World
Intellectual
Property
Report

Making Innovation Policy Work for Development

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Foreword


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Against a global backdrop of shifting economic tides, geopolitical tensions and digital acceleration, the importance of economic diversification is gaining renewed interest around the world.

In economies of all sizes, we are seeing a resurgence in industrial policymaking. This includes in many developing and least developed countries, who are increasingly targeting economic diversification – and the innovation, creativity and technology required to achieve it – as a means of securing supply chains, addressing national and international challenges and driving sustainable growth.

But economic diversification is a tough process. It asks policymakers difficult questions about which areas to support, which not to support, and where untapped potential lies. It also requires the flexibility to move swiftly and seamlessly into new areas of specialization, as well as the focus to build new, often complex innovation capabilities.

Here is where this edition of WIPO's World Intellectual Property Report can make a difference. Our economic team has devised a novel methodology, mapping 20 years of innovation capabilities across over 150 Member States, to help lift the lid on innovation policy design and the secrets to success.

This process has involved crunching the data linked to nearly 40 million patent filings, over 70 million scientific papers and economic activity worth more than 300 trillion dollars. As a result, we can pinpoint the progress different countries have made in boosting their economic diversification in areas of technology, science and exports.

For instance, during the past two decades, China jumped from being specialized in 16 percent of technological capacities to 94 percent. While India has increased it areas of scientific specialization from 42 percent to 68 percent and Colombia from 7 percent to 21 percent.

We want to support more countries to make similar jumps. Indeed, in a world where more and more economies see their future in innovation, creativity, technology and entrepreneurship, it is essential that we support policymakers in all regions to make diversification, and the advanced capabilities behind it, a reality.

We hope this report proves illuminating and instructive to all Member States looking to harness innovation for productivity, competitiveness and development. Diverse innovation ecosystems are the strongest innovation ecosystems – more durable, more dynamic and better placed to deliver sustainable economic growth.

Daren Tang
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Chapter 1 and 2: A team from The Growth Lab of the Center for International Development in the Harvard Kennedy School provided background research on "Innovation Policies Under Economic Complexity" and "Global Trends in Innovation Patterns: A Complexity Approach." The team was led by Prof. Ricardo Hausmann and included Muhammed A. Yildirim, Christian Chacua, Matte Hartog and Shreyas Gadgin Matha.

Chapter 3: Gregory D. Graff provided background research on "Innovation Complexity in AgTech: The Case of Brazil, Kenya and the United States."

Chapter 4: Paolo Aversa (Kings College London) provided the background research on "The Evolution of the Two-Wheeler Industry: A Comparative Study of Italy, Japan, and India."

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Executive summary: Making innovation policy work for development

To bridge the gap between the poorest and richest countries, economists and policy makers need to address the question of how economies diversify. By building, diversifying and applying knowledge embodied in technology, economies can boost innovation and drive development. This report draws on original analysis and three case studies to explore how economies can successfully diversify their capabilities with the support of innovation policies.

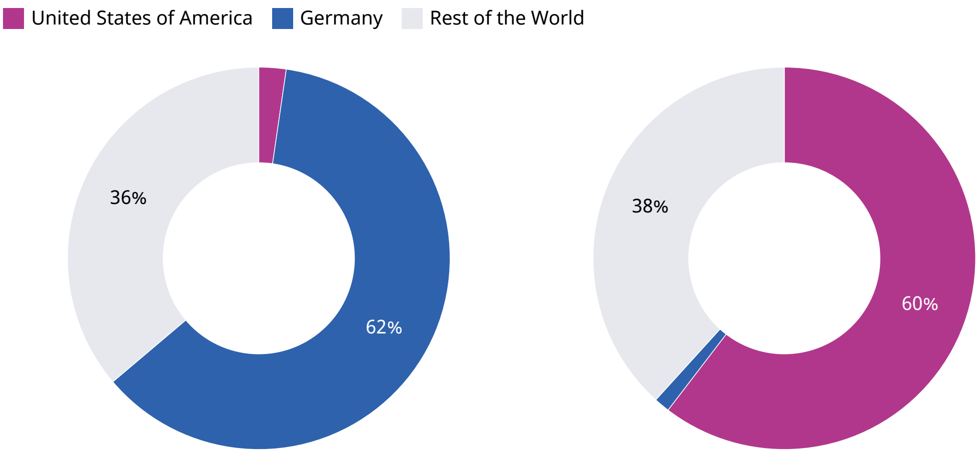
Knowledge is key

Knowledge is constantly increasing. Some of it is embodied in tools, machines or equipment; much more is codified through documentation, standardization and classification; while some knowledge remains tacit – that is, stuck in individuals' brains. Take the ICT industry, for example: knowledge starts as an idea in a researcher's head; some of that is shared through publications, speeches, patents or other means; and only a proportion ends up in devices such as computers, smartphones and autonomous vehicles. These products are easily traded internationally, but the knowledge and capabilities to produce them is not.

