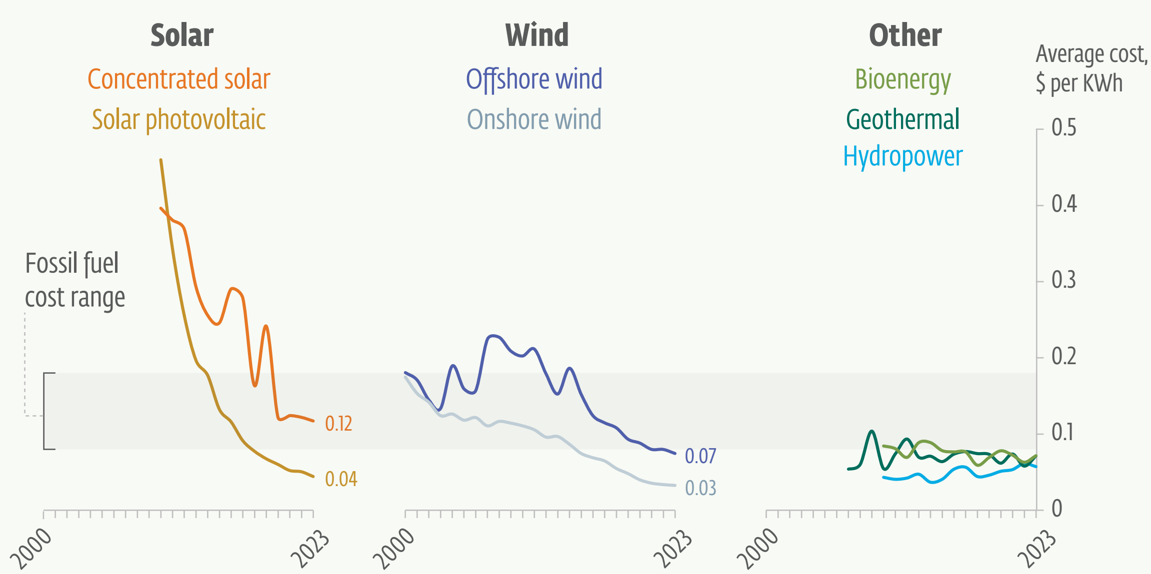
- Economic development requires adopting new technologies and expanding energy access and private sector development.
- This is increasingly taking place against the background of the green transition—the mitigation and adaptation to climate change, as well as efforts to conserve scarce natural resources and reduce harmful local pollution.
- Technological breakthroughs have reduced the cost of renewable energy and more generally made the green transition better aligned with the goal of economic development.
- Markets for related products and technologies will likely grow faster than the rest of the economy.
- As new technologies partly replace older ones along with the business models of incumbents, opportunities emerge for new entrants, including firms from low and middle income countries.
- Factors in favor of firms from low and middle income countries include:
    1. Less technological lock-in in legacy technologies.
    2. For some countries, favorable conditions for exploiting cheap renewable energy.
    3. For some countries, an abundance of critical minerals.
    4. Greater exposure to droughts and other manifestations of extreme weather stemming from climate change, which create markets for adaptation technologies and products.

Economic development and poverty reduction in low income and emerging economies require new technologies, major increases in energy access, and the pursuit of profitable opportunities by the private sector.

Development is now happening against a backdrop of green transitions, where economies conserve or make more efficient use of scarce natural resources, decarbonize, build resilience, and adapt to the consequences of climate change. With rapid technological progress reducing the cost of many new energy technologies, such transition is becoming less of a burden on economic development. Solar energy generation, for example, has already become the cheapest source of energy in many places (**figure 1.1**). And it is forecast to be the cheapest source (including the cost of electricity storage) virtually everywhere in the near term.[1] Greater access to low-cost, more abundant energy can lift longstanding constraints, especially in low and middle income countries (LMICs). Likewise, as shown in this report, LMICs innovate in diverse technologies and products such as desalination, wave energy, and biodegradable synthetic wood. New technologies will also open doors for firms to enter new markets and associated value chains.

FIGURE 1.1

Green tech is becoming the cheapest tech



Source: Data downloaded from OurWorldInData, based on data from IRENA (2024).
Note: This figure presents the global average cost per unit of energy, generated across the lifetime of a new power plant. The data are expressed in U.S. dollars per kilowatt-hour, adjusted for inflation but not accounting for differences in living costs across countries.

1 Nijsse et al. (2023).

A fast-expanding green economy

Products associated with the green transition have become a growth market (**box 1.1**). During the last one and a half decades, exports of green products have been outgrowing other export markets with a compound annual growth rate of over 4 percent compared to 3 percent for total goods exports (**figure 1.2A**). In 2022 green exports accounted for a share of at least 10 percent of total exports. Goods related to the supply chain of green products accounted for around 20 percent of exports. Moreover, technology development in green technologies has been outpacing even such emerging fields as AI (**figure 1.2B**).

Growth in demand for green products stems from rapid innovation in green technologies and policy measures in many countries (**figure 1.3**). If developing country firms can succeed in these markets, they can become engines of economic growth.

A wave of creative destruction

Are developing country firms well placed to enter green markets? One aspect that could work in their favor is that the green transition entails a wave of Schumpeterian creative destruction.[2] Like previous and concurrent waves—steam power, motor vehicles, the computer, the internet, or advanced artificial intelligence (AI) tools—the transition underway involves widespread replacement of legacy technologies by new, more advanced technologies. In many cases, this will make existing business models no longer tenable, opening a window for innovative newcomers to enter and thrive in novel markets.

Examples of companies that have achieved such outcomes already abound. Among many others, some of the better known include Tesla for the global electric vehicle (EV) market, as well as Chinese companies in solar, batteries, and EVs, such as Tongwei, CATL, and BYD. Octopus is a U.K. energy company now expanding internationally with innovative solutions to energy service retailing. A perhaps less well known but impressive example is Rimac cars from Croatia (**spotlight 1.1**).[3]

Many of these new companies are in geographies outside the previously well-established clusters of incumbents. For instance, even though California had many great technology companies, it was not previously noted for its car industry—nor were China and Croatia.

Such waves of creative destruction can thus present an opportunity for newcomer firms to create jobs and boost incomes. But which countries will such firms come from?

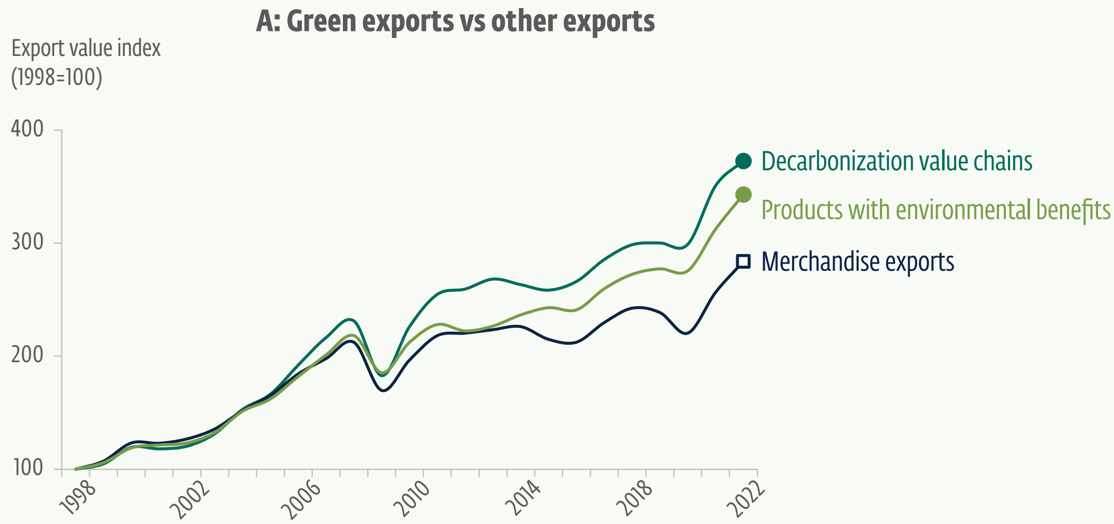
This report explores whether LMICs have a comparative—if not absolute—advantage in

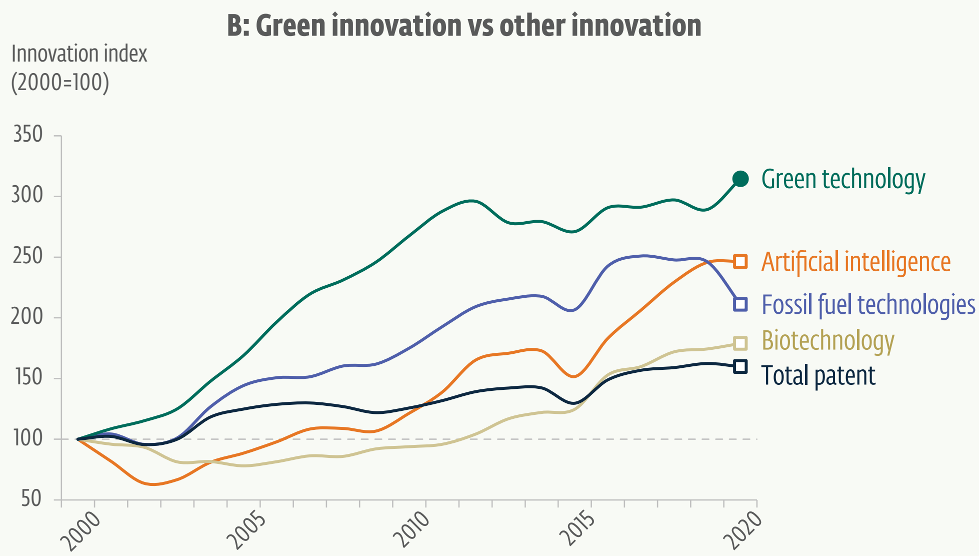
2 Austrian economist Joseph Schumpeter (1883–1950) coined the term "creative destruction" to describe the process by which new innovations replace outdated technologies and practices, driving economic progress. More recently, economists like Philippe Aghion and Peter Howitt modeled how creative destruction fosters economic growth, emphasizing the obsolescence of old technologies and the role of industrial innovations (Aghion et al. 2015; World Bank 2024).

3 When Rimac started in 2009, Croatia was still 10 years from being classified as a high-income country.

FIGURE 1.2

Green exports and innovations have expanded faster than other goods

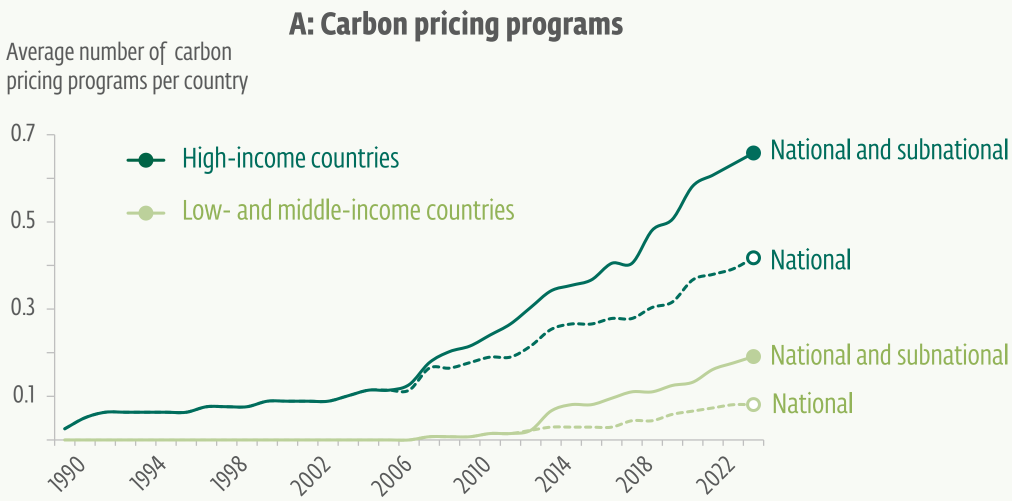


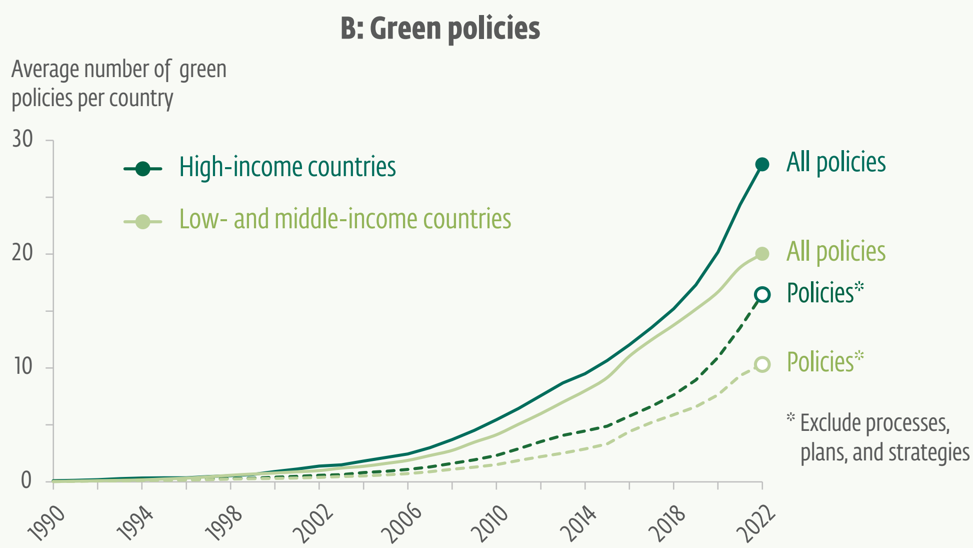


Source: IFC calculations based on BACI (Base pour l'Analyse du Commerce International), 2023 Patent Statistical (PATSTAT), and World Bank World Development Indicators. **Note**: Panel A explores the value of exports, and panel B the number of innovations. Green exports are either those with environmental benefits or those belonging to five major decarbonization value chains. Products with environmental benefits are defined as in Mealy and Teytelboym (2022) and pool all existing environmental goods classifications from the World Trade Organization, Organisation for Economic Co-operation and Development, and Asia-Pacific Economic Cooperation into a single, comprehensive dataset of 543 green products across a range of environmental categories, such as air pollution, wastewater management, recycling and renewable energy. Decarbonization value chains are defined as in Rosenow and Mealy (2024) and include electric vehicles (EVs), heat pumps, solar PV, wind turbines, and electrolyzers. Export values are deflated using GDP deflator calculated as nominal GDP over constant GDP (in 2015 U.S. dollars). Green innovations follow the classification of patents from the European Patent Office. See online appendix 1 for further explanations on the classification.

FIGURE 1.3

Climate policy programs have become more widespread





Source: Carbon pricing programs data are from World Bank (2025)—Carbon Pricing Dashboard. Policy data are from Grantham Research Institute at the London School of Economics and Climate Policy Radar (2023)—Climate Change Laws of the World. **Note**: In panel A, carbon pricing programs include emission trading programs and carbon taxes, and subnational carbon pricing programs refer to pricing systems set up by cities or provinces. In panel B, policies refer to legal documents directly relevant to climate change mitigation, adaptation, loss and damage, or disaster risk management. These include documents that have full legal force, having passed through the legislature or through an executive decision-making body, or set out a current governmental policy objective or set of policy objectives. Processes, plans, and strategies are a policy category provided in the database and could include carbon pricing but also emission standards or laws phasing out fossil fuel technology. Income classifications are thus based on latest World Bank data.

green technologies and products.[4] Some authors have put forward reasons why they might not. For instance, Shapiro (2023) argued that green products often rely on complex inputs that need credible contracts and strong judicial institutions to enforce them. Moreover, some green technologies—such as solid-state batteries, modular reactors, highly efficient solar panels—require a broad base of science and skills, advanced manufacturing techniques, and economies of scale. That combination of factors might not be readily available in LMICs. However, many LMICs have some advantages for technological transformation.

- First, they are not locked into legacy technologies.[5]
- Second, whereas some technologies—such as solid-state batteries—are advanced and require specialized skills or sophisticated research and production facilities, many promising technologies—such as electric bicycles or energy

BOX 1.1

Technologies and business activities covered in this report

To conserve space, this report defines "green" technologies, products, services, and business practices as those that broadly reduce local pollution, conserve scarce natural resources, mitigate climate change, or adapt to its impact.

Mitigation activities include solutions to reduce greenhouse gas emissions or enhance their absorption. Examples include technologies related to renewable energy generation (such as solar, wind, geothermal, and hydropower), energy efficiency solutions in buildings and infrastructure, sustainable agricultural and manufacturing practices, environmentally friendly transportation methods, circular economy processes, and greenhouse gas capture and storage (engineered or nature-based solutions). Adaptation solutions complement these strategies by helping societies adjust to climate impacts through measures such as flood defenses, drought-resistant agriculture, and improved water resource management.

The definition also includes enabling technologies and services—such as green finance, grid technologies, and ICT solutions that optimize energy management—that indirectly but significantly support mitigation or adaptation goals. In parts of the analysis here, the scope of green also includes inputs that are indispensable in developing and deploying decarbonization technologies. Examples include critical minerals used in producing batteries, which are essential in electric vehicles.

The report adopts the above definition of green as a guiding framework. In practice, however, different datasets vary somewhat in how they classify green activities (see **appendix 1**).

4 "Absolute advantage" refers to the ability of a country or business to produce a good or service more efficiently than others, using fewer resources. "Comparative advantage" refers to the ability of a country or business to produce a particular good or service at a lower opportunity cost than others. This means that even if one entity is less efficient at producing all goods, it can still benefit from specializing in the production of goods for which it has the lowest opportunity cost, and trade for others.

5 Acemoglu et al. 2012; Aghion et al. 2016.

storage using sand[6]—are simpler to develop and implement.

- Third, many LMICs benefit from favorable conditions for solar, wind, or geothermal energy.
- Fourth, several LMICs have abundant critical minerals for the green transition. These can be a source of revenues, or a stepping stone for processing such materials.
- Fifth, many of these countries are at the forefront of impacts from climate change and are thus well positioned to lead in developing innovative solutions for climate adaptation.

Although green markets are still predominantly served by high-income countries, the trend is changing—mainly due to China, but also to other LMICs that are improving their comparative advantage in those markets, suggesting that entrepreneurs in those countries are developing green skills and capabilities.

This report proposes a framework to systematically examine countries' innovation capabilities, based on various stages of what can be conceptualized as a knowledge economy value chain. At the upstream stage this involves fundamental knowledge measured via academic publication output that feeds into commercial innovation. Further downstream, successful innovation will be embodied in entrepreneurial ventures or marketing and branding activities by firms. Our overall findings suggest that LMIC firms currently have a strong green comparative advantage in upstream segments, but not yet in downstream ones. Converting this latent comparative advantage into commercial success would require strategic attention from policy makers and investors.

6 Sand's thermal properties make it suitable for cheap, accessible storage of heat derived from excess renewable energy. There is also ongoing research into using sand in a gravitational way similar to pumped hydro storage. This has been suggested as an opportunity to re-use abandoned mines.

Spotlight 1.1

Rimac Automobili—Pioneering the replacement of legacy technology

Waves of Schumpeterian creative destruction often replace legacy technologies with innovative newcomers. Rimac Automobili offers an example of such a process, located outside established clusters of incumbent car manufacturers.[7]

Rimac Automobili, an electric vehicle company based in Croatia, was founded in 2009 by Mate Rimac, whose entry into the automotive world started in his garage, where he converted a 1984 BMW 3 Series into an electric car after its combustion engine failed during a race. This project led to several world records for electric cars and laid the foundation for his future endeavors. In 2009, at the age of 21, Rimac founded his company with the vision of creating high-performance electric vehicles. His first model, the Concept One, debuted in 2011 and was one of the fastest mass produced electric vehicles at the time.

Despite starting out in Croatia, which had never had a car industry and few technology-based industries, Rimac was able to push the boundaries of battery efficiency, electric drivetrains, and vehicle dynamics through mostly in-house innovations. The company holds many patents, including those for advanced battery cooling systems, electric powertrains, and autonomous driving.

Some examples:

- System and process for maintaining working temperatures of battery cells for starter accumulators in vehicles.
- Electric power limiter.
- Joint forecasting of feature and feature motion.

Rimac's innovative approach and dedication have earned the company recognition and investment from major automotive companies like Porsche and Hyundai. Rimac has also diversified beyond the niche market of electric sports cars into technology licensing, stationary energy storage, and component manufacturing for the broader EV market.

Through its subsidiary Rimac Technology, the company supplies electric drivetrain components, battery systems, and complete powertrain solutions to other automakers. Strategic partnerships with brands like Porsche, Bugatti, and Hyundai allow Rimac to generate revenue through technology licensing and component supply contracts.

And with the launch of Rimac Energy, the company has expanded to apply its expertise in battery technology and power electronics to support renewable energy integration and grid stability, opening additional revenue streams in the clean energy market.

7 The discussion in this spotlight is based on a number of sources, including:
https://en.wikipedia.org/wiki/Rimac_Automobili,
https://en.wikipedia.org/wiki/Mate_Rimac
https://www.press.bmwgroup.com/global/article/detail/T0440947EN/bmw-group-and-rimac-technology-agree-long-term-partnership,
https://emerging-europe.com/made-in-emerging-europe/croatias-rimac-moves-beyond-evs/,
https://www.rimac-newsroom.com/press-releases/rimac-technology/ceer-partners-with-rimac-technology-for-high-performance-electric-drive-systems.

2

Opportunities— Green Product Markets

KEY TAKEAWAYS

- Trade in green products remains dominated by firms from high income countries with a comparative advantage in key segments of green value chains—including solar panels, wind turbines, heat pumps, electrolyzers and electric vehicles—but not raw materials.
- However, low and middle income countries have established a stronger foothold, improving their comparative advantage in green exports faster than high income countries.
- Low and middle income countries also have a strong comparative advantage in scientific and innovation output related to green technologies and markets—the upstream segments of a knowledge economy value chain.
- This does not necessarily mean they are better in these technologies, but there is evidence that green innovation in low and middle income countries is of high quality and economic value.
- Low and middle income countries have more limited comparative advantage downstream, which is indicative of barriers preventing the efficient development of a latent comparative advantage.
- This does not apply uniformly across all clean technology fields. Low and middle income countries have a high revealed technological advantage in climate change adaptation technologies.
- The top green revealed technological advantage categories for low and middle income countries within broad country groupings are:
    1. Greenhouse gas capture for East Asia and Pacific.
    2. Green agriculture for Europe and Central Asia.
    3. Circular economy technology for Latin America and the Caribbean.
    4. Adaptation technology for the Middle East and North Africa and for Sub-Saharan Africa.
    5. Green information and communication technology for South Asia, India, and China.

This chapter explores the landscape of green product markets and the emerging capabilities of low and middle income countries (LMICs). The latent comparative advantages of LMICs highlight the potential for future innovation and growth in green technologies, while recognizing variation across market segments and across countries.

Firms from high income countries still dominate

More than two-thirds of green global exports still originate in high income countries (HIC), down from more than 80 percent at the beginning of this century (**figure 2.1A**). The rise of China as an exporter of green products explains a large proportion of this shift, but the share of other LMICs in green exports also increased from 13 percent on average between 1998 and 2002 to 17 percent between 2018 and 2022 (combining India and other LMICs). Low income countries (LICs) also dramatically increased their exports, although from a low base (**figure 2.1B**).

The expansion of the green market share captured by LMICs is primarily driven by gains in processed materials and subcomponents (**figure 2.2**).[8] Only China has managed to gain its market share in end products as well. For raw materials, the HIC share has remained stable, even though the size of the overall market expanded considerably over the last 20 years. Raw materials are also the segment where the share of LMICs excluding China is the largest at more than 30 percent.

Low and middle income countries are developing green capabilities

A country's market share in green products is determined by two factors. First, its contribution to overall trade. Second, its specific capabilities—skills, technological knowhow, and geographic advantages—that make it competitive in these markets.