Because tacit knowledge cannot easily be transferred, it becomes concentrated in certain places, which means that particular regions or countries dominate certain sectors. To take just two examples of niche areas of expertise: in 2021 Germany exported 62 percent of the world's stereoscopic microscopes and the United States exported 60 percent of the world's aircraft landing gears.

Regions or countries can dominate certain sectors

Figure 1 **Exporters of selected products in 2021**



Stereoscopic microscopes

Aircraft landing gears

Note: For complete notes and sources, see Chapter 1, Figure 1.1.

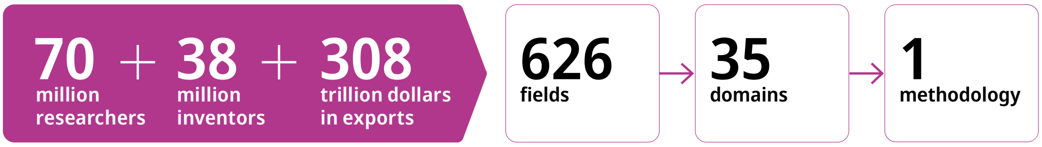
Leveraging innovation capabilities

One way to promote economic development is through the application and adaptation of existing innovation capabilities. Innovation capabilities can be categorized into scientific, technological and production dimensions.

Innovation capabilities based on scientific, technological and production know-how in a particular country or region can be measured by studying the data on scientific publications, patent applications and international trade respectively. In this report, this data is broken down into more than 600 fields (grouped into 11 scientific domains, 14 technological domains and 15 production domains).

Innovation policy design has to rely on Big Data techniques

Figure 2 Millions of records used to map innovation capabilities in the World Intellectual Property Report 2024

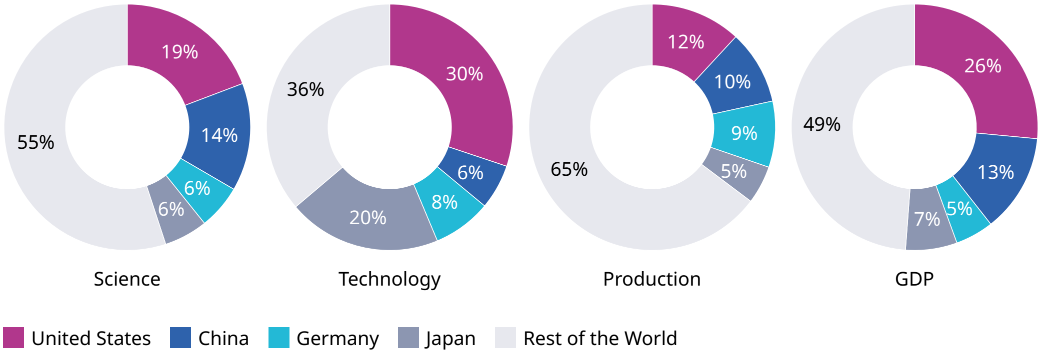


Note: See Chapter 2.

Analysis of data from 154 countries reveals that innovative outcomes are highly concentrated. Over the past 20 years, for example, the top eight countries (5 percent of those analyzed) account for 50 percent of exports, 60 percent of scientific publications and 80 percent of international patenting.

Innovative outcomes are highly concentrated

Figure 3 Share of innovative outputs vs. GDP share, 2001-2020



Note: For complete notes and sources, see Chapter 2, Figure 2.1.

The top economies for scientific, technological and production capabilities are all high-income countries (such as the United States, France, Germany, Japan and the Republic of Korea) and/or large economies (such as China and India). However, income and size alone do not explain where countries stand. For example, Germany has a greater concentration of exports, scientific articles and patents than its share of GDP while Indonesia's share of exports is above its GDP share, but its share of scientific articles and international patents is substantially below.