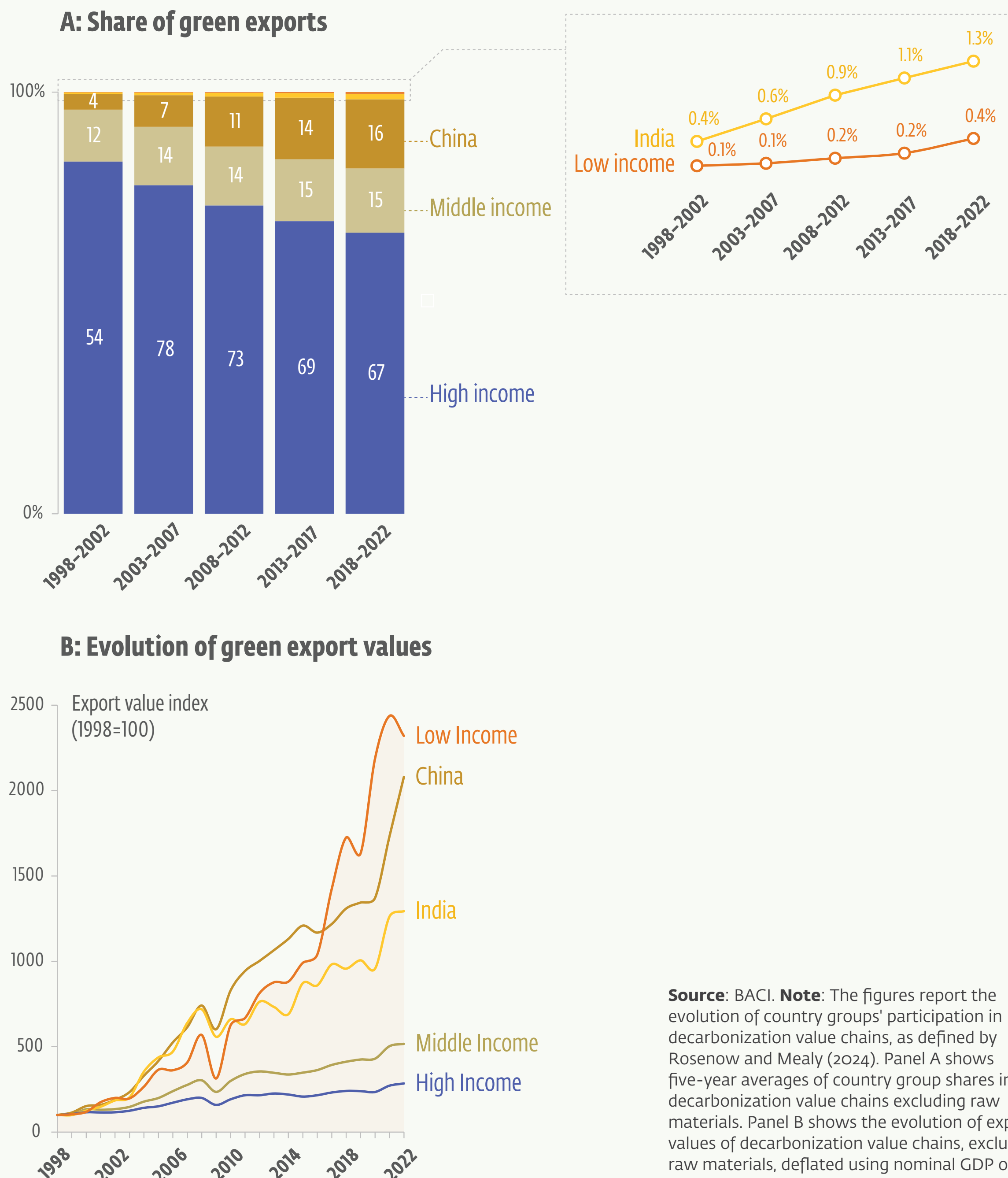
A simple indicator to assess such specific capabilities is a country's revealed comparative advantage (RCA) for a product category such as green. RCA is calculated as the country's export share in green products relative to the global share of exports of green products in total products. If a country's RCA in a product category is larger than one, it is more specialized in that category than other countries.[9] This measure is based on goods trade only and does not capture services—something addressed in the next chapter.

8 See online appendix 1 for a detailed description of the segments within the decarbonization value chain.

9 The results in the rest of this report present Symmetric RCA (simply referred to as RCA hereafter), a slight transformation of RCA that avoids extremely large values, which can occur for countries that export only very small quantities. Its interpretation is, however, the same as standard RCA. Whereas green standard RCA is calculated as $\frac{s_{green,c}}{s_{green}}$, where $s_{green,c}$ is the share of green exports in total exports of country c, and s_{green} indicates the world's share of green exports in total exports, we calculate green symmetric RCA as $\frac{s_{green,c}}{0.5(s_{green}+s_{green,c})}$. The latter ranges between 0 and 2, whereas the former ranges between 0 and an upper bound equal to the inverse of the global share of green exports; i.e. it can take on extreme values for small product categories. We further discuss potential issues with the measurement of RCA in online appendix 2.

FIGURE 2.1

Low and middle income countries are increasingly participating in decarbonization value chains

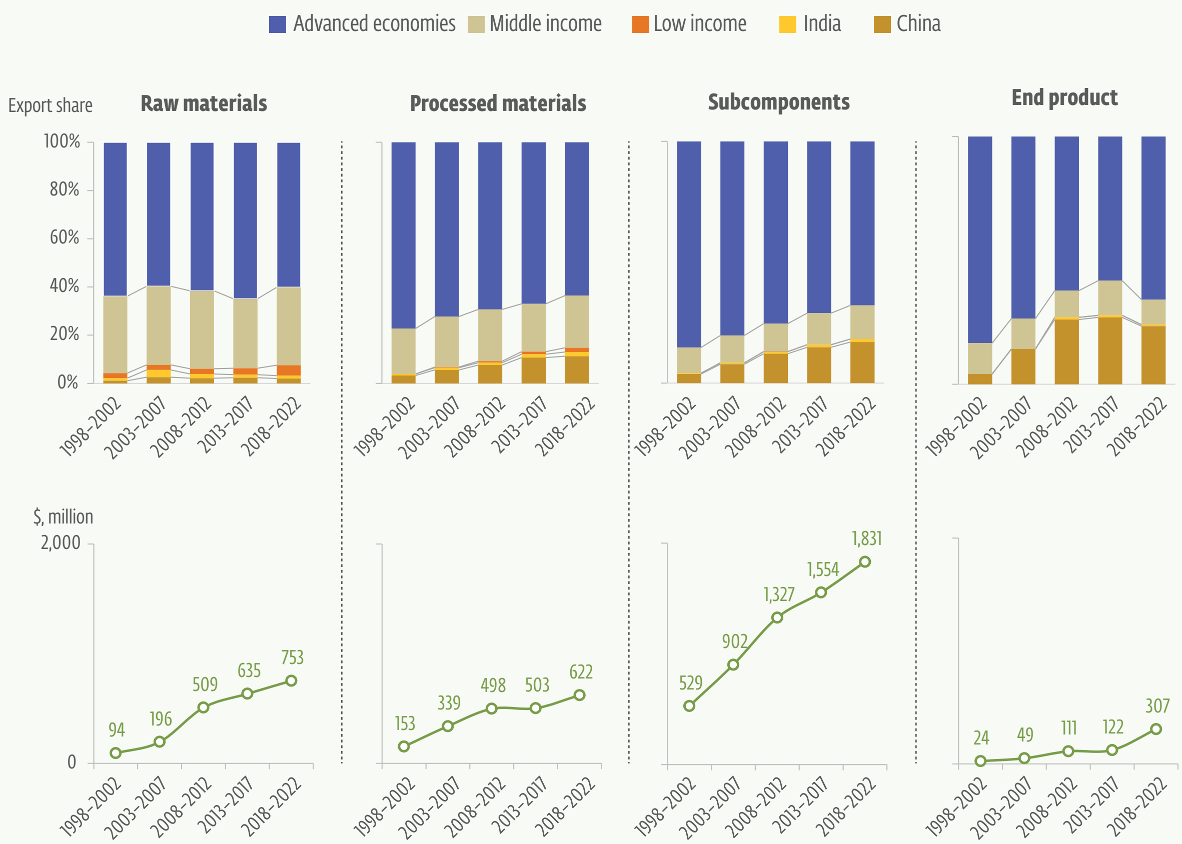


Source: BACI. **Note**: The figures report the evolution of country groups' participation in decarbonization value chains, as defined by Rosenow and Mealy (2024). Panel A shows five-year averages of country group shares in decarbonization value chains excluding raw materials. Panel B shows the evolution of export values of decarbonization value chains, excluding raw materials, deflated using nominal GDP over constant GDP in 2015 U.S. dollars.

One important way to interpret RCA is that, under certain conditions, it reflects comparative advantage, the relative productivity of a country—which can be driven by natural resources, labor, capital, or underlying capabilities due to factors such as technology. In other words, green comparative advantage reflects that a country has a lower opportunity cost of producing green goods than other goods, and that this gap between green and non-green goods is bigger than for other

FIGURE 2.2

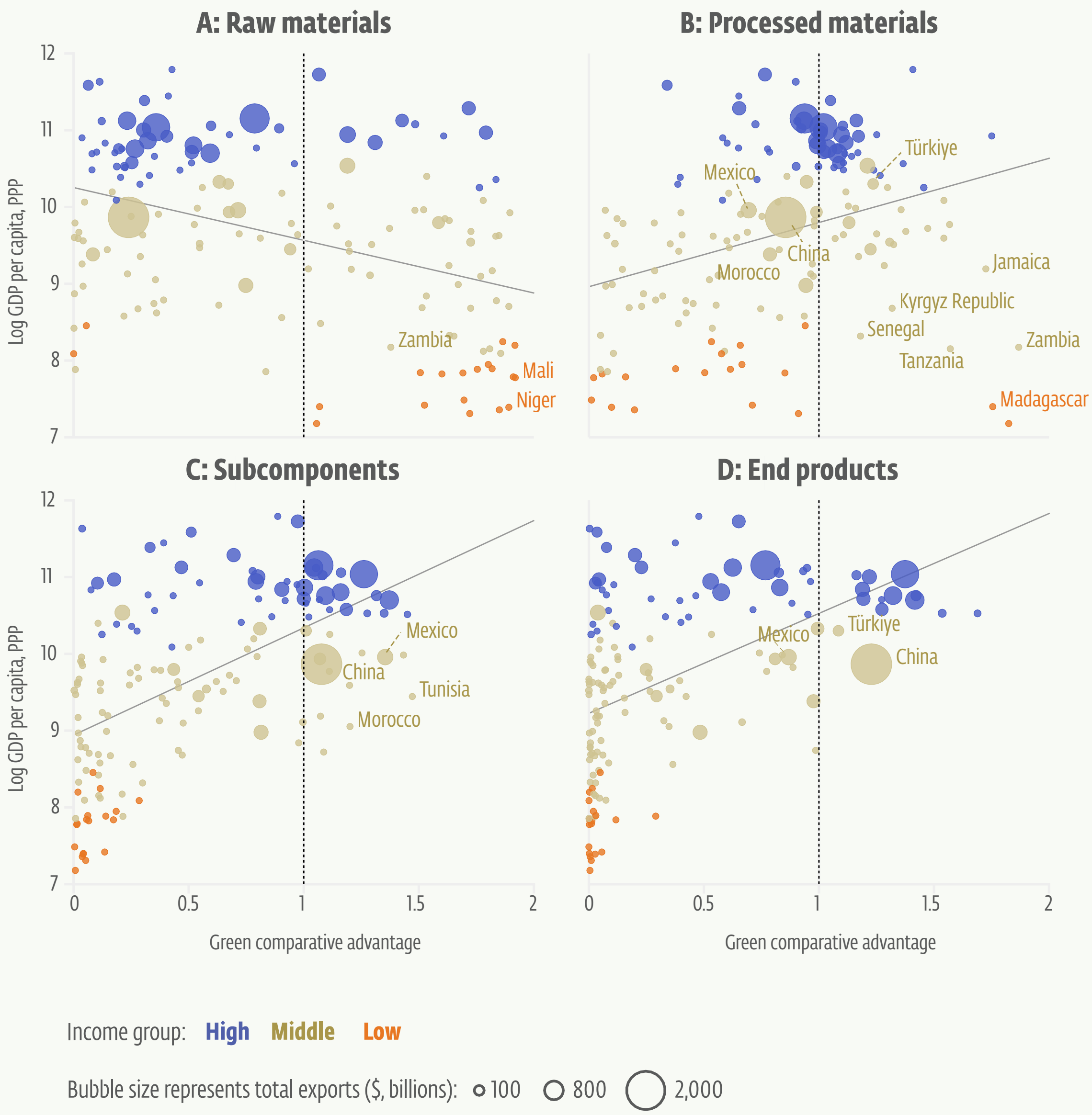
LMIC gains in green export market shares were mainly driven by processed materials and subcomponents



Source: BACI and IFC Green Value Chain Explorer (GVCE). **Note**: The figure reports the evolution of country groups' participation in decarbonization value chain stages, as defined by Rosenow and Mealy (2024): raw materials, processed materials, subcomponents, and end products. Product categories by stage in the value chain rely on data from IFC's Green Value Chain Explorer (GVCE). More information on the product classification can be found in online appendix 1. On the left, the figure shows the market share of exports along value chains for decarbonization products over time, by segment along the value chain. On the right, the figure highlights the market volume of each of the segments over time, deflated using nominal GDP over constant GDP in 2015 U.S. dollars.

FIGURE 2.3

Green export competitiveness in raw materials is stronger in poorer countries—all other production stages are stronger in richer countries



Source: IFC calculations based on BACI, World Bank Green Value Chain Explorer (GVCE). **Note**: The figures report scatterplots of the symmetric revealed comparative advantage (RCA) for decarbonization value chain stages between 2021 and 2022 against a country's per capita GDP in 2022. It is s defined as $RCA = s_{green,c}/(0.5 \times (s_{green,c} + s_{green}))$, where $s_{green,c}$ indicates the export shares of good i by country c and s_i indicates the world's share of good i's exports in all goods exports. The RCA measure is bounded between 0 and 2, and symmetric around 1, avoiding extreme values when countries export very few products. See appendix 3 for further explanations. Stages in the decarbonization value chain are defined as in Rosenow and Mealy (2024): raw materials, processed materials, subcomponents, and end products. Product categories by stage in the value chain rely on data from IFC's Green Value Chain Explorer (GVCE). More information on the product classification is in online appendix 1. The size of each marker is larger the greater the country's export volume.

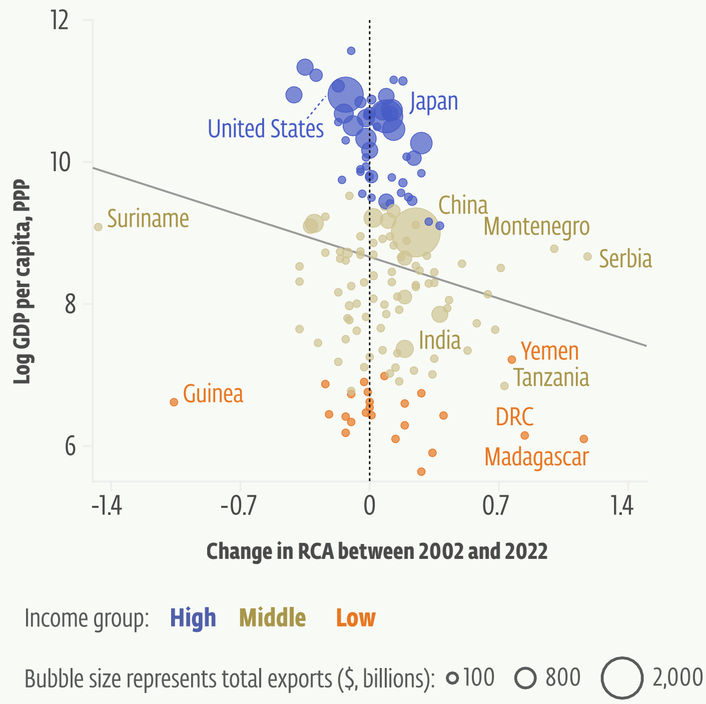
countries.[10] Note that country A might be less productive overall in producing green goods than country B. But if country B also has a higher productivity than country A in non-green goods, and this lead is even bigger than for green goods, country A may still have a comparative advantage in green goods.[11]

On average, high income countries display a revealed comparative advantage in green goods at all stages of the value chain, except raw materials (**figure 2.3**). But some LMICs display comparative advantage in more advanced production stages, though their presence in the green RCA>1 group declines closer to end products. China and Türkiye are the only middle income countries with a revealed comparative advantage in final goods.

LMICs are gaining green market share over the course of the 21st century. Again, it could simply be that they are growing faster overall and thus gaining market share in all products. Another reason is they are developing competitive capabilities in

FIGURE 2.4

Low and middle income countries gained green comparative advantage over 2000–2022



Source: IFC calculations based on BACI and World Bank Group, World Development Indicators.
Note: The figures report a scatterplot of the country-level changes in green symmetric RCA between 2000 and 2022 against a country's per capita GDP in 2022. The size of each marker is larger the greater the country's export volume.

10 See French (2017) and Reed (2024) for a review.

11 Comparative advantage does not necessarily have to result from differences in technology. It could also derive from differences in the abundance of production factors including natural resources or stem from returns to scale (Reed 2024). Moreover, the pattern of comparative advantage can be altered over time by technological change and events such as war or deliberate policies such as investment in education or other capabilities (Krugman 1987, Redding 1999).

FIGURE 2.5

Several low and middle income countries significantly increased their green comparative advantage

Source: IFC calculation based on BACI.
Note: The figures examine country-level changes in green symmetric RCA between 2000 and 2022 for two groups of countries. Panel A reports the change in RCA for the countries with the largest global export market share. Panel B reports the change in RCA for the 20 countries with the biggest increase in RCA over the same period. In each panel, countries are ranked from left to right, in descending order of change in RCA.

green products specifically. Looking at changes in comparative advantage across income levels shows on balance that LMICs are gaining green RCA faster (**figure 2.4**).

The overall trend masks diverging country trajectories, as shown by the sets of countries with the largest green market share in the early 2020s and those with the biggest gains in RCA since the year 2000 (**figure 2.5**). High income countries such as Germany and Japan, with a large market share throughout, deepened their comparative advantage. Others—such as the United States or France—saw their comparative advantage in green goods decline relative to other countries. Some of the largest improvements in RCA have come from LMICs such as Congo, Madagascar, Montenegro, and Serbia. This may be surprising given China's prominent role in many green markets. However, China's exports have spanned a wide range of product categories, many of which have expanded substantially over the past two decades. So, even as China's green export volume grows, the share of green goods in its total exports does not necessarily rise faster than in other countries.

What is the potential future of green comparative advantage?

Comparative advantage suggests capabilities—derived from skill, know-how, geographic good fortune, or natural resource abundance. In an increasingly knowledge-based economy, such capabilities can be gleaned from the activities of scientists, innovators, entrepreneurs, marketers, and designers. Such measures also capture products and services not necessarily traded across borders and thus not included in typical customs records.

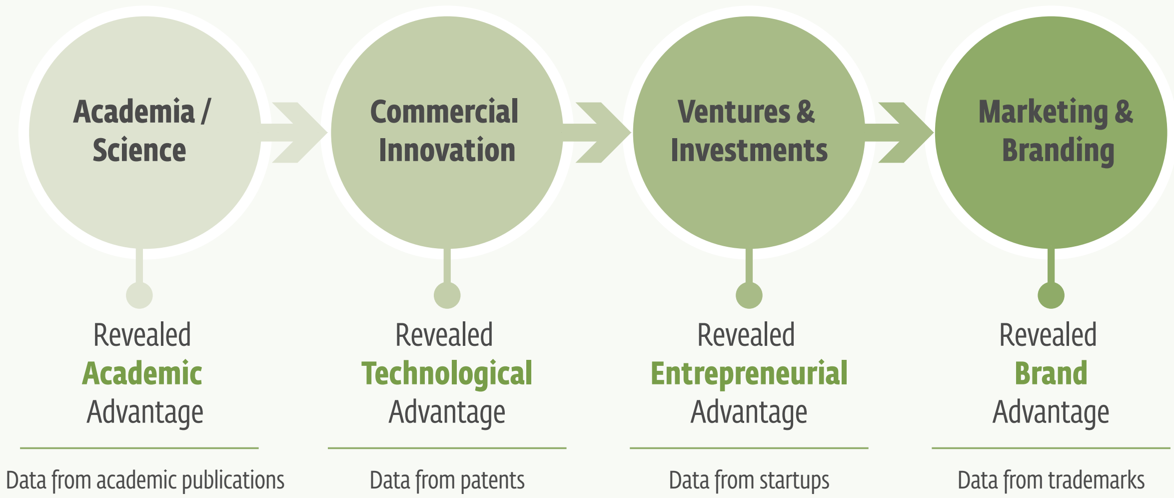
Think of this as tracing the value chain of the knowledge economy (**figure 2.6**). Academic research provides the raw material by generating new knowledge and basic research. Some of this knowledge has the potential to be turned into commercial products but not before some processing involving more applied research. Next, to deliver an innovation to the market, it needs to be embodied as a component of an entrepreneurial venture. Finally, brands and trademarks can help bring innovative products to the market and communicate their virtues to end users.

To get a more concrete measure of the capabilities underlying each stage in this knowledge economy value chain, we construct indicators based on academic publications, patent applications, data on startups and registered trademarks. Although the process of converting knowledge to innovation can take many forms, our most comprehensive proxy is based on patent data. Bringing innovations to market can happen within established firms, but it is well documented that key product innovations often enter the market through startups, for which comprehensive data are increasingly available.[12] Finally, trademark registers provide an accessible data source for branding activities.

12 Gompers and Lerner (2001) highlight the role of venture capital in supporting startups and fostering innovation. Lerner (2009) discusses the crucial role of startups in commercializing innovations and the challenges of government intervention in venture capital markets.