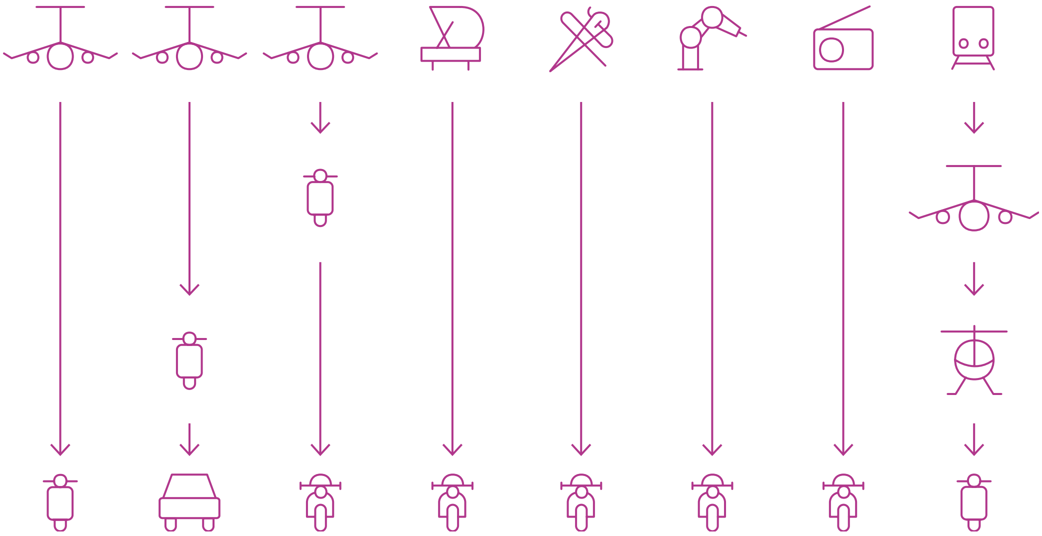
Specialization and diversification

The concentration of knowledge leads to specialization in certain capabilities. By specializing in their existing strengths, countries and regions can achieve higher levels of productivity and innovation.

For instance, in the Emilia Romagna region in Italy, the proximity to iconic sport carmakers (such as Ferrari and Lamborghini) has allowed motorcycle firms (such as Ducati) to infuse racing innovations into their designs. This has translated into improvements in engine, equipment, performance and other technological advances.

Many top motorcycle companies have emerged from related industries

Figure 4 Motorcycle firms have built on capabilities to specialize over time



Note: See Chapter 4.

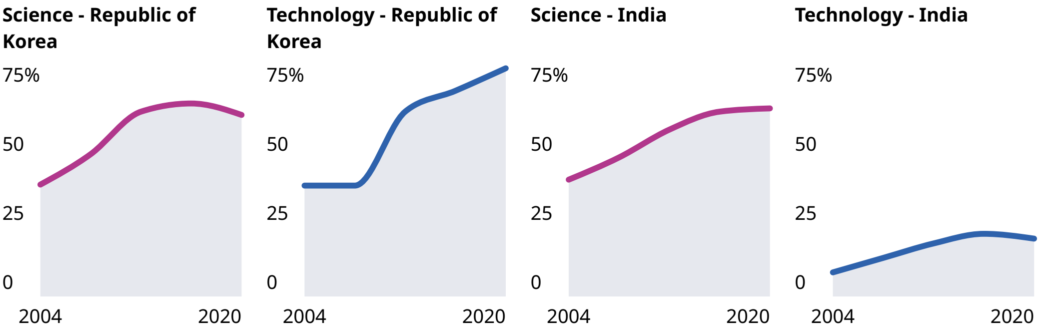
However, over-specialization can increase the vulnerability to external shocks, market volatility and value chain disruptions. That is why economies are constantly seeking to acquire or develop new specializations through diversification. For example, the Brazilian government introduced in 1975 a national program to produce ethanol from sugarcane production. This innovation policy allowed agribusinesses to quickly diversify out of coffee production and avoid the hit of a severe frost that disrupted the country's coffee industry.

Notably, diversification can be driven by combining existing capability specializations. One of the reasons why countries with a greater range of economic activity (typically but not always rich countries) tend to grow more quickly is that they can diversify more easily – especially into products that are less common.