FIGURE 2.6

The Knowledge Economy Value Chain



Source: IFC

These data sources can be used to construct comparative advantage-like indicators. For instance, the share of a country's innovations (measured by patents)[13] in green technologies over the share of innovations in the same category globally, has previously been referred to as revealed technological advantage (RTA).[14] In a similar fashion, we calculate the share of green academic and scientific research articles in a country over the share globally—the revealed academic advantage (RAA)—, the share of green startups in a country over the share globally—the revealed entrepreneurial advantage (REA)—, and the share of green trademarks in a country over the share globally—the revealed brand advantage (RBA).[15]

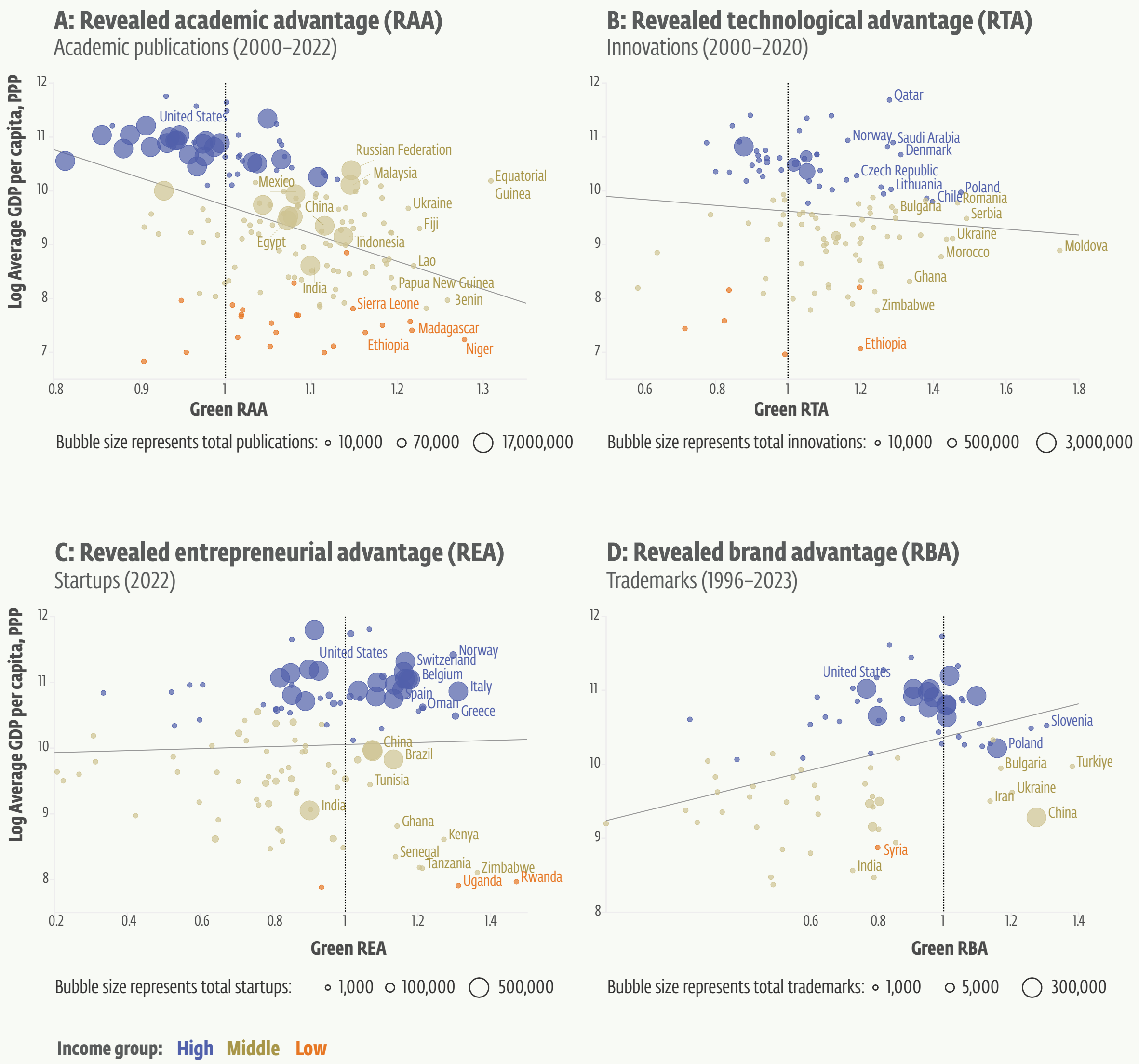
13 The units of analysis are patent families—which we call innovations—rather than individual patents. More economically valuable innovations are typically protected in many different jurisdictions by several patents that jointly make up the "patent family" of an innovation. For the purposes of computing innovative steps, we count patent families only once and attribute innovations to countries on the basis of the location of the involved inventors, who are sometimes distributed across a number of countries. We consider both single and multijurisdiction innovations.

14 Soete and Wyatt (1983).

15 Patents or academic papers are assigned to countries, using the location of inventors or co-authors on academic papers. These measures are highly skewed at the level of individual countries with innovators in leading countries like the United States filing over 3 million patents over our sample period (2000–2020) whereas some of the smaller lowest income countries have sometimes only a few patents associated with inventors based in the country. In these cases, it is not meaningful to construct comparative advantage indicators. We discuss in Appendix A how that this would introduce substantial measurement error. Thus, the analysis is restricted to countries with at least 100 units (academic papers, innovations, startups, trademarks). Appendix A also explores the robustness of the key results to variations of this threshold. For patents, this restricts the sample to primarily high and middle income countries, rather than low income countries.

FIGURE 2.7

Low and middle income countries reveal strong comparative advantage in the foundations of the knowledge economy



Source: IFC calculations based on OpenAlex, 2023 Patent Statistical (PATSTAT), CrunchBase, European Union Intellectual Property Office (EUIPO), and World Bank Group' s World Developemnt Indicators (WDI) Database. **Note**: Each panel relates countries' green symmetric revealed comparative advantage to GDP per capita, based on different knowledge measures. Panel A presents green revealed academic advantage (RAA) using academic publications, aggregated from 2000 to 2022. Panel B presents green revealed technological advantage (RTA) based on patents. Panel C presents green revealed entrepreneurial advantage (REA) using data on startups, aggregated from 2000 to 2022. Panel D presents green revealed brand advantage (RBA) using data on trademarks. The sample includes countries meeting two criteria: having at least 500,000 inhabitants, and total numbers of academic papers, patents, startups, or trademarks at or above 100. GDP per capita is PPP, constant 2021 international dollars, averaged over the period. The size of each marker is larger the greater the country's total number of papers, patents, startups or trademarks. The grey solid line depicts fitted values from the unweighted OLS estimate of log GDP per capita on symmetric comparative advantage. See online appendix 1 for further details on sector classification.

LMICs tend to have a stronger comparative advantage in academic output (RAA) (**figure 2.7A**). On average, countries with a green comparative advantage (RAA>1) have a per capita income that is $18,000 lower than countries in the (RAA<1) group.

Likewise, there is the tendency for green RTA to be more pronounced in poorer countries (**figure 2.7B**). So, while there is less overall innovation and scientific activity than in high income countries (**figures A4.2** and **A4.3** in appendix 4), a larger fraction of what takes place in these countries is devoted to green topics and technologies. As for RCA, this does not necessarily imply that scientists and engineers in LMICs are better at doing research on green technologies; it suggests that they are better in green than in non-green technologies. How real are the innovations driving LMICs' comparative advantage in green technologies? Spotlight 2.1 highlights concrete examples of meaningful green innovations from LMICs.

Moving further downstream to look at startups, there is no clear relationship between revealed entrepreneurial advantage (REA) and a country's income (**figure 2.7C**). And for trademarks, the relationship is sharply positive, akin to the pattern for final products in the previous chapter (**figure 2.7D**).

So, LMICs tend to have a green comparative advantage in the upstream segments of the knowledge economy but not so much in the downstream segments.

How to interpret this finding?

One possibility is that this reflects the timing of innovation. It takes time for scientific research and innovation to work its way through to new startups, marketable products, and trademarks, and today's upstream advantage is naturally less dominant than the downstream advantage. Clean research and innovation may align well with the characteristics of LMICs for several reasons. For instance, green research projects may involve lower development costs, making them more accessible to new entrants and LMIC firms with limited resources. In addition, pro-environmental preferences, a potential driver of green innovation, may be more pronounced in these countries.

Another possibility is that these patterns could indicate latent capabilities not yet fully translated into commercial opportunities, owing to policy barriers or market failures, which could include financing constraints or the presence of large knowledge spillovers insufficiently considered by private investors, leading to underinvestment. These hypotheses are explored in chapter 3 (on possible drivers for the observed comparative advantage patterns) and chapter 4 (on potential market failures).

What is the quality of LMIC innovation and science?

A common way to examine quality differences in patent data is to take patent citations as an indicator of innovation quality (**figure 2.8A**).[16]

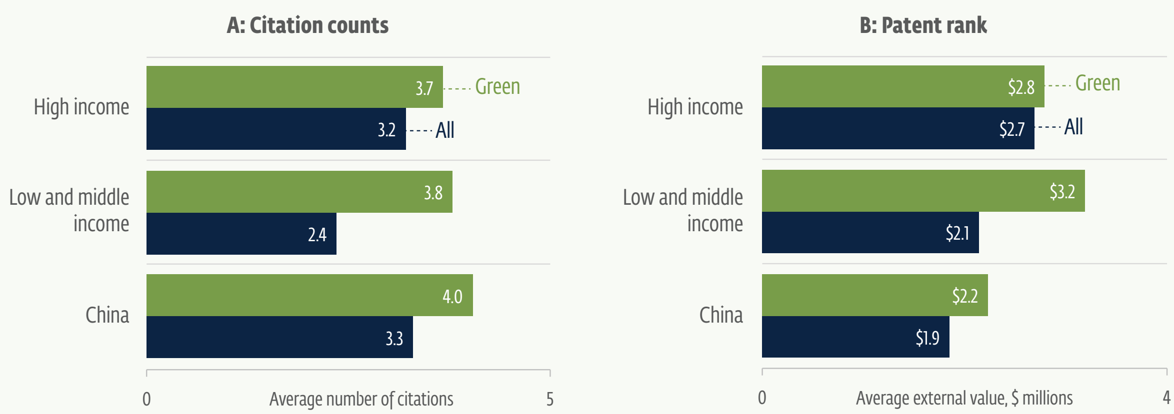
16 Adjusting for citations can also deal with potential institutional differences in the use of patents across different jurisdictions. For instance, various patent offices treat innovative steps in different ways. The Japanese patent office for many years required innovations to be broken up into several parts whereas in other places innovators could combine several related claims to novelty in one "larger" innovation. Patents also differ in the rigor that is applied to establish novelty. Many Chinese patents follow the so-called "Utility Model," which requires less scrutiny by patent examiners in exchange for a faster administrative process.

Citations can reflect the extent of knowledge spillovers, making them a useful proxy for assessing the broader societal value of an innovation beyond its private returns (see chapter 4). Green innovations have higher simple citation counts on average than non-green (**figure 2.8A**). What these results suggest is that LMIC innovations are not low quality and that on average they are, directly or indirectly, cited by valuable later innovators across the world. However, counting innovation citations does not account for the value of innovation—and only offers a limited perspective.

To measure both the private and spillover values of patents, Guillard et al. (2021) develop a new metric called Patent Rank (P-Rank). This method uses a patent's full citation network, adapted from Google's Page Rank algorithm, and leverages Kogan et al. (2017)'s approach to estimate the private value of innovations from stock market data.[17] P-Rank estimates how much a patent contributes to the profits

FIGURE 2.8

For green patents, LMIC innovation is more valuable, on average, than HIC innovation



Source: IFC calculations based on Guillard et al. (2021) using data from PATSTAT and Kogan et al. (2017). **Note**: Panel A reports average citation counts of patented innovations across different regional groupings as well as separately for green innovations. Panel B reports average values of Patent Rank following Guillard et al. (2021). This provides a method to assess the quality of patented innovations using citations while considering both direct and indirect citation and to account for economic value differences of the cited innovations. Patented innovation from LMICs are on average 20 percent (2.14/2.69 – 1) less valuable than those from HICs. By contrast, this is reversed for green innovations where LMIC innovations are on average 14 percent more valuable than those from HICs. Chinese innovations are of lower value on average than both HIC and LMIC innovations. Note that in all regions green innovations have an above-average value. The difference is most pronounced in LMICs, with a nearly a 50 percent gap.

17 This approach overcomes several shortcomings of a simple patent count which considers all cited patents to be of identical value. For further details see Appendix b.

of the original inventor and to later innovations that directly or indirectly build on it. The sum of the direct and indirect economic value represents the total economic value of an innovation (**box 2.2**).

Estimates from the P-Rank approach suggest the economic value of LMIC innovations is comparable to HIC ones (**figure 2.8B**), confirming results from the citation counts. On average, innovations from LMICs (excluding China) are valued at around $2.1 million, compared with $2.7 million for those from HICs. Although Chinese innovations lead in citation counts (**figure 2.8A**), they are valued a bit lower, at around $1.9 million (**figure 2.8B**). This suggests that Chinese patents are more likely to be cited by less valuable follow-on innovations. Overall, green innovations in LMICs outside of China emerge as the most valuable category, compared with either non-green patents or HIC patents.

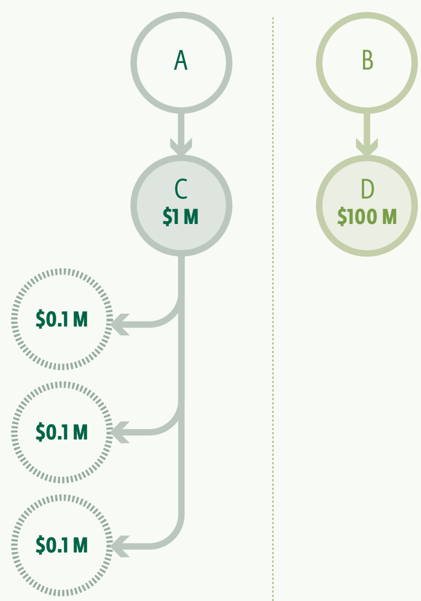
Several factors might explain the relatively high value of LIMCs' innovations. First, the types of technologies being developed can differ. Guillard et al (2021) find that private values from innovation tend to be high in fields such as pharmaceuticals

BOX 2.2

The Direct and Indirect Value of Innovation

Patents are a convenient way to measure the occurrence of innovation. But it has long been recognized that individual innovative steps vary widely in their economic value. Patent forward citation counts are a common way to address this: if a patent is cited a lot, it is plausible that it is more valuable. But simple citation counts do not account for the quality of the citers. If a citing innovation is highly cited (such as C below), simple citation counts of innovation A lead to the exact same value as in the case of innovation B that is cited by an innovation without further citations. Citation counts are also not a direct measure of economic value; innovations can have economic value without necessarily inspiring further innovative ideas (such as D below valued at $100 million). The Patent Rank (P-Rank) measure developed by Guillard (2021) and used in figure 2.8b addresses both issues by adapting the Google Page Rank algorithm to account for both direct and indirect linkages in the patent citation network (as opposed to webpages) as well as using estimates of the value of patents derived from stock market responses to the granting of patents.

Illustration of Patent Rank (P-Rank)



and biotechnology. If LMIC innovators are more likely to focus on these high-value sectors, this could help explain their high average value. Second, the way innovations are assigned to countries matters. Since innovations can be assigned to the inventor's location rather than the headquarters of the firm, innovations by inventors associated with multinationals can be counted in their LMIC affiliates. LMIC inventors may be disproportionally working with large multinational firms, engaging in more valuable projects, and more likely to have their innovations diffused globally, thus maximizing opportunities for citations. Moreover, looking closely at the flow of knowledge (explored further in chapter 4), LMIC innovations may have disproportionally higher spillover values because it is predominantly HIC inventors who benefit from LMIC innovations.

In addition, green innovations are more valuable than their non-green counterparts, across all countries and particularly in LMICs (**figure 2.8B**). On average, green LMIC innovations are valued at $3.2 million, higher than the $2.8 million average for green innovations from HICs. In other words, there is a green gap—where green innovations perform better than non-green ones—that is even larger for LMICs (see further in chapter 4).

How special is green?

Could the negative relation between income level and green RTA or RAA simply be a feature of newly emerging technologies in general? To answer this, **figures 2.9** and **2.10** display the correlation between country income and RTA, RAA, or REA for a range of other emerging technologies. The correlation is negative only in one other case—the RTA for biotechnology. This suggests that a negative correlation is not unique but not self-evident either.

Chapter 3 delves deeper into some of the possible drivers and characteristics that might explain a latent comparative advantage in green technologies for LMICs.

Not all green technologies are created equal

The term "green" incorporates a broad field comprising many different sectors and technologies. For the RTA of a variety of green subfields, heterogeneity is substantial both across technologies and countries. In other words, even though LMICs tend to show a stronger comparative advantage in green technologies overall, this pattern does not hold uniformly across all green subfields. Nor is it always the same countries that lead in all types of green innovation. To examine this heterogeneity and highlight specific countries, more detailed "green" categories can be differentiated, ranging from technologies for adaptation to climate change to green energy (**figure 2.11** illustrates the leading countries in adaptation and transport technologies; **figure A4.2** in appendix 4 shows additional results for green agriculture, green ICT, circular economy, and green energy).[18]

18 For the precise definition of all categories see online appendix 1.

FIGURE 2.9

Revealed technological advantage (RTA) for emerging technology areas

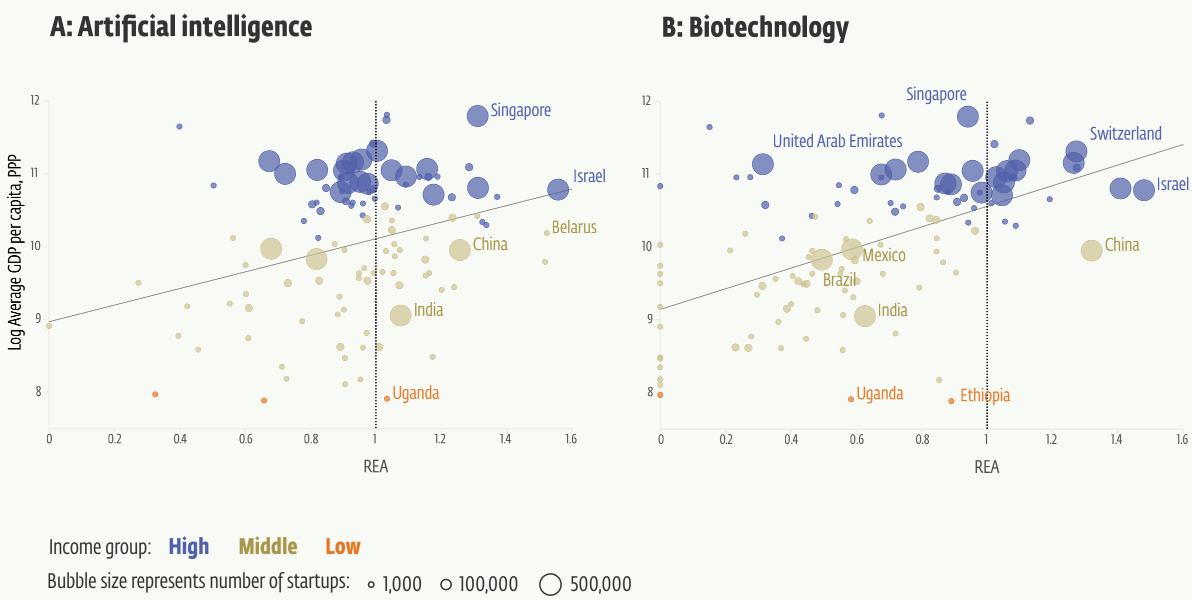
Source: IFC calculations based on 2023 Patent Statistical Database (PATSTAT) and World Bank Group data.

Note: The calculations include 159 countries with a population size of at least 500,000 and total patent count during 2000–2020 above 100. The patent count is at the DOCDB family level and includes both applicants' and inventors' locations. On the X-axis is the symmetric RTA for each country calculated based on total patents between 2000 and 2020. On the Y-axis is the logarithm of the average GDP per capita between 2000 and 2020. The grey solid line depicts fitted values from OLS estimate of log GDP per capita on symmetric RCA. The size of each marker is larger the greater the total number of patents in the country by quintile. See online appendix 1 for further details on patent data used and technology classifications.

Results from a further breakdown of green technologies show that LMICs tend to be stronger in technologies related to adaptation, green agriculture,[19] or green ICT. Nine out of 10 countries with the highest RTA in adaptation are LMICs. Although at least a few LMICs appear in the top RTA group across all green technology categories, they are much less represented in areas like green transport, where HICs like Germany and

FIGURE 2.10

Revealed entrepreneurial advantage (REA) for emerging technology areas

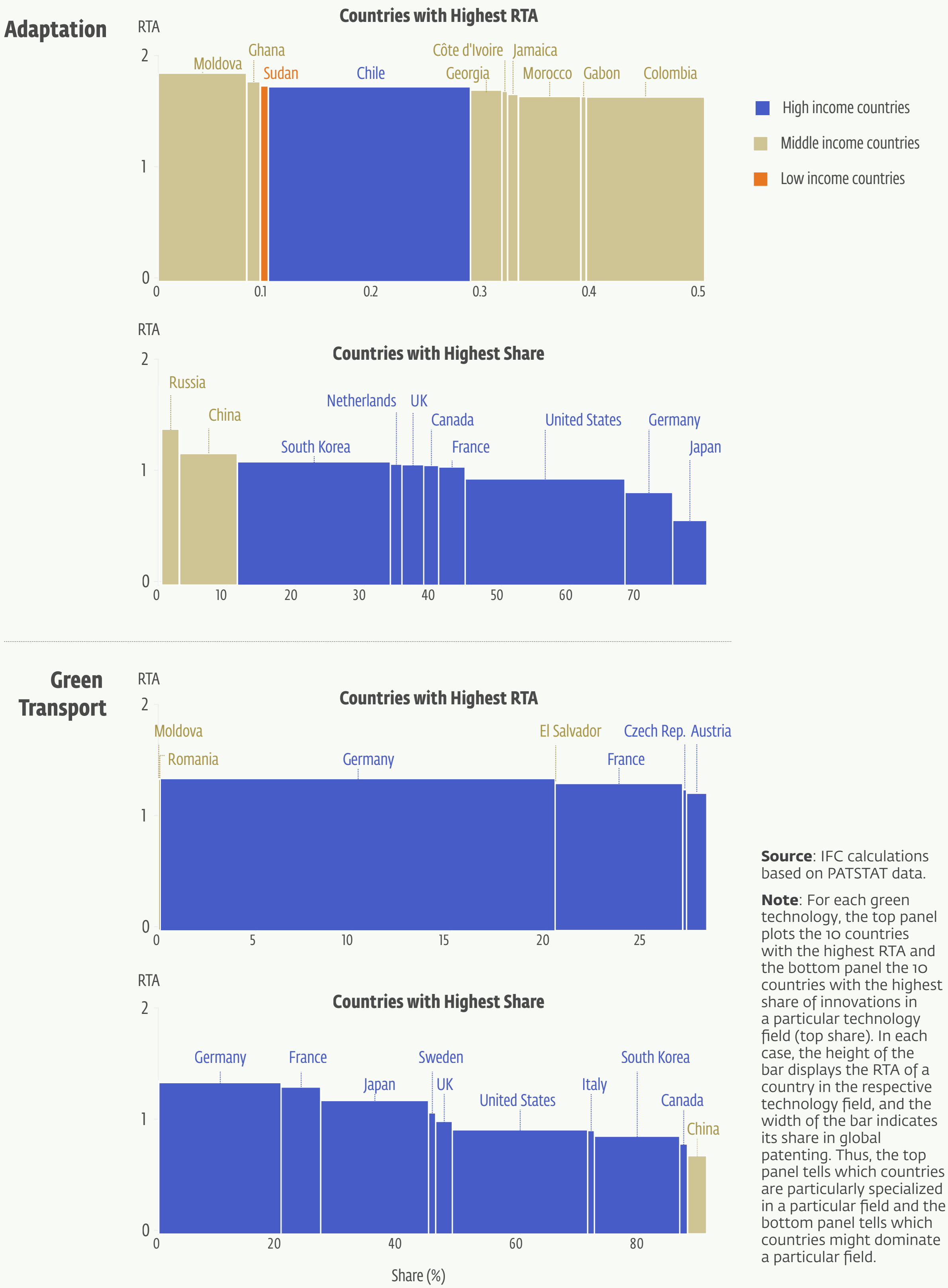


Source: IFC calculations based on CrunchBase and World Bank Group data. **Note**: The figures relate symmetric revealed entrepreneurial advantage using data on startups to country per capita income. Data are from CrunchBase, aggregated from 2000 to 2022. The sample includes countries meeting two criteria: countries having at least 500,000 inhabitants, and a total number of academic papers, patents, startups, or trademarks at or above 100. GDP per capita is PPP, constant 2021 international dollars, averaged over the period. The size of each marker is larger the greater the country's number of startups. The grey solid line depicts fitted values from the unweighted OLS estimate of log GDP per capita on symmetric revealed entrepreneurial advantage. See appendix 1 for further details on sector classification.

19 Note that green agriculture designates agricultural technologies for carbon mitigation. Agricultural technologies for adaptation are included as part of the adaptation category. For further details see online appendix 1.

FIGURE 2.11

Specialization in green varies substantially across subfields and countries



Source: IFC calculations based on PATSTAT data.

Note: For each green technology, the top panel plots the 10 countries with the highest RTA and the bottom panel the 10 countries with the highest share of innovations in a particular technology field (top share). In each case, the height of the bar displays the RTA of a country in the respective technology field, and the width of the bar indicates its share in global patenting. Thus, the top panel tells which countries are particularly specialized in a particular field and the bottom panel tells which countries might dominate a particular field.

France not only have high RTAs but also dominate the overall share of innovations.[20]

Moreover, no one size fits all. Some LMICs rank among the top RTA performers across multiple green technology categories, but many others—spanning all continents—specialize in just one or a few areas. For instance, Tunisia and Morocco lead in green energy, whereas Brazil is dominant in circular economy technologies. India stands out as the top performer in green ICT, possibly building on its earlier ICT successes. And some countries display broad strength: Moldova makes it to the top in all categories apart from ICT. Morocco is in the top category for circular economy, energy, and adaptation, and Colombia for agriculture, adaptation, and circular economy.

These results suggest that the most profitable green opportunities for LMICs will differ by country. Besides considering what they are good at doing, LMICs will also need to consider the size of demand and market structure in different sectors. In markets where large successful incumbents have established a strong foothold, it can be more challenging for LMIC firms to gain a competitive edge. For example, the market for lithium batteries is highly concentrated, with the top two suppliers accounting for nearly half of the global market.[21] Entering such a market would likely require a wide range of capabilities to succeed. Alongside this report an interactive explorer will be released, allowing deeper dives into both LMIC comparative advantage and market characteristics across green subtechnologies.

Variation at the country level carries through to regional groupings (**figure 2.12**). The trend holds that LMICs tend to be greener (a larger fraction of the cells in the LMIC category is green). But there is substantial heterogeneity. For green transport, only Europe and Central Asia show a green RTA larger than one. Almost all LMIC regions have an advantage in adaptation technologies. China has an RTA above one in all clean categories except transport and greenhouse gas capture. All LMIC regions except India have an advantage in green energy technologies while India has a strong bias toward green ICT.

20 Despite the recent success of the Chinese electric vehicle sector, most innovations in green transport of the last 20 years originated in HICs. Nevertheless, China now commands a sizable share, as suggested in panel B of figure 2.11, though China's green transport RTA remains below one. China is responsible for a large share of green energy innovation, but it does not show a particularly strong specialization in green energy technologies. China patents a lot in those technologies due to its size, but it patents even more in other technologies.

21 https://source.benchmarkminerals.com/article/which-companies-control-the-lithium-ion-battery-supply-chain-2.

FIGURE 2.12

Heterogeneity of green RTA remains at the level of the main regional groupings

		Adaptation	Circular Economy	Carbon capture	Green agriculture	Green buildings	Green energy	Green ICT	Green manufacturing	Green transport	Fossil fuel technologies	AI	Aerospace	Biotechnology	Blockchain	Healthtech	Wireless
Low and middle income countries	East Asia & Pacific	1.26	1.22	1.37	1.29	1.05	1.07	1.18	1.2	0.55	0.93	0.86	0.61	1.11	1.06	0.73	1.03
	Europe & Central Asia	1.38	1.39	0.79	1.66	0.95	1.24	0.6	1.4	0.92	0.82	0.8	1.17	1.08	0.68	0.58	0.52
	Latin America & Caribbean	1.57	1.65	1.17	1.53	1.03	1.2	0.6	1.24	0.86	0.87	0.92	0.95	1.13	0.93	0.88	0.65
	Middle East & Northern Africa	1.39	1.28	1.12	1.07	1.06	1.21	1.34	1.18	0.73	0.99	1.1	0.88	1.2	0.92	1.01	1.41
	South Asia	1.32	0.73	1.26	0.79	0.75	1.08	1.5	1.17	0.56	0.84	1.03	0.64	1.26	1.07	1.16	1.49
	Sub-Saharan Africa	1.32	1.14	0.93	1.05	1.05	1.01	0.77	1.27	0.62	1.06	0.92	0.87	1.11	1.38	1.04	0.9
	India	0.99	0.78	1.11	0.51	0.77	0.78	1.5	0.94	0.73	1.13	1.39	0.88	1.14	1.32	1.12	1.4
	China	1.16	1.26	0.67	1.32	1.19	1.11	1.38	1.18	0.68	0.95	1.22	0.86	0.86	1.05	0.72	1.44
High income countries	East Asia & Pacific	0.95	1.08	0.87	1.09	1.03	1.11	0.9	1.05	0.99	0.96	0.89	0.76	0.94	0.91	0.77	0.9
	Europe & Central Asia	0.99	0.94	1.09	0.78	1.04	0.99	0.73	0.98	1.16	0.96	0.82	1.07	1.05	0.8	0.88	0.87
	Latin America & Caribbean	1.68	1.68	1.43	1.41	0.71	1.19	0.42	1.53	0.58	1.02	0.84	0.62	1.33	0.85	1.12	0.42
	Middle East & Northern Africa	1.13	0.94	1.32	0.85	0.83	0.82	1.34	0.91	0.4	1.21	1.34	1.15	1.07	1.23	1.39	1.12
	North America	0.94	0.76	1.07	0.81	0.88	0.8	1.11	0.85	0.9	1.07	1.13	1.15	1.03	1.18	1.26	1.03

Source: IFC calculations based on PATSTAT data. **Note**: The figure reports RTA for various green and trending subcategories, confirming trends already illustrated.

Spotlight 2.1

Examples of innovation in middle income countries

Despite their relatively low levels of innovation overall, many LMICs innovate disproportionately in green technologies, compared with other fields. This box reports some concrete examples from businesses or universities in Morocco, Montenegro, and Romania. Although these countries are not global leaders in the fields considered here, the examples suggest that local innovations are feasible and can make a meaningful contribution

Ecological desalination in Morocco

Morocco has one of the highest comparative advantage figures in adaptation technologies. The country has been focusing on innovations that could help tackle local challenges, such as water scarcity. A notable example comes from the University of Rabat, which filed a patent for a seawater desalination process (WO2015076648A1) that significantly reduces energy consumption—an important factor in a country with limited freshwater resources. The technology, designed for small-scale stations, uses a unique system to distil seawater, making it a cost-effective solution for communities that struggle to access green water.

Wave energy from Montenegro

Many LMICs show a high comparative advantage in green energy. Montenegro has made notable strides in wave energy technology. A patent (US10989163B2) filed by Sigma Energy features a device that converts ocean wave motion into electricity. While the company is still in the development phase, it is working on scaling the technology and has plans for full-scale deployment.

Synthetic wood-manufacturing plant in Romania

Circular economy is yet another field where LMICs show a strong comparative advantage. Innovators in Romania[22] have been exploring ways to create eco-friendly materials, such as synthetic wood made from recycled waste. A patent filed by Universitatea Tehnică "Gheorghe Asachi" outlines a process to create composite wood from agricultural, forestry, and plastic waste. The biodegradable synthetic wood offers an alternative to traditional wood products, which could help reduce deforestation and plastic waste.

Whether it's tackling water scarcity in Morocco, exploring renewable energy in Montenegro, or reducing waste in Romania, innovators in each of these nations are carving out a niche to address local or regional needs. Their work shows that even in middle income economies, there is potential to drive change and attain commercially viable solutions in sustainable technologies.

22 As of 2021 Romania is classed as a HIC. However, over sample period that underpins most of the data used in this the report, Romania was classed as a middle income country.

3

Drivers—
Changing Comparative Advantage

KEY TAKEAWAYS

- Evidence suggests that comparative advantage in green innovation may stem from lower research and development (R&D) costs. In turn, these may be particularly attractive for financially constrained firms in low and middle income countries.
- Poorer countries are now more concerned about climate change than richer economies, and there is some evidence that this could be driving a sharper focus on green technologies by innovators in low and middle income countries. Indeed, public concern about climate is strongly correlated with increased innovation intensity in adaptation technology.
- Climate policies in low and middle income countries have also contributed to clean innovation.

Low and middle income countries (LMICs) are improving their comparative advantage for green goods. They also tend to have a comparative advantage in the upstream of the knowledge economy value chain, perhaps indicative of future or latent comparative advantage. What could be the deeper structural reasons for these patterns? There are at least four possible drivers.

First are resource endowments that are critical for the green transition. Could this advantage be a springboard for success in more downstream parts of the green value chain?

Second are characteristics of green products and markets that make them less reliant on specialized skills, finance, or facilities (such as advanced research labs) that may be scarce in LMICs.

Third are demand-side factors. For instance, some LMIC innovations are particularly focused on adaptation technologies. This might be in response to a particular urgent local need to cope with the consequences of climate change.

Fourth are policies. Recent years have seen an increase in climate policies across both high-income countries and LMICs (**figure 1.2**). They have also seen a resurgence of vertical industrial policy, which is often aimed at triggering private sector development, including innovation. Is there evidence that such efforts were successful in LMICs?

The critical-mineral connection

The green transition relies on critical minerals such as copper, lithium, nickel, cobalt, and rare earth elements—essential inputs to wind turbines, power networks, and electric vehicles. Can a country's comparative advantage in minerals be leveraged as an entry point to further opportunities along the supply chain of green products? And is an abundance of raw materials already driving the emerging comparative advantage in green technologies or markets in some countries?

Historically, leveraging raw materials has proven a challenge especially for poorer countries, often despite policy commitments and investments. A key reason is the lack of complementary industries that are difficult to build from scratch. Such constraints are amplified where there is a lack of institutional capabilities, which leaves resource-dependent economies more prone to rent-seeking or conflict.[23]

Perhaps this time, things are—or could be—different? For the new generation of green value chain raw materials, downstream steps might be more accessible to poorer countries, a point discussed in chapter 4. It could also be that the organization of global value chains for fossil fuels depends on some specific characteristics that don't apply to green value chains.[24]

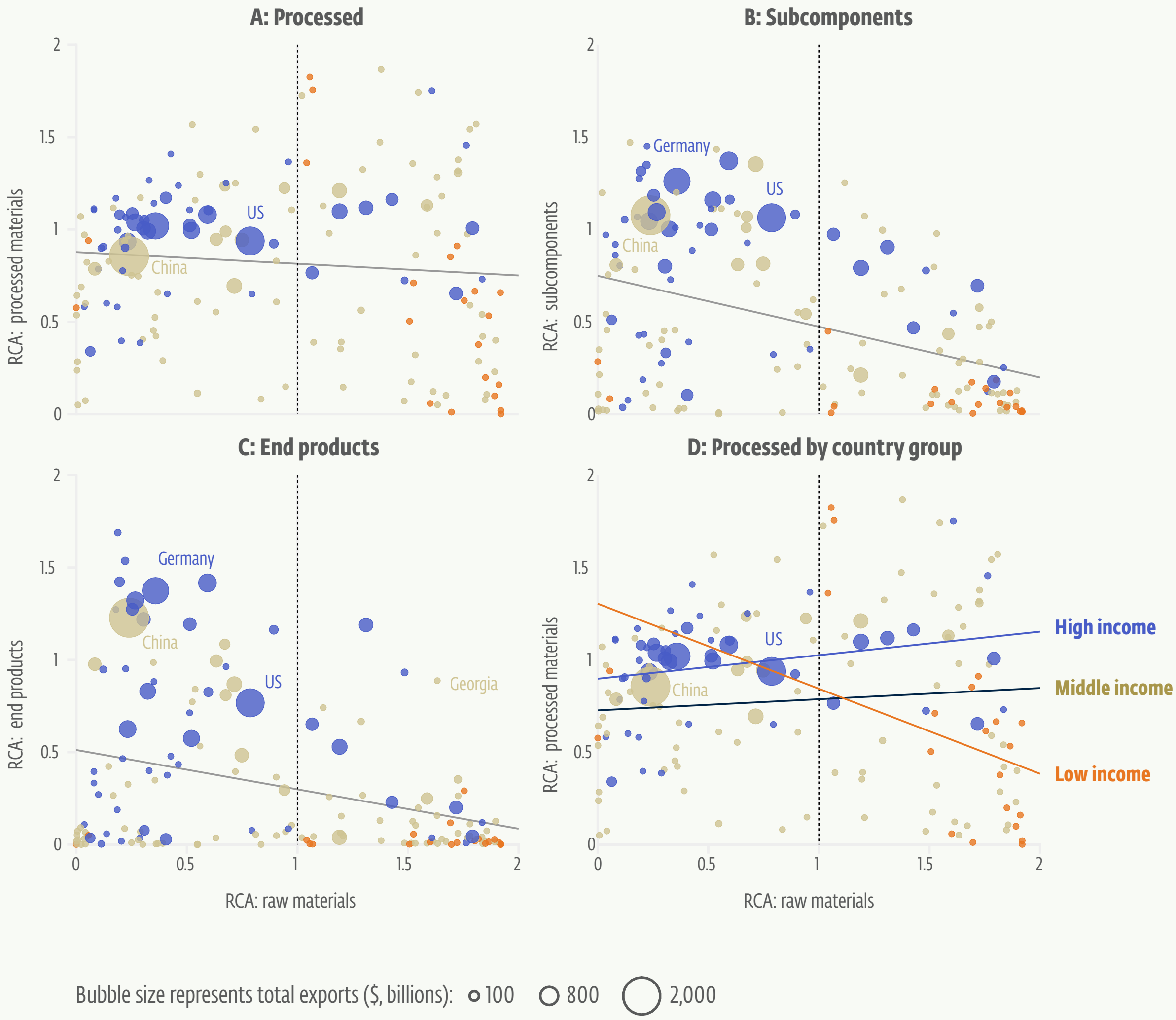
Examined here is the relationship between green value chain (GVC) resource abundance—that is, comparative advantage in green raw materials—

23 Some studies point to a possible "resource curse," where people seek the economic rents afforded by abundant natural resources, instead of engaging in productive activities (Sachs and Warner 1995; Ploeg and Poeldekke 2010).

24 For instance, oil refineries are usually located close to the end users of gasoline.

FIGURE 3.1

The critical-mineral connection works for processed materials and middle income countries



Source: IFC calculations based on BACI and IFC Green Value Chain Explorer (GVCE). **Note**: The figures correlate symmetric revealed comparative advantage (RCA) in green raw materials with RCA in downstream segments of the green value chains. Overall, the negative relationship means that there is no evidence that abundance in raw materials has led to comparative advantage downstream. The negative relationship is weakest for processed materials in panel A. Closer inspection in panel D suggests that this is a composite of a negative relationship for LICs and a positive relationship for MICs and HICs. This is consistent with the idea that factors such as lacking capabilities or institutions might hinder the emergence of downstream industries in LICs. Stages in the decarbonization value chain are defined in Rosenow and Mealy (2024): raw materials, processed materials, subcomponents, and end-products. Product categories by stage in the value chain rely on data from IFC's Green Value Chain Explorer (GVCE). More information on the product classification can be found in online appendix 1. The size of each marker is larger the greater the country's export volume.

and comparative advantage in downstream segments of green GVCs (**figure 3.1**). A negative correlation is typical: raw material RCA is on balance not associated with advantage in further downstream parts of the value chain (panels A–C). Instead, the opposite seems to be the case: countries that have a green comparative advantage in raw materials are not, on average, the countries that have a green comparative advantage in processed materials, subcomponents, or final products. And the link is weakest for processed raw materials, which would seem the natural starting point for a development path along the supply chain. Exploring this relationship by income shows that for some country groups (MICs and LICs) the relationship is indeed upward sloping, while it is not for LICs (panel D). This is consistent with green comparative advantage in raw materials translating into downstream advantage only in countries that have reached a certain level of economic development.

Examined next is the relationship between RCA in green raw materials and green RTA to assess whether comparative advantage in green raw materials could also lead to technological development and innovation, particularly in areas closely related to resource extraction. However, there is no evidence that abundance in raw material is already associated with a technological advantage: countries with a higher RCA in green raw materials do not exhibit a corresponding increase in green RTA (see **figure A4.1** in **appendix 4**).

Green innovation is more accessible for new entrants

Another potential driver of comparative advantage lies in accessibility. Green technology markets may be more accessible for new entrants not just because they are less mature, but also because some green products involve simpler production processes and value chains. For example, they may require fewer moving parts and, thus fewer complementary inputs and capabilities.[25] This translates into lower fixed costs and reduced barriers to entry, making these sectors attractive for newcomers. Similarly, the costs of becoming an innovator in green technologies may be lower on average. Green technologies may rely less on expensive labs or specialized research staff.

A new way to estimate the fixed R&D costs is associated with inventive steps specific to various technologies. Guillard et al. (2021) infer R&D costs from the distribution of innovation values across detailed technology fields (as explained in **box 3.1**). Fields with fewer low-value innovations have higher estimated fixed R&D costs because investors are less willing to pursue lower-value ideas when innovation is expensive.

Results using this approach suggest that green technologies tend to have slightly lower R&D costs, by 3 percent on average (**figure 3.2A**). Interestingly, the average R&D cost seems to be higher in LICs, but green R&D is disproportionally cheaper than other technologies in these countries. Furthermore, there is a strong negative correlation between the relative cost

25 For example, electric vehicles have fewer moving parts than internal combustion engine cars due to a simpler power train (Liu et al. 2021).

BOX 3.1

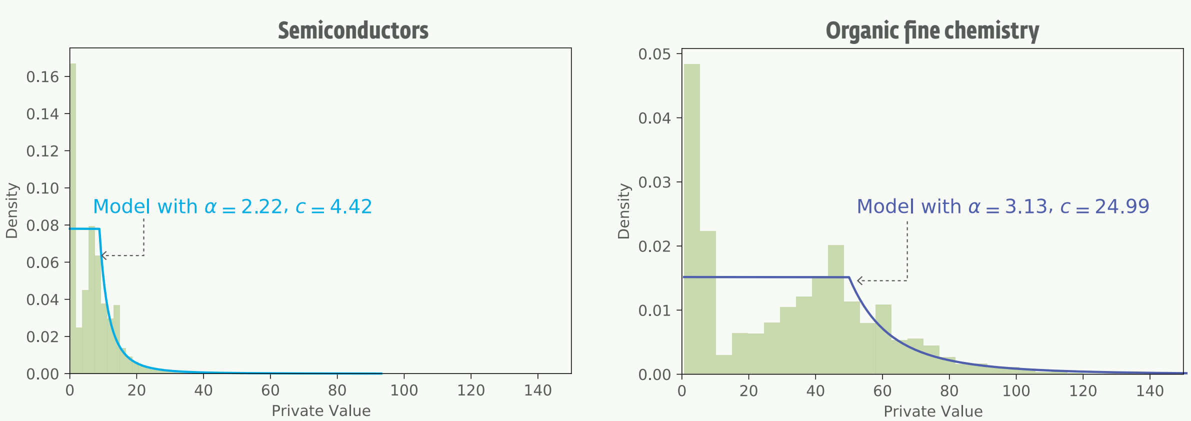
Inferring the cost of innovation

While patent data are readily available as a measure of innovation outputs, there is much less information on inputs and the cost of producing these innovations. Guillard et al. (2021) developed a method to infer the cost of making an inventive step in different technology areas.

For different technology fields, they examine the distribution of the present discounted value of innovations for the innovating firm. They follow Kogan et al. (2017) to estimate those values from the stock market response when the firm's patent related to the innovation is first granted.[1] They develop a model where the realized value of an inventive step is determined by two parameters: First, the shape of an underlying idea generation process which is typically skewed—some technologies are more skewed with many ideas of little value and the occasional "super star" idea that generates very high profits for the innovating firm. Second, before an idea can be turned into a commercially valuable innovation it requires investment in R&D, the cost of which varies by technology. Only after incurring the sunk R&D cost will the actual value of the idea be known. If all ideas succeeded, we would expect to see only high-value innovations, those above the minimum value needed to justify the R&D cost. Ideas below that threshold would not be developed. But in reality, not all promising ideas succeed. If outcomes are uncertain, some low-value innovations will still be observed. This creates a kink in the distribution of innovation values at the cutoff point.

By fitting observed data to this pattern, we can infer R&D costs across technology fields: the further to the right the kink is, the higher the underlying R&D cost as illustrated below (figure 3.1.1). Here, costs are estimated by granular technology categories. In figure 3.2, they are aggregated at the country and broad technology type level.

Figure 3.1.1 The value distribution of innovations in semiconductors and organic chemistry



Note: The figure illustrates how Guillard et al. (2021) derive estimates of R&D costs across different technology areas by a modeled distribution function (Model) to the actual distribution of (private) innovation values derived using the Kogan et al. (2017) approach—that is, by examining the shock on share prices of stock listed innovators.

1 These are the same private values used in Patent Rank calculations reported in figure 2.11.

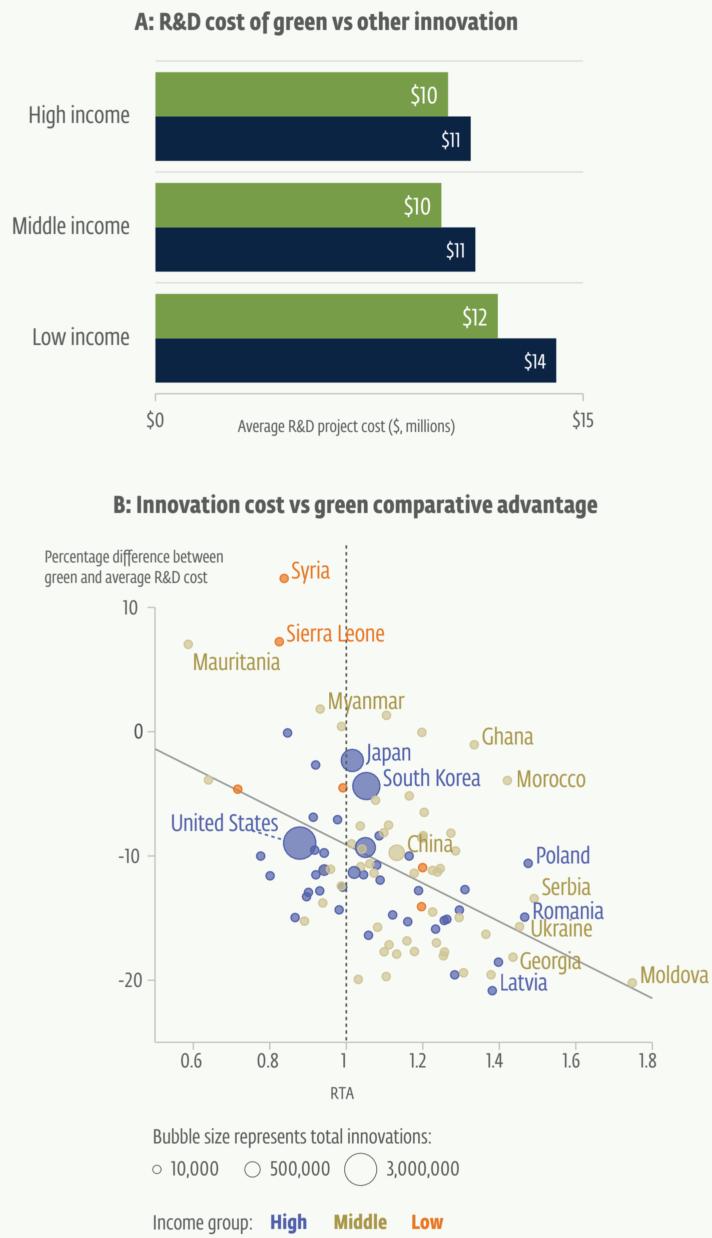
of green technologies and green RTA across countries (**figure 3.2B**). In other words, countries where green innovation is relatively cheap tend to specialize more in it. In fact, variation in R&D cost differences between green and non-green innovation accounts for more than 20 percent of the variation in RTA across countries.

Demand factors

LMICs' strong presence in adaptation technologies (**figure 2.11**) aligns with their exposure to climate change impacts, as a result of their geographic location and higher reliance on sectors such as agriculture and fisheries. These factors could shape demand directly. For instance, a higher frequency of extreme weather events can increase demand for weather-resistant crops, which in turn might spur agricultural innovation. Similarly, changing ocean conditions and more frequent storms can drive demand for climate-resilient fisheries. One example of innovations arising from adaptation needs is the use of agrivoltaics to provide affordable energy and to make agriculture more resilient to heat stress (**spotlight 3.1**).

FIGURE 3.2

Green innovation is cheaper



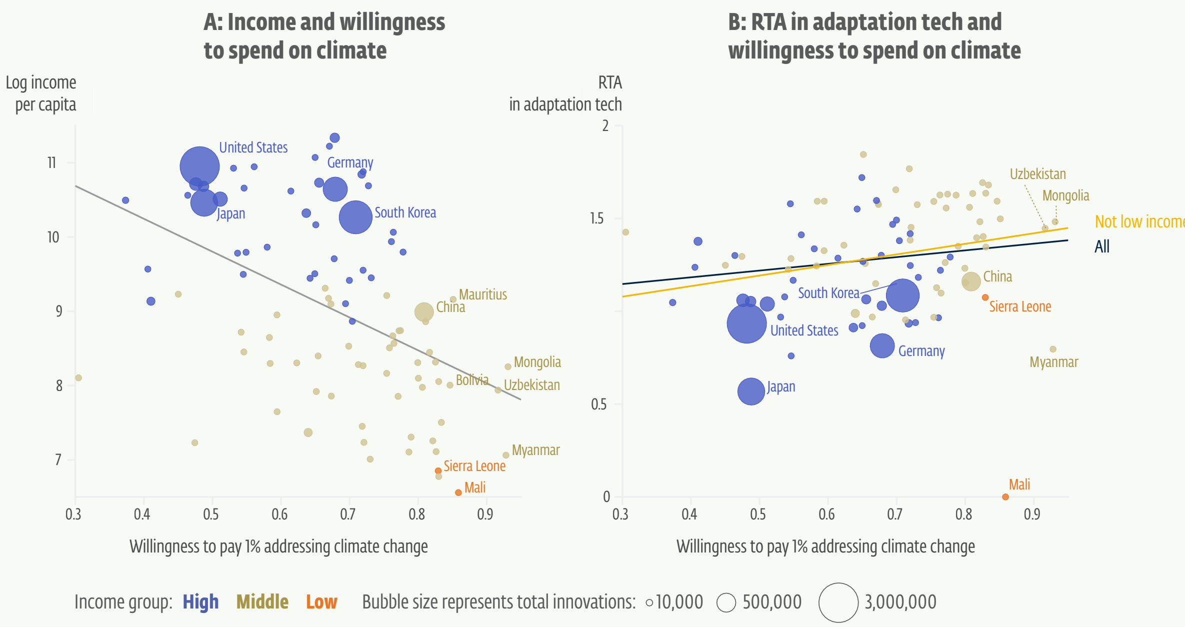
Source: IFC calculations based on data from PATSTAT and Kogan (2017).
Note: The figure explores the country level variation in an estimate of detailed technology-specific R&D costs from Guillard et al. (2021).

Exposure to climate risk can also affect pro-environmental preferences of consumers, which in turn can redirect innovation. A global Gallup survey of more than 130,000 individuals in 125 countries finds a highly negative correlation between income and the willingness to give up 1 percent of income for climate mitigation and adaption (**figure 3.3A**).[26] In other words, citizens in poorer countries would seem to be more concerned about climate change than those in richer countries, because they experience more frequent severe weather events.

The original analysis here finds a positive, though not significant, correlation between green RTA and the willingness to give up income to address climate change (**appendix figure A4.5**). But there is a stronger relationship between RTA in adaptation technology and the willingness to pay for climate (**figure 3.3B**).[27] This result is consistent with the idea that willingness

FIGURE 3.3

Willingness to act on climate appears stronger in low and middle income countries



Source: IFC calculations based on Andre (2024) and PATSTAT.
Note: Panel A plots the relationship between log (income per capita) and the share of the population willing to spend 1 percent or more of their income to address climate change. Panel B plots the willingness to forgo income to address climate on RTA in adaptation technologies.

26 Andre (2024).

27 This relationship becomes even stronger within the subsample of HICs and MICs. A potential explanation is that higher income countries are more able to develop solutions in response to their concerns about climate change impact due to, for example, a larger knowledge base.

to pay to address climate change is driven by experience of climate impacts and thus triggers innovation in response to adaptation needs.

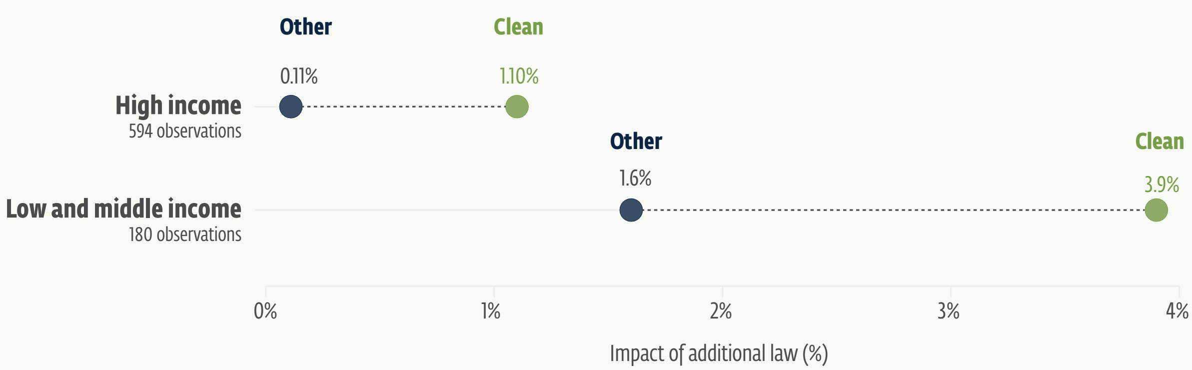
Do climate policies encourage innovation?

Climate policies can stimulate demand for green products and help resolve uncertainty and coordination failures in the private sector, thereby redirecting innovation toward green technologies. Is there evidence that such policies are effective in practice? Most studies have focused on high-income countries (see a review in online appendix 3). This report looks more broadly, using data from the Grantham Research Institute to examine whether climate laws affect green innovation.

The results suggest a significant link: countries that pass more climate laws tend to produce more green patents (**figure 3.4**). The effect is stronger for LMICs, where each new law is associated with a 3.9 percent increase in green innovation, compared with just 1.1 percent in HICs.[28] This suggests that, while there are fewer climate policies in LMICs than in HICs on average, policies in LMICs appear to have a larger impact on innovation.

FIGURE 3.4

The effect of climate laws on innovation



Source: Policy data are from the Grantham Research Institute at the London School of Economics and the Climate Policy Radar (2023)—specifically, mitigation policies identified under the "Topic/Response" column in Climate Change Laws of the World. Patent data are from the 2023 Patent Statistical Database (PATSTAT). **Note**: The figure visualizes the coefficient estimates of a regression of innovation at the country year level on the number of new climate laws passed, with year and country fixed effects. The analysis covers the period from 1996 to 2014. The full regression table is reported in online appendix 3. Climate law here refers to a broad definition of climate legislation, including parliamentary acts, executive orders, and policies of equivalent importance. It covers the full range of interventions promoting low carbon transitions, which reflects the relevance of climate policy in areas including energy, transport, land use, and climate resilience. Excluded are laws focusing solely on adaptation to concentrate exclusively on mitigation measures, following the methodology of Eskander and Fankhauser (2020). The regression includes two groups of countries. The first group comprises 33 high-income OECD countries: Australia, Austria, Belgium, Canada, Chile, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, the United Kingdom, and the United States. The second group includes 10 large emerging economies: Brazil, China, Colombia, Costa Rica, India, Indonesia, Mexico, Russia, South Africa, and Türkiye.

28 Counting laws is a somewhat simplistic—although common—approach.

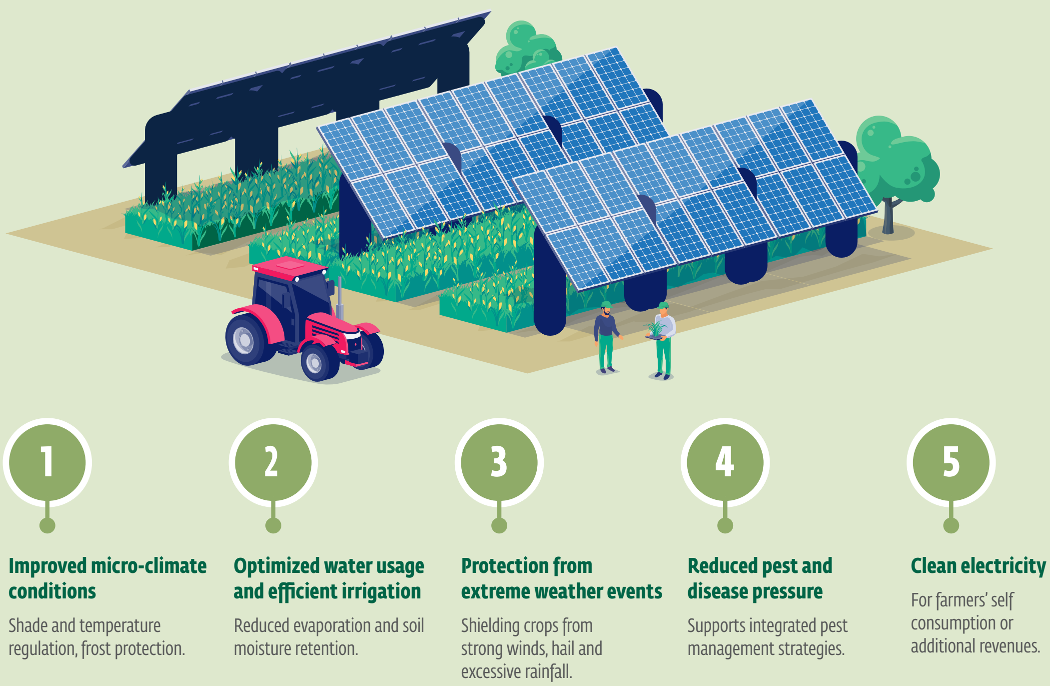
| SPOTLIGHT 3.1

Agrivoltaics—A novel solution for agricultural, energy, and environmental challenges

Agrivoltaics is an emerging novel technology that combines agricultural production with photovoltaic energy generation on the same land, providing shaded space and habitat for crops, livestock, and aquaculture, under and between panels depending on the system. By providing shade, the system makes agriculture more resilient to heat stress. It also provides a cheap and green source of energy, which powers irrigation pumps and other machines, improving agriculture's resilience to drought and heat stress. So, it is both a mitigation and an adaptation technology (**figure S.3.1.1**).

Farmer pocketbooks also benefit.[29] Agrivoltaics can maximize land use efficiency, provide electricity to communities with limited grid access, and diversify farmer incomes, thus addressing critical challenges in resource-scarce areas. As such, it is a promising

Figure S3.1.1 Agrivoltaics combines agricultural production with photovoltaic energy



Source: Adapted from https://ember-energy.org/latest-insights/empowering-farmers-in-central-europe-the-case-for-agri-pv/.

29 Benefits to farmers include: resilience of crops and yields to climate change by reducing demand for irrigation and protecting land and agricultural produce against wind erosion, excessive sunlight, sunburn, hail, and heavy rain (Sponagel et al., 2024; Wagner et al., 2023; Busch and Wydra, 2023; Wang et al., 2024); improved crop quality and value (Widmer et al., 2024); optimized light to create ideal plant growth conditions through tracked PV systems (Widmer et al., 2024); ecosystem economic viability: structural innovation with low elevation and long spans (Mamun et al., 2022); cost savings from use of PV substructures for protective nets or foil instead of traditional structures (Trommsdorff et al., 2023); income for farmers who generate clean electricity on their farms for subsequent sale to the grid. More energy production through efficient use of PV modules including bifacial modules (Roy and Ghosh, 2017; Kumpanalaisatit et al. 2022).

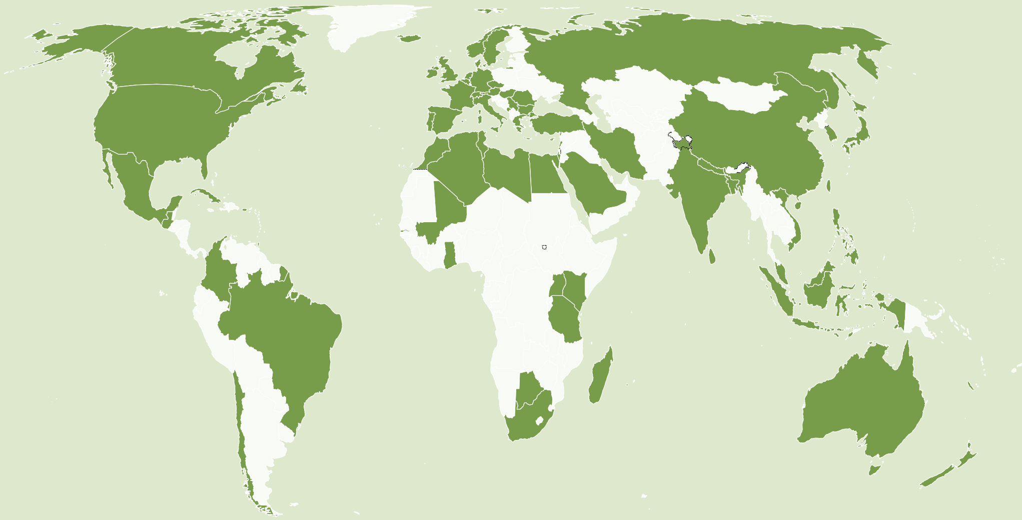
innovation, especially for LMICs, though its benefits extend beyond them.

Agrivoltaic systems have seen a remarkable surge in recent years, particularly in LMICs. By some estimates, the global market for agrivoltaics could reach 36 gigawatts (GW) by 2027 with a compound average growth rate of 45 percent during 2021–27.[30] But the potential of agrivoltaic systems is much larger. In Europe alone, covering just 1 percent of the utilized agricultural area with agrivoltaic systems could result in 944 GW of installed capacity,[31] or almost exactly the current amount of the globally installed wind power capacity, amounting to 1 terawatt.[32]

So far, the Asia-Pacific region dominates the global agrivoltaics market, with the rising adoption of solar modules in China, Japan, and India.[33] China's pioneering efforts in this field started in 2011 with more than 500 agrivoltaic projects involving crop cultivation, livestock grazing, aquafarming, greenhouses and tea plantations. A forthcoming 2025 Agrivoltaics Study—an IFC initiative in collaboration with PwC—analyzed agrivoltaics projects in 218 countries. It finds 36 LMICs and 37 HICs with ongoing agrivoltaics projects (**figure S2.1.2**).

Most ongoing research to improve the technology is in LMICs. The IFC–PwC Agrivoltaics Study (forthcoming) reports that LMICs are engaged in agrivoltaic research, while HICs are more involved in the commercial implementation of agrivoltaic projects. Of 73 countries with agrivoltaic projects, 50 were in the research phase, and the remaining 23 in the commercial phase. The involvement of LMICs in this research is substantiated by the data on agrivoltaic patents. LMICs have been filing an increasing number of patents in recent years. Several LMICs also show a high comparative advantage in agrivoltaics. Bulgaria, Morocco, and Romania are among the top 10 countries with the highest RTA in agrivoltaics.

Figure S2.1.2: Global penetration of agrivoltaic systems



Source: IFC PwC analysis (forthcoming). **Note**: The figure shows countries with active agrivoltaic projects.

30 UnivDatos Market Insights (2024).

31 Chatzipanagi et al (2023).

32 World Wind Energy Association (2023).

33 IRENA (2024).

4

Fostering Innovation in Low and Middle Income Countries

KEY TAKEAWAYS

- Knowledge spillovers from clean technologies—measured as direct and indirect citations of innovations—tend to be higher than for other technologies.
- Most knowledge spillover flows occur between countries, and the value of spillover flows from low and middle income to high income countries is high, and particularly for clean technologies. This implies high economic returns for high income countries from investments in R&D in low and middle income countries.
- There is a link between climate finance and green innovation intensity that could imply that green innovation is held back by financing constraints.
- The commercial value of academic research originating from low and middle income countries is, on average, much lower than that from high income countries.
- Low and middle income country firms rely on academic research for innovation to a similar degree as high income countries.
- Improving the quality of academic research in low and middle income countries could be an important avenue for increasing innovation by firms.

Evidence of comparative advantage in green technologies and innovation does not necessarily mean further support for such technologies is the most growth-enhancing strategy. To assess that, we need to identify policy barriers or market failures that prevent firms and innovators from exploiting all existing opportunities. Four categories are considered:

- First, knowledge spillovers from R&D or cross-firm learning-by-doing that are not considered by private investors and prevent private capital from flowing to such technologies. Do green technologies exhibit greater knowledge spillovers and, if so, does this hold for low and middle income countries (LMICs)?
- Second, information asymmetries leading to financing constraints. Do investors ignore opportunities in green technologies in particular?
- Third, misaligned incentives[34] or information barriers that might hamper the absorption of existing knowledge from academic research into commercial research and final products. Are these frictions particularly binding for LMICs?
- Fourth, distorting policies that bias investments away from green technologies. Are policies preventing the development of clean innovation in LMICs? A notorious example is the persistence of fossil fuel subsidies.

This chapter provides some tentative evidence on the first three of these barriers in LMICs. A wide range of reports have already discussed policies such as fuel subsidies.[35]

Knowledge spillovers

Knowledge spillovers are assessed here, building on the Patent Rank metric and the R&D cost estimations introduced in **chapters 2** and **3**. Patent Rank shows that green innovation on average generates more valuable citations. To assess whether shifting R&D toward green sectors raises economic welfare, however, it is necessary to bring research costs into the picture. As explained in **box 3.1**, Guillard et al. (2021) propose to infer the R&D costs of additional innovation steps in different technology fields by examining the distribution of innovation values for the inventor. If those costs are higher, there is less mass on very low innovation values because innovators will incur those sunk R&D costs only for ideas that look ex-ante more valuable. This model framework also allows examining what happens on the margin if further ideas just below the inventors' idea rejection threshold are being implemented. Inventors will be on the margin indifferent between implementing these ideas and thus marginal private returns are approximately zero. But there might be substantial returns

34 Academics might have incentives other than commercialization of their research. Any intellectual property and associated commercial value might also be held by academic institutions (Lerner et al 2024).

35 Parry et al. 2021.

in spillovers to other inventors. These returns are likely to differ between technology fields as well as across countries.[36]

Figure 4.1 reports the green return gap—the percentage change between marginal spillover returns in green versus other technologies—across various countries. Results for LMICs indicate a strong green premium in most LMICs: green technologies generate higher returns on average (**panel A**). The same is the case in most HICs (**panel B**). Indeed, in many LMICs such as Türkiye, premiums are exceeding those of the HICs with the largest green premiums. In other words, green innovations tend to generate outsized spillovers in both HICs and LMICs. Targeting green technologies should therefore lead to more innovation spillovers and thus to more innovation.

These sizable knowledge spillovers do not accrue only within the originating country's borders.[37] In most cases, inventors outside the originating country are even bigger beneficiaries, although the degree of outward spillover varies across technologies. As a result, national policymakers (especially from small countries) may be less inclined to support R&D than would be optimal considering global spillovers.

But to what extent are returns internalized within LMICs? Such a perspective might be of particular interest to impact investors concerned with the growth of LMICs as a group. **Figure 4.2** reports the estimated average returns that would stem from hypothetically spending an extra $100 on R&D in different country groups, distinguishing between spillover flows within and across these country groups. Panel A shows the average spillovers for all technologies, panel B for green innovations only. Three stylized facts emerge:

- First, within all country groupings, the return to R&D investments in green technologies is above the average return for all technologies combined: for LMICs, $5.9 for green technologies compared to $4.8 for all innovations. Thus, a shift of investment flows toward green should be growth-enhancing because it increases the overall rate of spillovers in the economy.
- Second, while there are substantial flows of spillovers from HICs to LMICs, the results suggest that LMICs experience higher spillovers from R&D by other LMIC inventors rather than R&D investments elsewhere.
- Third, spillovers from LMICs to HICs are considerable. This result is driven by, first, a much larger number of inventors in HICs.[38] However, it is also testament to the quality of LMIC patents cited by HIC inventors. This finding implies that investments in LMICs can have growth benefits for HICs. Indeed,

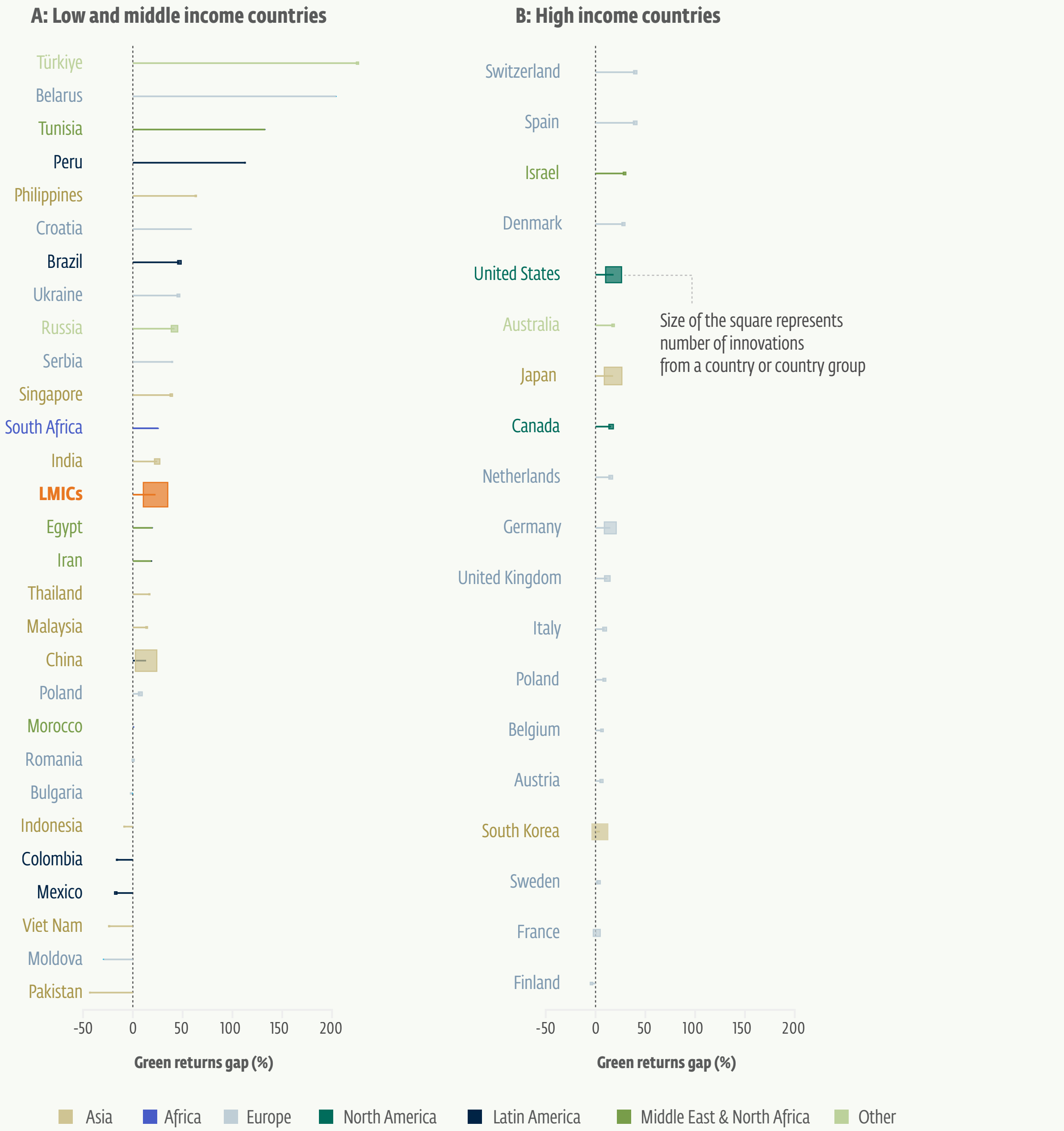
36 Guillard et al. (2021) infer the value of these spillovers by looking at spillovers of innovations with below-rejection-threshold private values. We can observe such innovations because they are innovation projects that looked ex-ante more promising and thus were not rejected for implementation incurrence of sunk R&D costs. Hence, they assume that the ex-post innovation value is a sufficient statistic for the amount of spillover an innovation can generate, and in particular the ex-ante valuation of a not yet developed idea is irrelevant once the ex-post value is known.

37 Martin and Verhoeven (2023).

38 Over 80 percent of inventors globally are based in HICs (see figure A4.3 in appendix 4).

FIGURE 4.1

Green innovations generate more spillovers than alternative technologies in both high income and low and middle income count



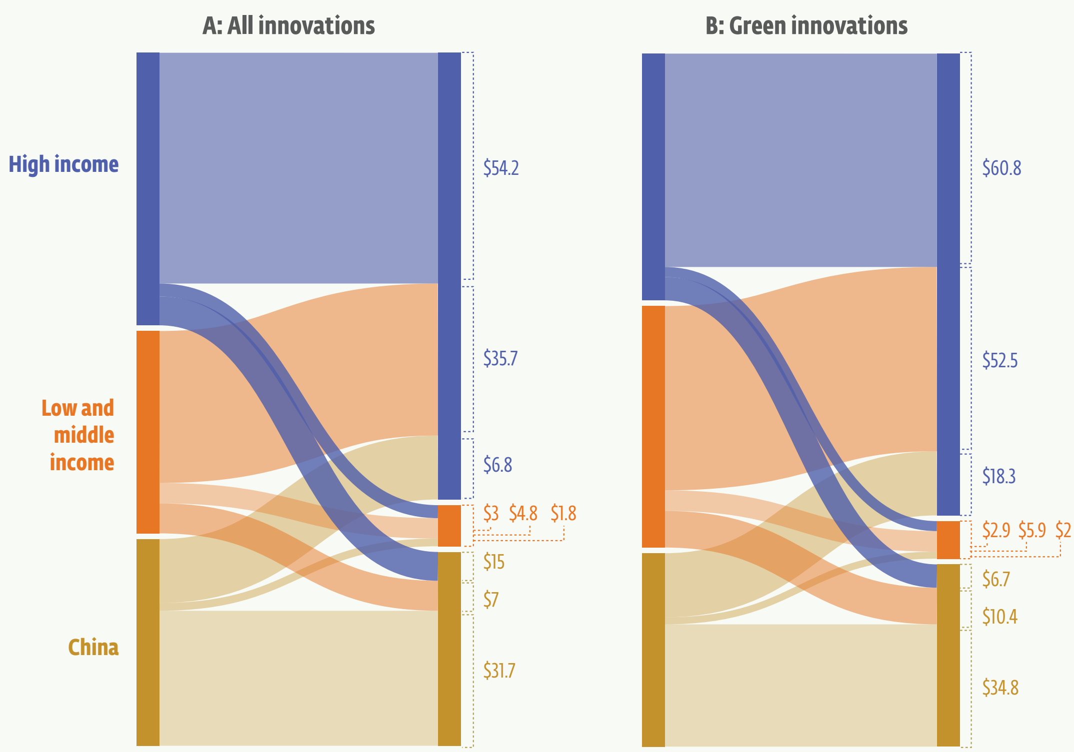
Source: Martin and Verhoeven (2023). **Note**: The Green Returns Gap captures the difference in marginal economic returns to innovation in green versus other technologies. For every country, the average return is calculated across all green innovations and compared with the average return for non-green innovations expressed as (average return in green/average return in nongreen-1)×100. Estimates are based on the citation network from PATSTAT patent data and the methodology developed in Guillard et al. (2021). The size of the squares is proportional to the number of innovations from a country or country group.

these spillover benefits, at $52.5 per $100 invested in green innovations in LMICs—although lower—are not too far off R&D investment by HICs, where $60.8 flows for every $100 invested directly within HICs.

Thus, additional investments in green in LMICs should have positive effects on growth in both LMICs and HICs. Crucially, investing in LMICs will be a more effective way to support LMICs than waiting for a technology trickle down effect. This is also in line with findings that HICs' technological inventions are often "inappropriate" for LMICs.[39]

FIGURE 4.2

Spillover flows between country groups from additional R&D investments



Source: IFC calculations based on PATSTAT data. **Note**: The figure reports RTA for various green and trending subcategories, confirming trends already illustrated. LMICs tend to be greener (a larger fraction of the cells in the LMIC category is green. But there is substantial heterogeneity. For green transport, only Europe and Central Asia displays green RTA larger one. Almost all LMIC regions have an advantage in adaptation technologies. China has an RTA larger than one in all clean categories except transport and GHG capture. All LMIC regions except India have an advantage in green energy technologies as well. India by contrast has a strong bias toward green ICT.

39 See, for instance, Moscona and Sastry (2025).

Financing constraints

To what extent is green innovative activity driven or constrained by finance? It is beyond the scope of this report to provide a comprehensive analysis of financing constraints to green innovations in LMICs.[40] But recent data from the IFC's Climate Finance Explorer—which allows for a distinction between climate-related and non-climate-related (announced) FDI flows as well as (actual) IFC investment flows—provide some useful indicators.[41] Using this data, a comparative advantage style indicator of finance can be constructed—green revealed investment advantage (RIA), a country's share of green investment relative to the global share of green investment.[42] **Figure 4.3** reports the relationship between green RIA—based on FDI or IFC investment flows.

This suggests a pattern that is consistent with the idea that a lack of finance might hold back green innovation: countries with more intensive IFC climate investment flows (relative to total IFC investments) tend to have higher RTAs. The relationship is particularly strong in countries where IFC invests a lot relative to a countries' GDP (solid line). There is also a positive relationship between RTA and private clean FDI intensity in countries where those investments are important relative to GDP. However, the relationship is weaker and not significant. This could be because private investment flows are based on announcements that might not have materialized. Or it could reflect stronger targeting by development finance institutions (DFI) such as IFC of co-benefits from investments including innovation.[43] Of course reverse causality could also be behind the simple correlations in **figure 4.3**. While this simple exercise does not allow for definitive conclusions, the results are a motivation for further analysis of financing barriers to climate innovations and the potential role that DFIs such as IFC could play. See **spotlight 4.1** for examples of innovations supported by development finance.

40 There is evidence of the importance of financing constraints for green investment more broadly for Eastern Europe in de Haas et al. (2024). See also Aghion et al. (2025) for the case of Germany.

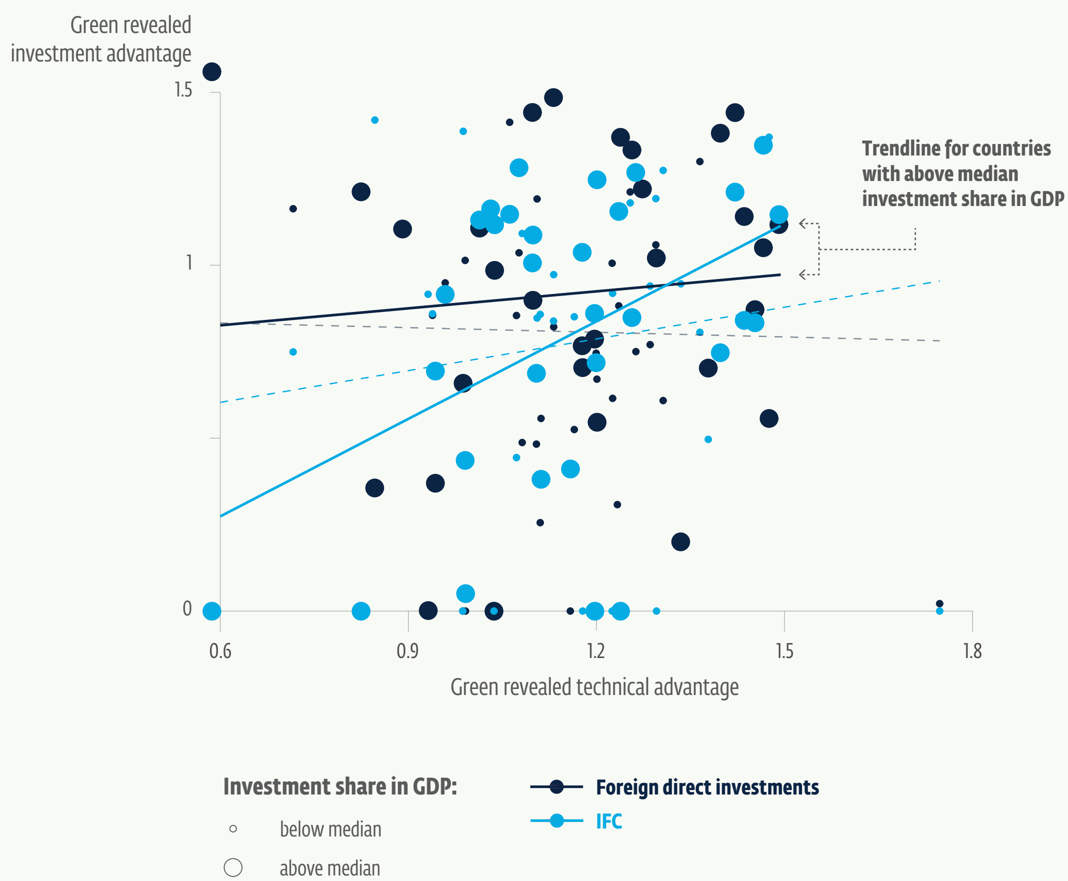
41 To define climate FDI, we utilize fDi Market's proprietary classification system for tracking use of proceeds. Climate FDI is defined by all investment projects that fall under the fDi Markets "Environmental Technology" cluster or projects that contain a FT tag related to emission reduction activities. This definition extends beyond renewable energy technologies to include intermediate subsectors such as batteries and steel products, which are essential inputs for sustainable transportation technologies. Moreover, this definition of climate investment has been checked for accuracy and vetted by IFC staff. We do not currently have comparable data for investment by other DFIs. However, we assume that other DFIs will follow a broadly similar pattern so that we can use the IFC figures as a broader index of DFI investment flows.

42 Because the Climate Finance Explorer covers only LMICs, it is based on global investment flows to LMICs.

43 Analysis of IFC investment deals by Flammer, Giroux, and Heal (2024), for example, suggests that they tend to have a higher degree of concessionality for projects that have a higher sustainability impact per dollar invested. Moreover, the concessionality is higher for projects in countries with higher political risk and a higher degree of information asymmetries. Such results are consistent with the idea that DFIs allocate budget across projects to create societal value.

FIGURE 4.3

Countries with large shares of climate finance have a stronger green RTA



Source: Financial Times fDIMarkets, internal IFC investment project data, and PATSTAT. **Note**: The figure explores the relationship between RTA and RIA. There are two versions of RIA: one on the basis of (announced) climate FDI flows, and the other on the basis of actual investment flows by IFC. A weakly positive correlation is seen between RTA and IFC RIA and no correlation for FDI flows (dashed lines). This turns into a strong correlation for IFC RIA and a weakly positive correlation for FDI if considering only countries with above median shares of total investment (FDI or IFC respectively) in GDP. The median FDI share in GDP is 14 percent. The median IFC investment share in GDP is 1 percent.

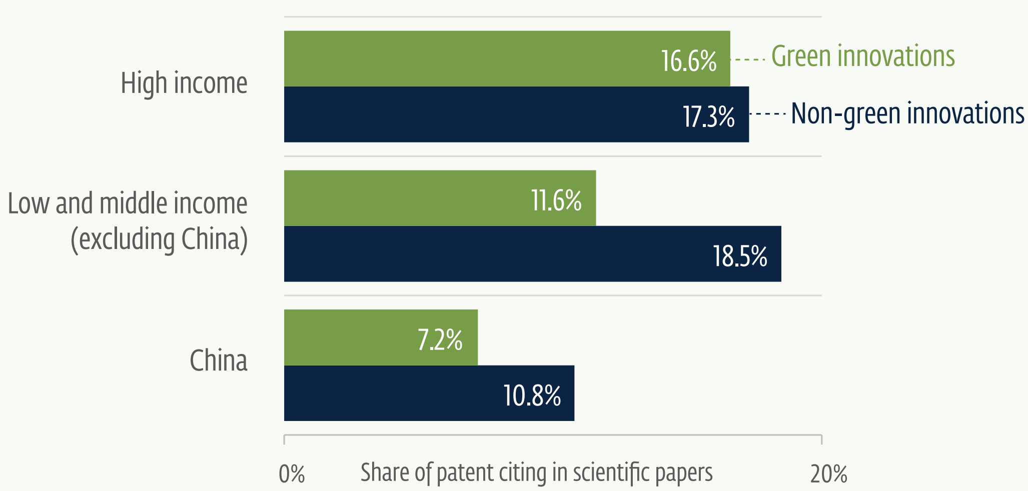
Absorption gaps

Can we identify barriers to the flow of knowledge within the Knowledge Economy value chain? One area that is often suspected to be fraught with barriers is the flow of knowledge between academic research and commercial innovation. **Figure 4.4** examines how important academic knowledge is for innovators in LMICs, showing what share of patented innovations cite academic research. Surprisingly, the number is of a similar order of magnitude in HICs. Indeed, looking across all innovations (**figure 4.4**) the figure is 18.5 percent, slightly higher in LMICs (excluding China) than in HICs (17.3 percent).[44] Interestingly, green technologies exhibit somewhat lower reliance on academic papers, at 11.6 percent.

As for patented innovations, it is relevant to examine the quality of academic research in LMICs. An extension of the patent rank methodology in chapter 2 can help with that. Martin et al. (2025) propose to use the combined network of academic and patent citations to attribute commercial value to academic papers. Thus, an academic paper is valued by the value of patents that cite the paper either

FIGURE 4.4

Low and middle income country firm innovators rely more heavily on academic knowledge than higher income country innovators but not for green innovation



Source: IFC calculations for this report based on PATSTAT and Open Alex data. **Note**: The figure reports the share of innovations (measured through patents) that cite academic papers. This fraction is comparable for HICs and LIMCs other than China. Indeed for non-green technology, LMICs are slightly more likely to cite academic output. But this changes for green innovation, with LMIC innovators citing academic output less than HICs.

44 This could be because LMIC firms are less able to provide funding for basic research than their HIC counterparts and thus have to rely more on academic research.

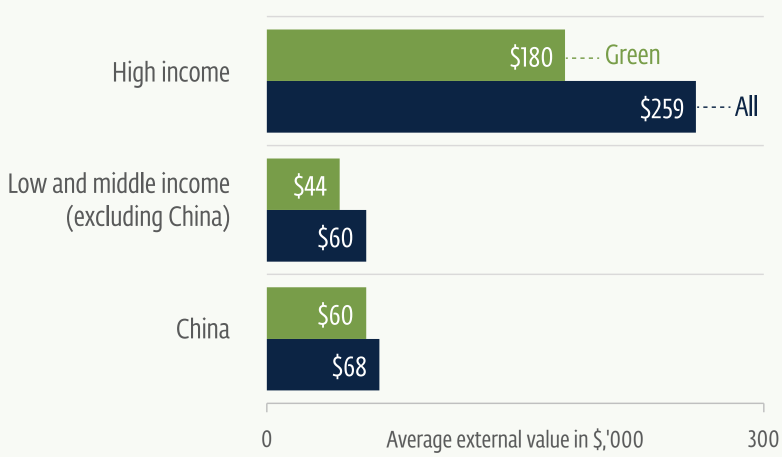
directly or indirectly.[45] Unlike for LMIC patents which were of relatively high value, there is a substantial value gap between HIC and LMIC (**figure 4.5**). For instance, the average value of HIC paper is more than $250,000 whereas the average value of LMIC papers is $60,000. Interestingly, the green gap between HICs and LMICs is less pronounced, which might in part contribute to the relatively high levels of green RTA discussed in **chapter 2**.

A broad literature has documented positive innovation, growth, and employment effects from universities and research institutions.[46] Many of these papers also stress the localized nature of these effects. Some emphasize that it is particularly the research quality of institutions that drives for instance entrepreneurship.[47] So, the quality gap in **figure 4.5** might be responsible for a growth and jobs gap.

An important question to address going forward is how to close this gap. A first step to answering is to point out the substantial heterogeneity in academic quality behind the average figures in **figure 4.5**. **Figure 4.6** shows the top LMICs academic institutions by the value their research generates. Some generate academic output

FIGURE 4.5

A quality gap of green academic research in low and middle income countries



Source: IFC calculations based on 2023 PATSTAT, OpenAlex and Kogan et al. (2017). **Note**: The figure reports average values of the academic patent rank (Martin et al. 2025) grouping academic papers by country groupings and a "green" tag. Academic Patent Rank (AcaP-rank) assigns commercial value to academic papers based on the value (inferred from event studies following Kogan (2017)) of patented innovations that cite an academic paper directly or indirectly.

45 This is unlikely to capture the full societal value especially in academic subjects that are unlikely to lead to commercial innovation. However, it provides a useful metric to compare how academic output from different countries or institutions connects to business opportunities.

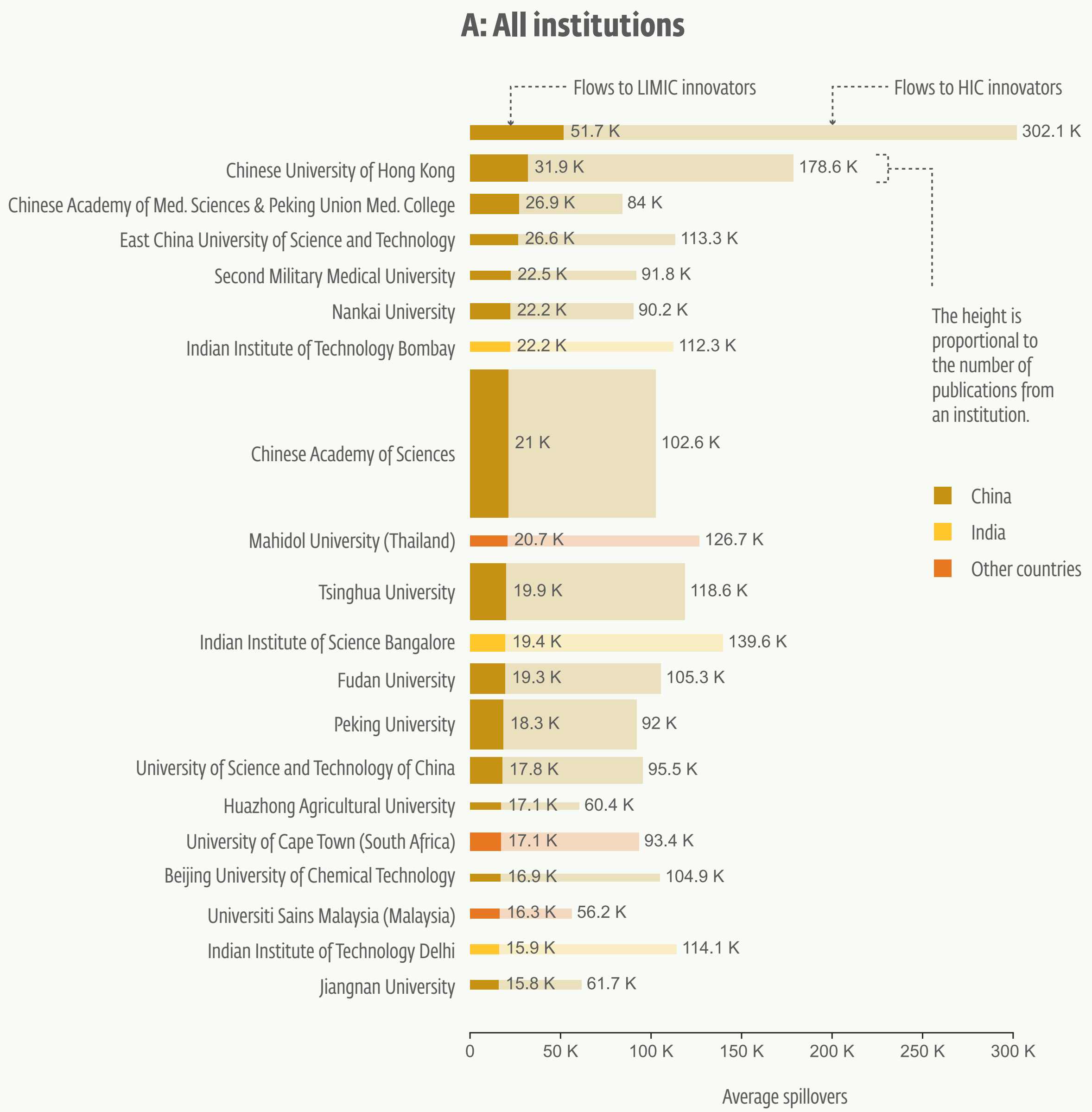
46 Bergeaud and Guillouzouic (2024); Tartari and Stern (2021); Valero and van Reenen (2019); Aldieri (2008).

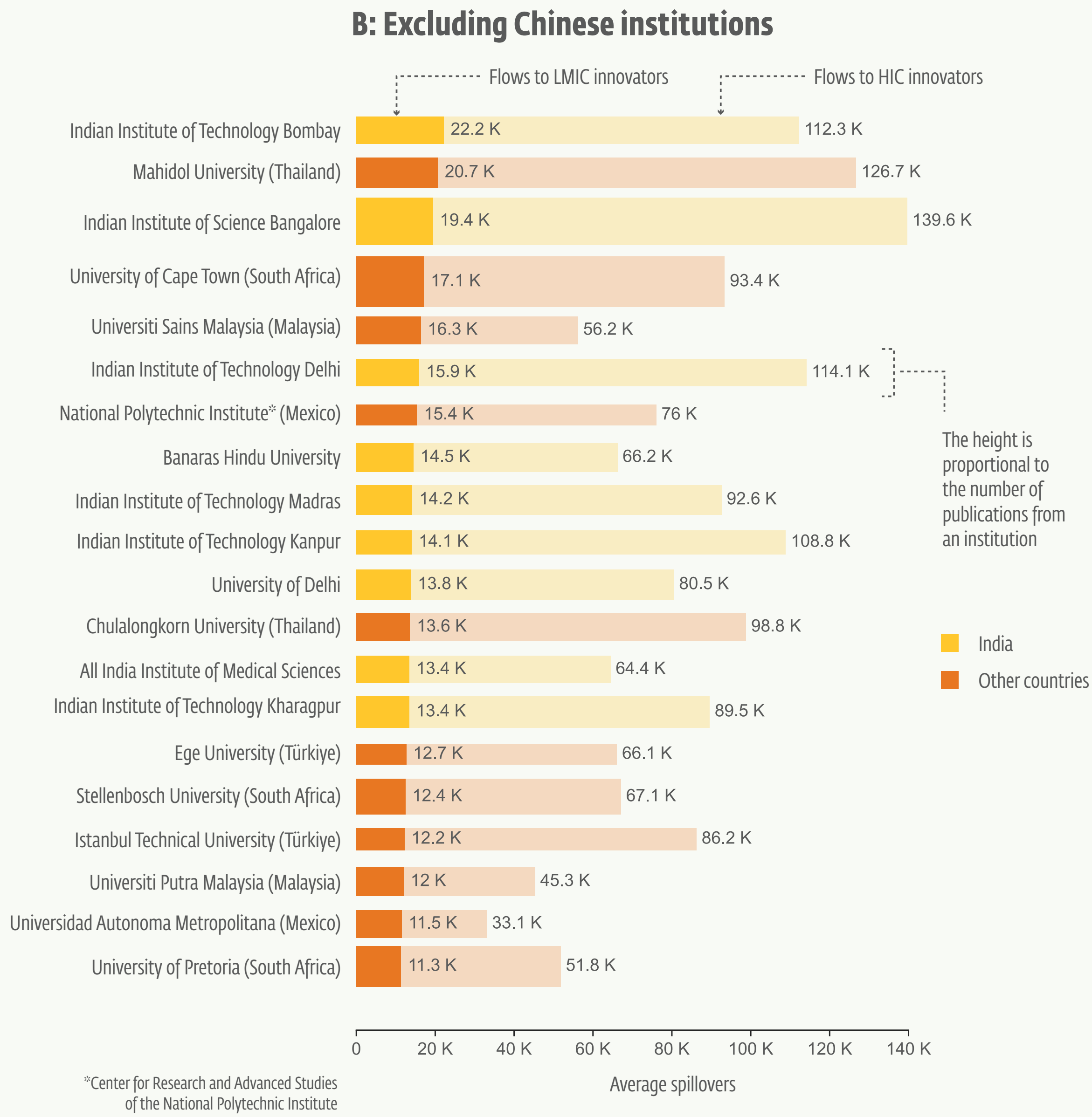
47 Tatari and Stern (2021).

FIGURE 4.6

The top LMIC academic institutions on the average value generated for innovators in low and middle income countries

Spillover value flow from academic institutions to patenting innovators





Source: IFC calculations based on Open Alex, PATSTAT and data from Kogan et al (2017). **Note**: Panel A ranks the 20 institutions from LMICs with the highest average (value per paper) generated for LMICs. The list is dominated by Chinese universities. So panel B repeats the exercise excluding Chinese Institutions. Values are calculated by extending the methods of Guillard et al. (2021) from patent data to a combined citation graph of patent and academic citations (Martin et al. 2025). Appendix 3 repeats the exercise including all institutions globally, leading to a ranking dominated by U.S. institutions that is far above the LMIC average value of $60,000 seen in **figure 4.5**. For instance, Hong Kong University averages $302,000 per paper, and the Indian Institute of Science in Bangalore, $139,000. Most of the institutions generating the highest value are based in China. But outside China, “above average” value research institutions exist across all regions (**figure 4.6B**), such as South Asia (Indian institutions), Africa (the University of Cape Town at $93,400) and Latin America (the Center for Research and Advanced Studies of the National Polytechnic Institute in Mexico at $76,000). Even for these institutions, however, most of the spillover value flows to inventors in HICs.[48] The share captured by LMICs varies sharply: the Chinese Academy of Medical Sciences directs roughly one-third of its value to LMIC inventors, whereas the Indian Institute of Technology in Delhi captures only about 5 percent.

48 In the context of academic papers, this is further reinforced by a similar distribution of academic research and researchers across country groupings—more than two-thirds of academic research originates in HICs, although the LMIC share has been expanding in recent years.

SPOTLIGHT 4.1

Financing green innovation in low and middle income countries

Innovation in low and middle income countries often consists of new services and business models that respond to local climate-related needs. Development finance institutions (DFIs) and multilateral development banks (MDBs) often support such innovations, whether by helping with new financial service products or scaling technologies to take advantage of local resources.

In Latin America, the EcoMicro program— supported by the IDB Lab, Global Affairs Canada, and others— partnered with microfinance institutions to develop climate finance solutions for smallholder farmers. In countries such as Bolivia, the Dominican Republic, and Nicaragua, the program provides credit lines linked to climate risk assessments and crop performance, bundled with technical support for water-saving practices. As a result, more than 800 farmers adopted technologies like efficient irrigation and water harvesting. In Mexico and Peru, participating microfinance institutions mobilized more than $5.9 million in additional financing for clean energy and efficiency upgrades for 5,000 micro, small, and medium enterprises, reducing emissions by up to 20 percent.

In Morocco, DFIs have helped jumpstart large-scale green hydrogen production through the Jorf Lasfar Hydrogen Platform, which aims to produce green ammonia using solar and wind power. A €30 million grant from Germany's Power-to-X Development Fund, though modest in relation to total investment needs, plays a strategic role by alleviating risks on the project at an early stage, which can crowd in private and institutional investment. The project leverages Morocco's abundant solar and wind potential and positions the country to become a supplier in the growing global hydrogen market. The platform will serve both global and local demand: exports are expected to supply the EU's growing need for clean hydrogen inputs, while domestic buyers like the OCP Group will use green ammonia to reduce reliance on fossil-based fertilizers.

These examples show how targeted support from DFIs and MDBs can help LMICs turn local strengths and demand into scalable solutions that leverage green technology.

Photo: Solar photovoltaic area © Jenson via Shutterstock

5

Conclusion

KEY TAKEAWAYS

- Low and middle income countries do not yet have a large market share or comparative advantage in green export markets.
- However, they display a comparative advantage in scientific output and innovations.
- This may indicate a latent commercial comparative advantage that could, with backing by policymakers and investors, turn into private sector opportunities, job creation, and higher economic growth.
- Depending on country circumstances and preferences, backing could involve measures such as climate policies, R&D subsidies, or investment strategies targeting green R&D projects. Support by DFIs can also help create new markets and unlock opportunities.
- The estimates point to significant international spillovers of innovation in green technologies, which can bring value to firms beyond one country's borders, including high income countries.
- In view of significant variation in comparative advantage across countries and across technologies, recommendations must be tailored to country-specific circumstances, drawing on granular analysis as sketched in this report and drawing on accompanying interactive tools.

The green market space has been a growth sector and will likely continue growing due to technological progress, climate policies, and increasing climate adaptation needs. Exports of green products remain dominated by high income countries, but low and middle income countries (LMICs) have made inroads. Moreover, there is evidence for LMIC comparative advantage in green innovation and scientific output, which can be conceptualized as the upstream stages of a knowledge economy value chain.

This upstream comparative advantage could be a leading indicator of emerging downstream comparative advantage—in final products. However, attaining and utilizing comparative advantage downstream would likely require overcoming barriers and market failures.

Green technologies generate more spillovers and thus a bigger gap between private and social economic returns, particularly for LMICs. Consequently, investment in green R&D and downstream commercialization has been lower than optimal from the perspective of society-wide profits (without considering climate or environmental impacts).

Revealed technological advantage indicators are positively correlated with more intensive green finance support, especially from development finance institutions. This is consistent with the idea that some green innovation opportunities exist that currently are not exploited due to lack of finance, although further research with better causal identification should confirm this.

There is also evidence consistent with gaps in commercialization or quality of academic research in LMICs holding back innovation, though these gaps are likely not biased against green innovation.

While LMICs will likely gain bigger shares of various green markets going forward under business as usual scenarios, a concerted effort by policymakers and the investment community to develop innovative business and research ventures in the green space in LMICs will contribute to economic development and have beneficial impacts for the climate and the environment.

Depending on individual country circumstances and preferences, such effort might involve, for example, R&D tax credits or grants, support for research, climate policies, business accelerators, or venture capital funds.

Not all countries are equally well equipped to have a thriving private sector focused on green products, and not all countries that do should focus on the same green products. Going forward there will be a need to examine the structure of green submarkets at greater levels of granularity. Equally needed is more causal evidence on the underlying drivers of green comparative advantage, innovation, and entrepreneurial activity.

As part of this report, dedicated IFC tools are being released to allow a more granular approach to the indicators and results developed here.

Photo: Ampersand electric bike factory in Kigali, Rwanda © Julia Schmalz/IFC

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Appendixes

Appendix 1

Robustness of income versus RTA relationship

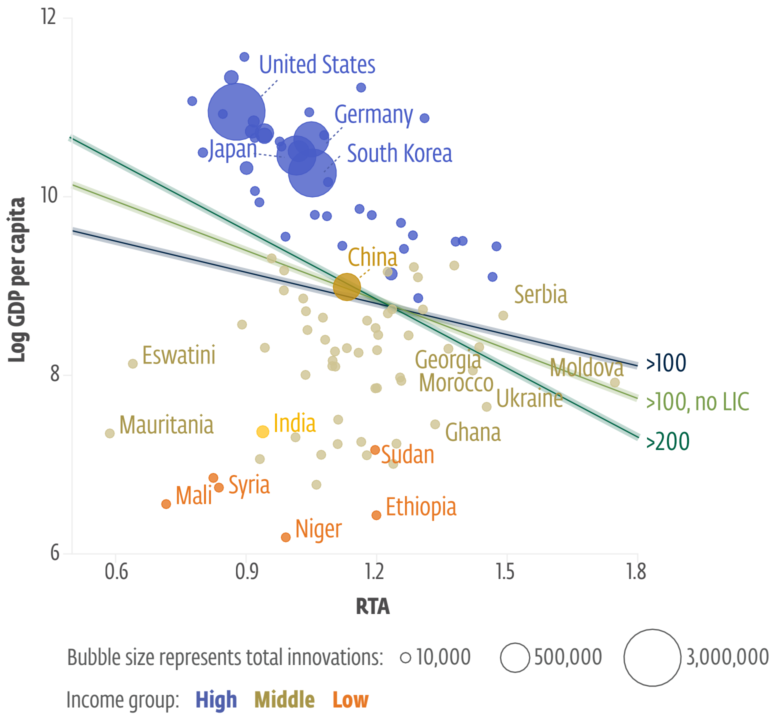
One concern with the results on the relationship between income and RTA could be that patent data might only capture a small fraction of all innovation output. Similarly, academic knowledge and skill is surely an incomplete measure of the availability of skills overall. However, for our purposes, we don't need to measure all innovation output. We only require that the difference between total innovative activity and patented innovation does not systematically vary across technology types and countries. Thus, we can allow for the possibility that the gap between overall innovation and patented innovation is systematically bigger (or smaller) in low income countries—or that the gap is bigger (or smaller) for green technologies in general. Our results would be jeopardized only if the gap is smaller (or bigger) specifically for green technologies in LMICs (if the gap is systematically bigger for green in LMICs it would bias against our downward-sloping result).

Another concern is reliability of patents (and similarly academic papers or data from startups) as an indicator when some countries might have only a handful of patents. Indeed, suppose a country has only one patent. If this patent is green, the country has a green share of 100 percent—something that would have been highly unlikely to ever occur in a country with thousands of innovations. If this patent is non-green, the country has a green share of 0 percent. As shown in detail in appendix 2, it is more likely that such a country has a green share of zero. This is introducing a positive bias in the relationship between RTA and income, such that it will be less likely to find a negative relationship between green patenting and income level. Nevertheless, to avoid small sample issues, the analysis is limited to countries with at least 100 innovations. The basic conclusions are robust enough to consider changing this threshold. For instance, in figure A1.1a, we show that the negative relationship between green RTA and income becomes even stronger when restricting the sample to countries with at least 200 innovations or to the sample excluding LICs.

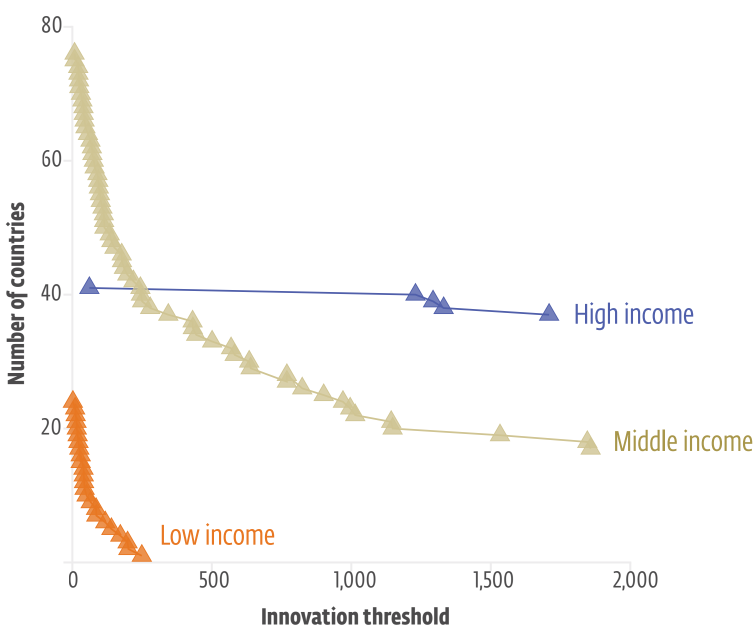
FIGURE A1.1

Varying the innovation threshold

A: Green RTA vs income for different thresholds



B: Number of countries exceeding different thresholds



Source: IFC calculations based on 2023 Patent Statistical (PATSTAT).
Note: Panel A shows the income per capita–RTA relationship for various subsamples such as the sample of countries with at least 200 innovations (over 2000–2020) or to only the HICs and LICs. Panel B reports the number of countries that exceed various thresholds across income categories. For instance, 100 countries had at least 100 innovations between 2000 and 2020. No LIC has more than 250 innovations. There are 40 HICs and 20 MICs with more than 1,000 innovations.

Appendix 2

Computing returns and spillover flows from innovation

Guillard et al. (2021) highlighted several shortcomings of simple citation counts—namely, that a simple count of citations does not consistently differentiate between being cited by an innovation that is highly cited itself compared with an innovation that is not (**Box 2.2**). Moreover, citation counts do not account for the potentially large differences in the commercial value of innovations irrespective of their ability to generate citations. For instance, counting citations suggests that a citation by patent USD618677S1, which describes design features of Apple's iPhone, holds the same value as being cited by patent JP2007016376A, which seeks patent protection for a head cooling device incorporating a fan into a builder's hard hat.

Guillard et al. (2021) propose a new approach to assess the value of innovations by adapting Google's Page Rank algorithm to patents. By combining Page Rank with estimates of the private value of patents, they show that it can be interpreted as the total economic value of an innovation comprising the private value of an innovation to the inventor and a fraction of the private value of all other (subsequent) inventors who cite the innovation directly or indirectly. They call this new indicator Patent Rank. In addition, they estimate R&D cost values as well as the marginal social return to further innovation funding in a specific innovation area by fitting a simple model of innovation to data on the distribution of private returns to innovation estimated from stock market data for listed firms. This follows Kogan et al. (2017), who infer the value of specific patents by studying the stock market response to the patent when first granted by the patent authorities. By assuming that stock-listed innovators are similar to non-stock–listed innovators within narrow technology classes, they can extend this approach to all patented innovations.

Formally, to derive the P-Rank we need to solve the equation system[49] defined by

$$V_i = PV_i + \sum_{j \in F_i} \phi_{ji} V_j \qquad (1)$$

where V_i is the P-Rank of innovation, PV_i is the private value of innovation i to its inventors and $\sum_{j \in F_i} \phi_{ji} V_j$ is a weighted average of the

49 While simply a linear equation system due to its consisting of several millions of innovations, we solve it using a recursive approach proposed in Google's page rank algorithm.

P-Ranks of all innovations j citing innovation i. Several ways to define weights ϕ_{ji} are plausible. Guillard et al. (2021) propose[50] as a benchmark to use $\phi_{ji} = \frac{\sigma}{N_{Bj}}$ where N_{Bj} is the number of backward citations of innovation j. This assumes an innovation i contributes more to j if there are fewer citations by j and all innovations cited by j contribute uniformly—in the same amount—to j. σ is an arbitrary scale factor Guillard et al. set to 0.5. While V_i would measure the global social economic value[51] we can also examine how much value is generated for specific geographical subsets—such as say LMICs country innovators—by only accounting for private values PV_j of innovators falling into that subset and setting all other private values to zero.

Guillard et al. (2021), in addition derive ISTRAX, an indicator that allows assessment of the marginal return of increasing innovation funding for specific technology subsets by fitting a simple model of the innovation process to the available data. They show that this boils down to computing

$$IStraX_a = \frac{1}{\#A}\frac{1}{c_a}\sum_{i\in A} SV_i \times (\alpha_a - \alpha_a \times I\{PV_i > 2c_a\} + I\{PV_i < 2c_a\}) \qquad (2)$$

where A_i is the set of innovations that fall into a particular category (e.g. green innovations in LMICs), c_a is an estimate of the cost of an R&D project in category a, $I\{.\}$ is the indicator function, and α_a is the curvature of the idea generation function from our simple model

50 Thereby following PageRank

51 This would account only for knowledge externalities but not for instances of any negative environmental damages of an innovation.

of innovation that determines how ideas are distributed across a quality measure. A high α_a implies that the idea generation function is more left skewed with more probability mass close to zero and less likelihood of "superstar" ideas with an extremely high quality and thus potential private economic value for the inventor. Guillard et al. (2021) identify these parameters by fitting a theoretical distribution of the value of innovations as obtained from Kogan et al. (2017)'s approach for narrow technology fields. This is illustrated in **Figure 3.1.1** in **Box 3.1**. The stylized model distribution (in blue) suggests a kink—indicated by the arrows—in the distribution which is determined by the fixed costs that is required to convert an idea into a patentable innovation. The higher the fixed costs, the further the kink will be to the right; e.g. $24.99 million for organic fine chemistry as opposed to $4.42 million for semiconductors. The intuition for this is that for higher fixed costs, R&D investors will impose a higher threshold on the quality of ideas that get developed. That said, even an idea that initially—before undertaking further research—looks very promising, has a chance of being not valuable at all. Thus, we have certain likelihood of encountering ideas of any value. The α parameter in turn determines the curvature of the distribution to the right of the kink. The higher α, the higher the likelihood of extremely high innovation values; e.g. for organic fine chemistry, we see a substantial number of innovations valued at $60 million or more, whereas there is virtually no innovation valued as high for semiconductors.[52] We compute these parameters at narrow (4 digit Cooperative Patent Classification) levels.

$SV_i = V_i - PV_i$ is the social value of an innovation. So, $IStraX_a$ is the weighted average of the social value part of P-Rank where weights depend on technology specific cost and quality distribution parameters. Note that the basic qualitative features of expression 2 are intuitive: The marginal response to further investment in an area will be higher if costs are small because a given amount of R&D will simply go further. It will also be higher if the curvature is more skewed towards zero (α_c is larger) because a greater mass of ideas can readily be turned into R&D projects with some extra funding. As for P-Rank, we can compute various versions of IStraX depending on whose private values we want to consider. In this way we can for instance compute the return to a given amount invested in—say—an LMIC to innovators in HICs.

Figure A2.3 shows IStrax results—that is social return estimates for R&D investments—for various green as well as other emerging technology areas. Panel A reports results for LMICs whereas panel B reports results for OECD economies. The figure reports "national" returns (via the solid part of the bars) and global returns (the full bar including the transparent part). The results reveal several insights. First, returns in both LMICs and HICs are comparable. Indeed, global returns are—on average—somewhat higher in LMICs (more than 150 percent), whereas national returns—considering only beneficiaries of spillovers located in the same

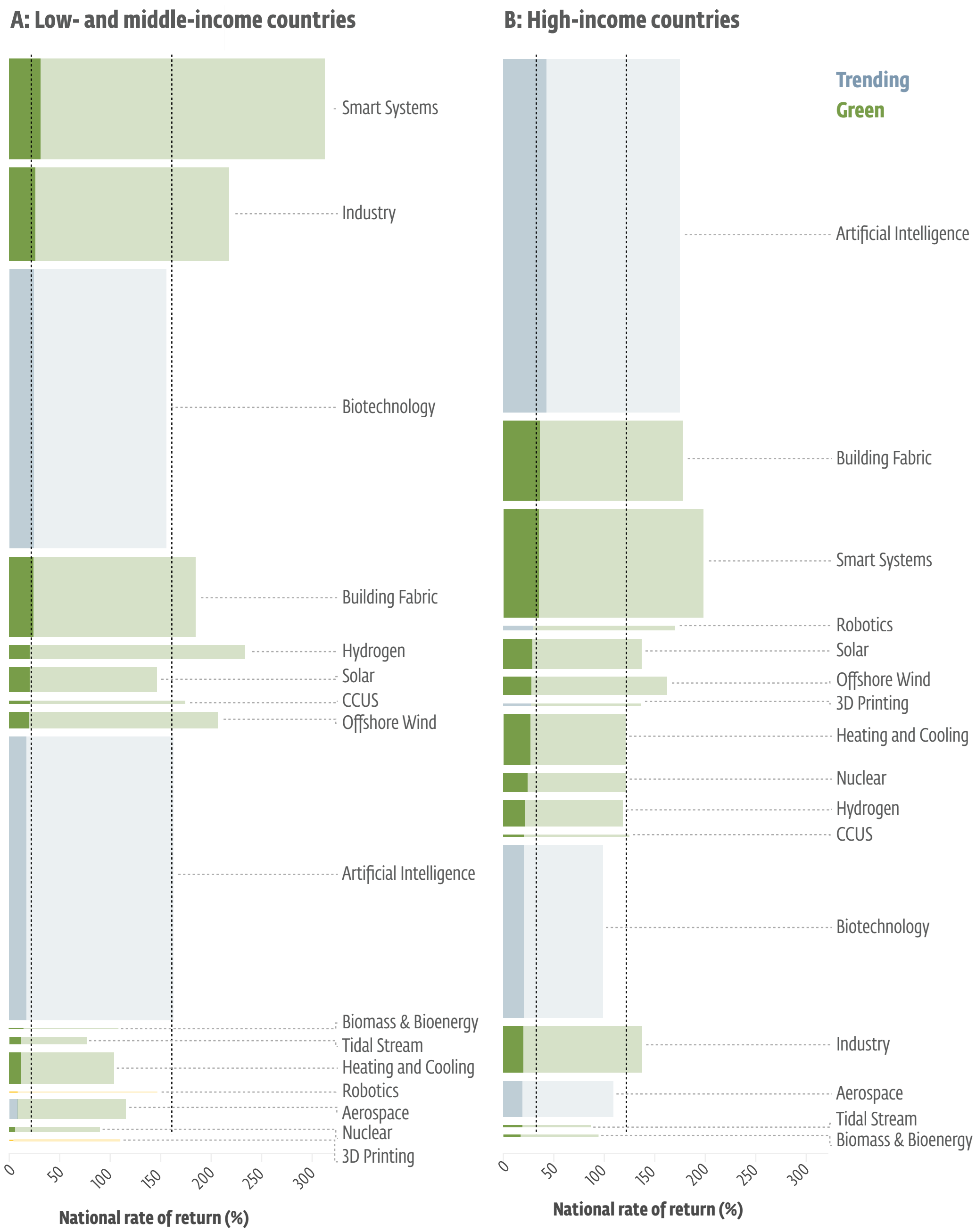
52 Note that these figures are not necessarily an indication of the overall profitability of the associated industries. Differences could also be driven by the nature of innovation in different areas. Some areas proceed in bigger and more valuable steps, where others have possibly more frequent but smaller steps.

country as the originator—are somewhat lower in LMICs (less than 25 percent) than in HICs. Second, in all cases the share of returns internalized in countries is substantially smaller than the share of returns realized outside a given country. In many instances, this changes the return ranking of different technologies.

Figure A2.4 examines how this changes the return ranking between green and non-green technologies. It shows the gap between returns for green vs non-green technologies, but this time for nationally internalized returns only. The global returns are shown as vertical marks. Thus, while for most countries there is a positive green returns gap when considering global spillovers, this often turns negative when comparing nationally internalized returns. The contrast is perhaps most striking for Türkiye, where global green returns are more than 200 percent higher than returns for other technologies but where national green returns are 10 percent lower than national returns for other technologies.

FIGURE A2.3

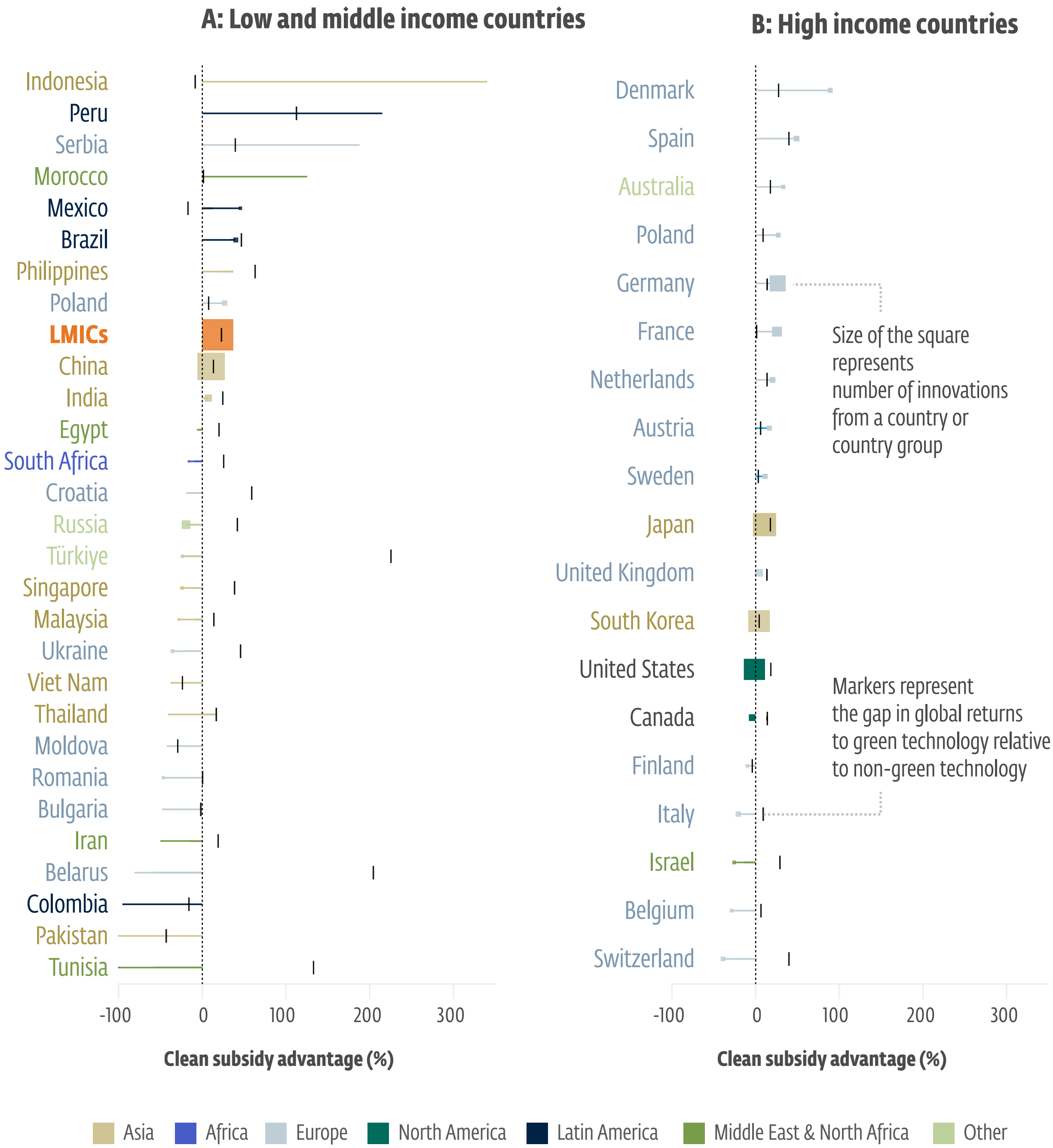
National and global returns to R&D



Source: Martin & Verhoeven 2023. **Note**: The figure reports returns from R&D investments for different technology types taking into account returns to original inventors as well as returns of inventors benefiting from spillovers. The solid colored part of the bars show returns when only taking into account returns internalized within the same country (national returns) whereas the combined solid and transparent height of each bar indicates the global returns. The width of the bars represents the number of innovations. Dotted lines indicate the average private (left) and social (right) returns across countries.

FIGURE A2.4

The green R&D returns gap



Source: IFC calculations based on data from Martin & Verhoeven 2023.
Note: The figure reports the gaps in global versus national returns from R&D investments for green vs. non-green technologies. Countries are ordered based on the gap in national returns to green technology relative to non-green technology (horizontal lines). The vertical markers represent the gap in global returns to green technology relative to non-green technology.

Appendix 3

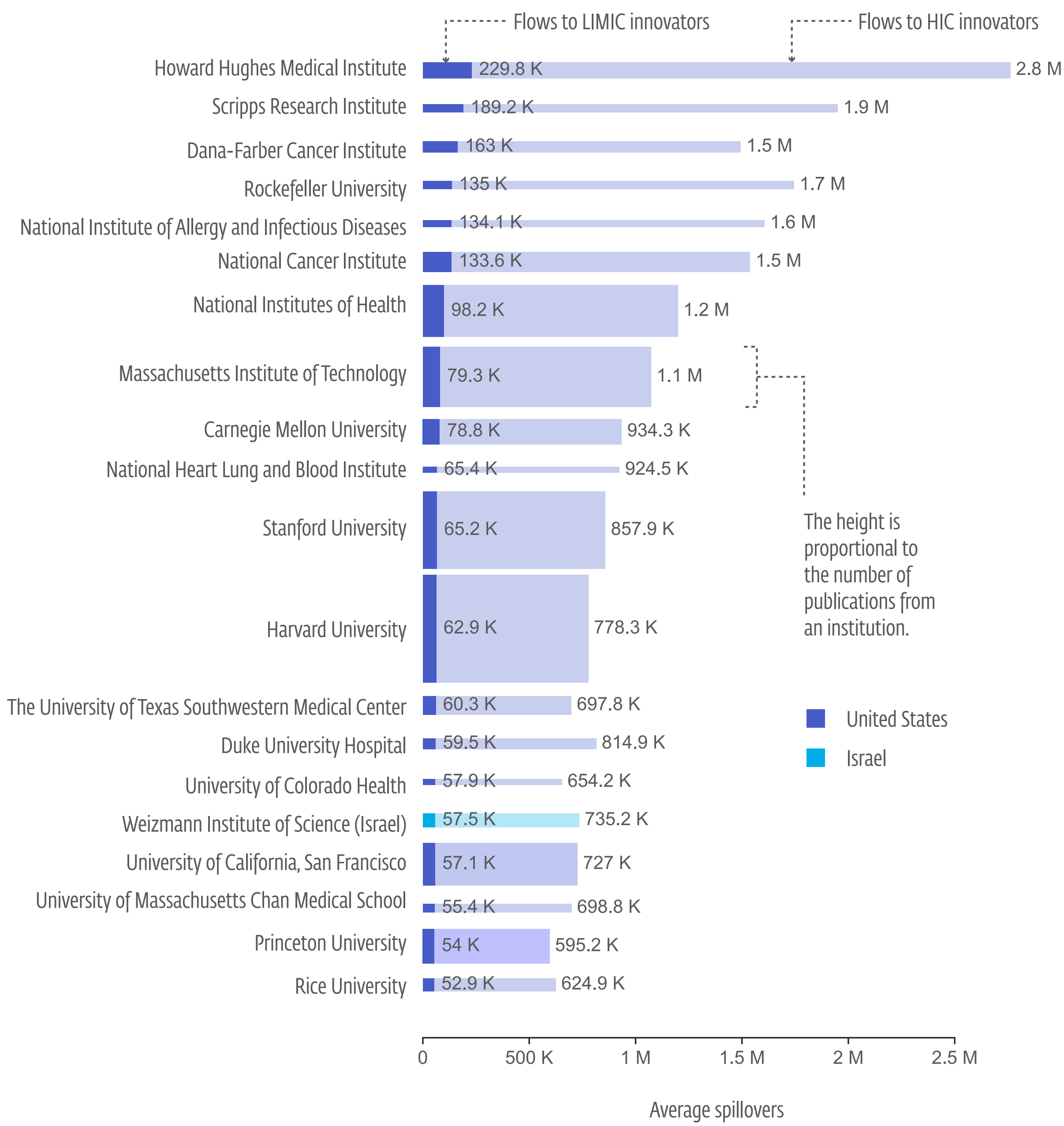
Computing spillover flows from academic activity

P-Rank considers only patented innovations and citations between them. However, it is straightforward to extend the analysis to include all academic papers using the integrated citation network; that is citations between academic papers, citations between patents, and citations of papers by patents. In other words, we can assign value to academic papers on the basis of them being cited—either directly or indirectly—by a patented innovation. We assign a higher value to a paper if it is cited by patents that themselves tend to be more valuable. Of course, this is unlikely to capture the full societal value, particularly for subjects unlikely to deal with academic endeavors related to commercializable products. However, it should be a useful metric for assessing the potential of academic research to induce private sector opportunities.

Figure A3.1 shows the top 20 institutions that generate the most per paper average value to innovators in LMICs. All 20 institutions except one are based in the Unites States.

FIGURE A3.1

Top 20 institutions globally by per paper average value for innovators in low and middle income countries



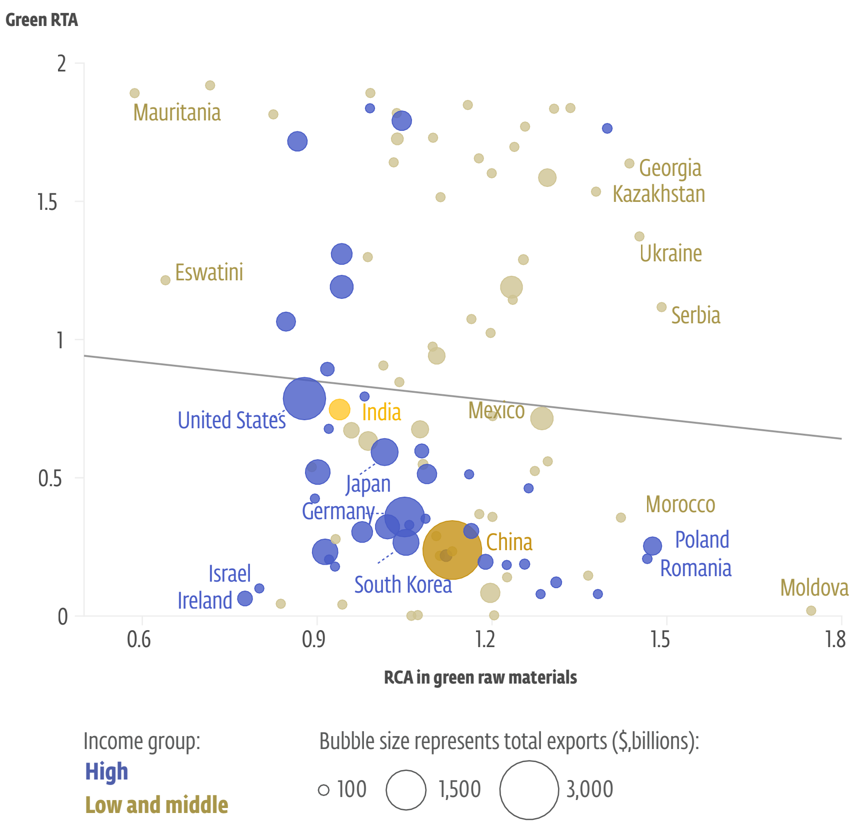
Source: IFC calculations based on Open Alex, PATSTAT and data from Kogan et al (2017). **Note**: The figure reports the 20 academic institutions with the highest value of AcaPrank benefiting firms in LMICs. All but one are based in the United States. Like for institutions based in LMICs, most of the value generated flows to firms in HICs.

Appendix 4

Additional results

FIGURE A4.1

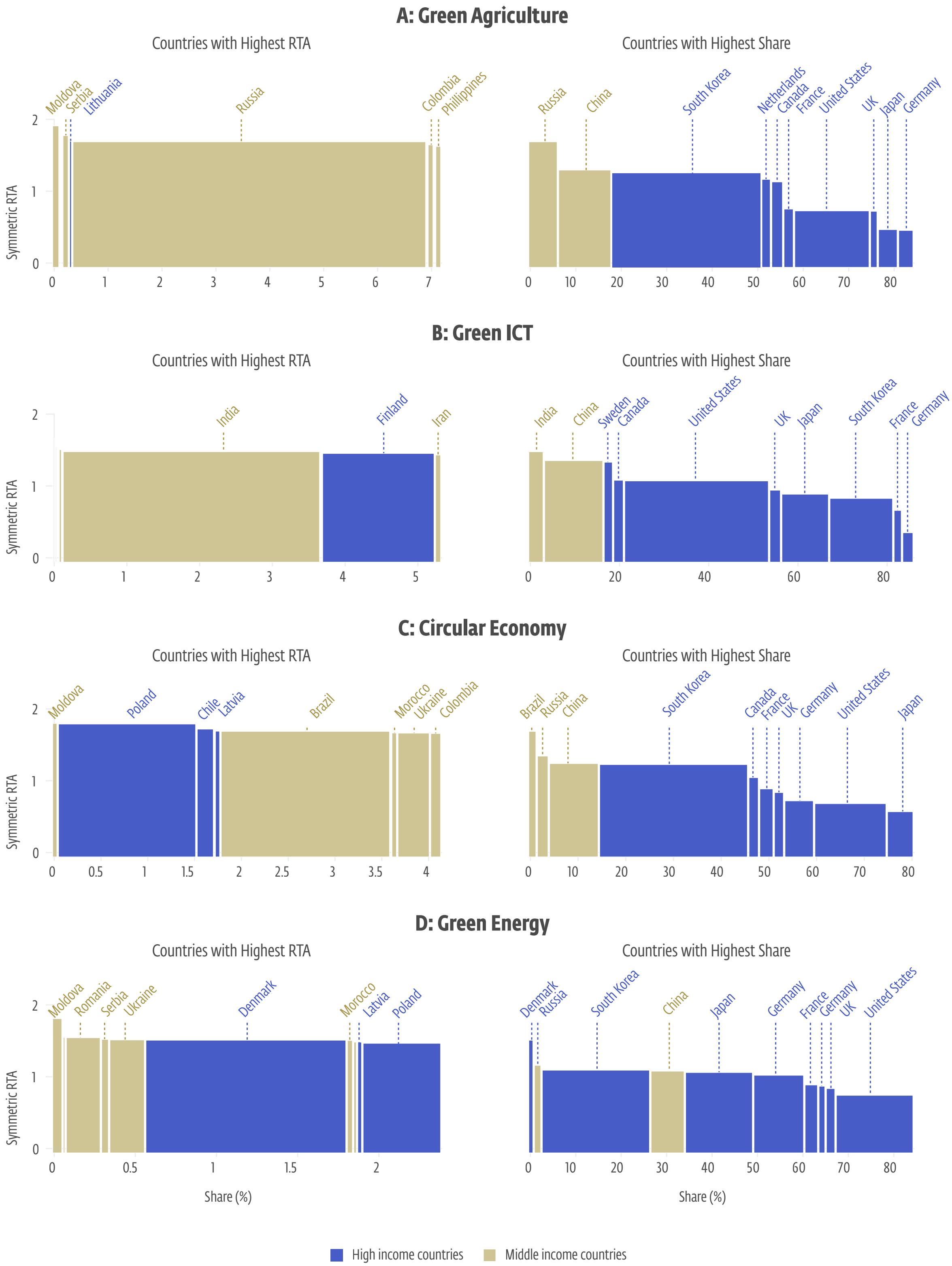
The critical minerals comparative advantage is not related to green revealed technological advantage



Source: BACI, IFC Green Value Chain Explorer (GVCE), 2023 Patent Statistical (PATSTAT) database. **Note**: The figure reports a scatter plot with green symmetric revealed technological advantage (RTA) on the vertical axis and symmetric revealed technological advantage (RCA) in green raw materials on the horizontal axis. The size of each marker is larger the greater the country's export volume.

FIGURE A4.2

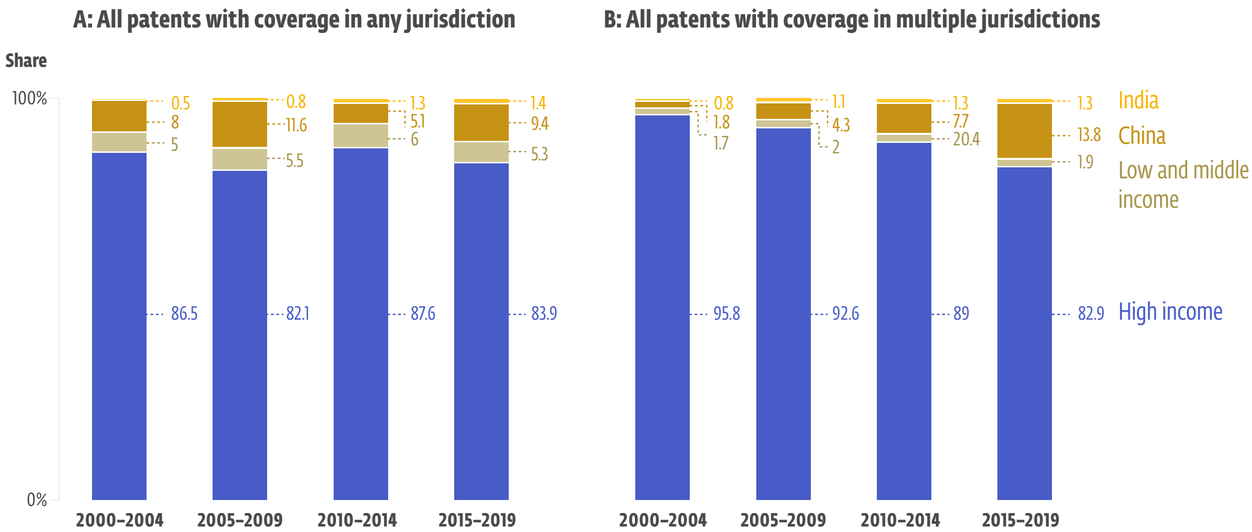
Specialization in green varies substantially across subfields and countries



Source: IFC calculations based on PATSTAT data. **Note**: For each green technology, the top panel plots the 10 countries with the highest RTA (top RTA) and the bottom panel the 10 countries with the highest share of innovations in a particular technology field (top share). In each case, the height of the bar plots displays the RTA of a country in the respective technology field, and the width of the bar indicates its share in global patenting. Thus, the top panel tells which countries are particularly specialized in a particular field, whereas the bottom panel tells us which countries might dominate a particular field.

FIGURE A4.3

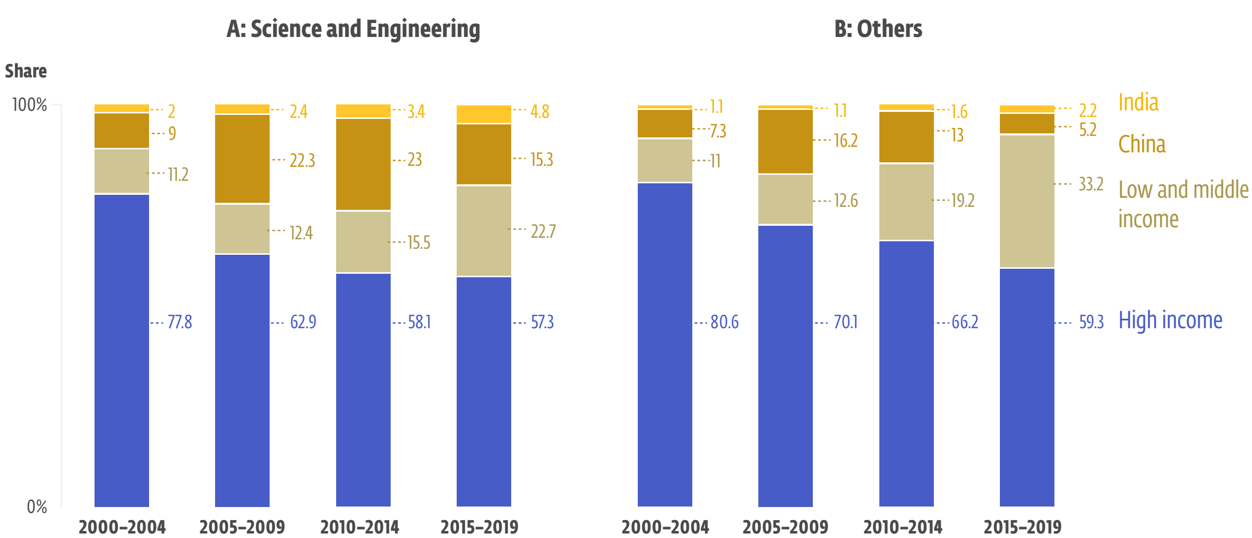
Most innovations are happening in high income countries



Source: IFC calculations based on the 2023 Patent Statistical (PATSTAT) database. **Note**: The calculation includes 159 countries with population size of at least 500,000 and total patent count between 2000 and 2020 above 100.

FIGURE A4.4

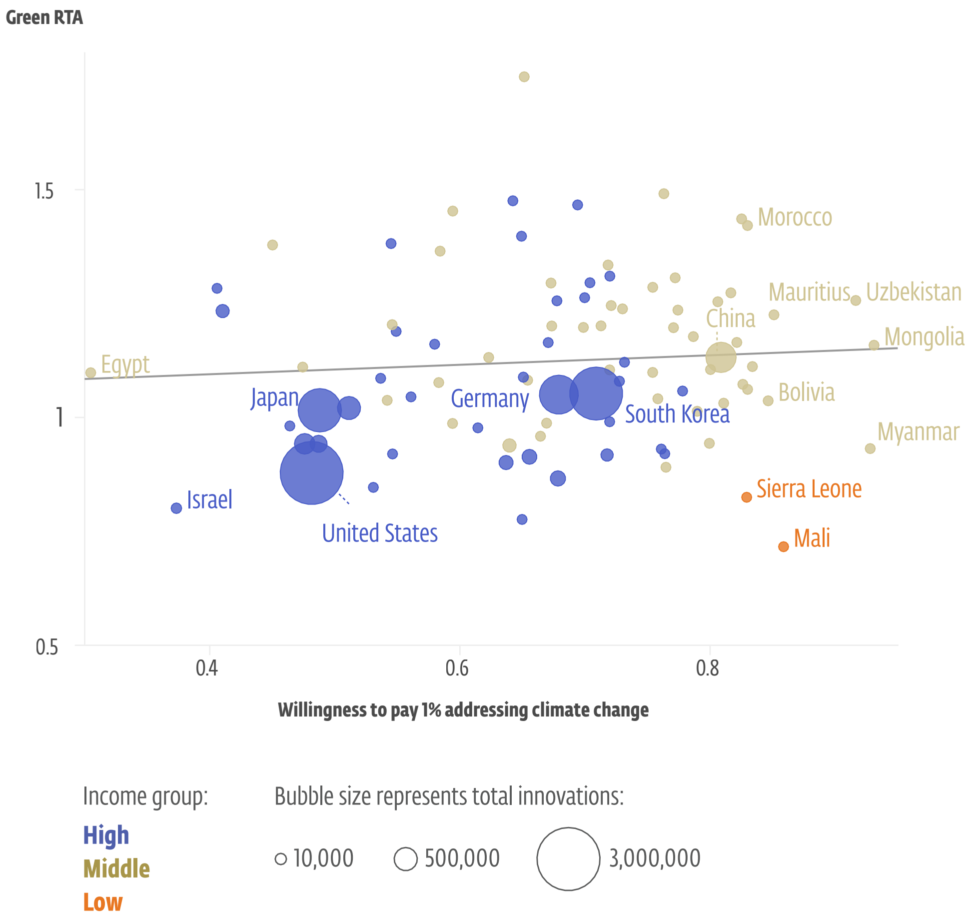
The share of academic papers from low and middle income countries has been expanding considerably



Source: IFC calculations based on openAlex data.

FIGURE A4.5

Green RTA based on all green technology categories is not clearly related to a countries willingness to pay for addressing climate change



Source: IFC calculations based on PATSTAT data. Note: This figure contrasts with RTA for adaptation technologies in figure 3.3.

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