Between 2001 and 2020, for example, the Republic of Korea jumped from being specialized in only 40 percent of all technological capabilities to being specialized in 83 percent. During the same period, its specialization in scientific capabilities increased from 40 percent to 66 percent. Similarly, the number of scientific and technological capabilities that India is specialized in jumped from 42 percent and nine percent to 68 percent and 21 percent respectively.

Diversification can be driven by combining existing capability specializations

Figure 5 Share of scientific and technological capabilities, Republic of Korea and India, 2001-2020



Note: For complete notes and sources, see Chapter 2, Figure 2.4.

As countries become more diversified, their capabilities become less common. For example, Afghanistan is specialized in only two capabilities (the production of spices and of fruit and nuts) which are very common, whereas Germany specializes in more than 500 capabilities, and on average less than 12 per cent of other countries specialize in these.

Innovation complexity

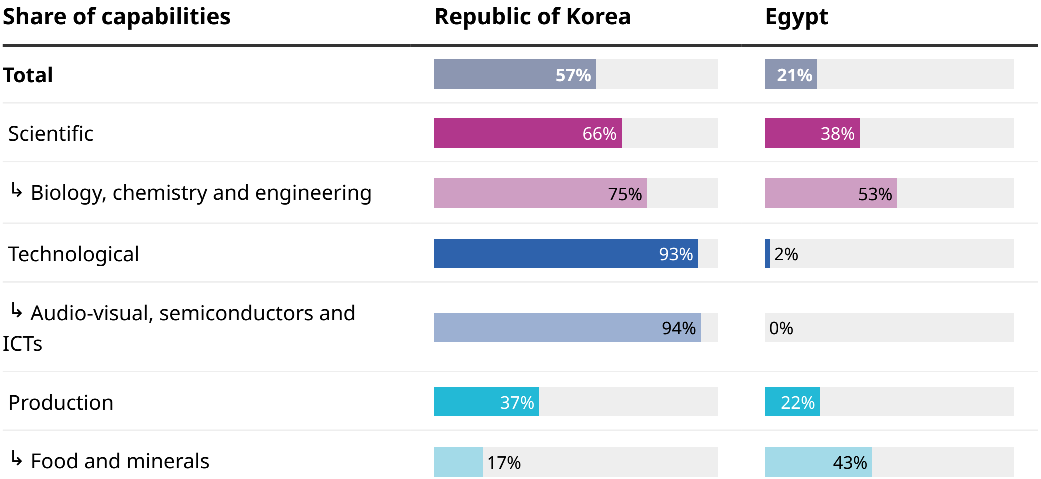
One way of addressing the diversification question is by considering innovation complexity. Innovation complexity is the knowledge in an economy as expressed in the diversity and sophistication of the science, technologies and products it produces.

Consider if an economy were like a group of musicians: the musical diversity and sophistication of the group will depend on the number of musicians, the diversity of instruments they can play and the proficiency of their performance. The complexity of an economy ranges from a one-person band to a sophisticated philharmonic orchestra.

A broad set of innovation capabilities leads to more sophisticated economic outputs. Complex capabilities are rare and only diversified innovation ecosystems can make use of them. The concept of innovation complexity therefore enables a better understanding of how moving to new and more complex industries while building on relevant existing capabilities can lead to sustainable development.

More diversified economies tend to have a more complex basket of capabilities

Figure 6 Republic of Korea and Egypt's innovation capabilities, 2017-2020



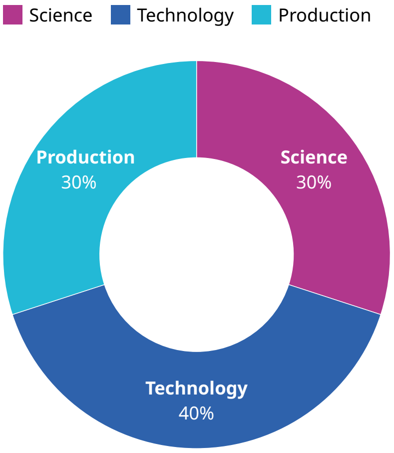
Share of capabilities	Republic of Korea	Egypt
Total	57%	21%
Scientific	66%	38%
↳ Biology, chemistry and engineering	75%	53%
Technological	93%	2%
↳ Audio-visual, semiconductors and ICTs	94%	0%
Production	37%	22%
↳ Food and minerals	17%	43%

Note: For complete notes and sources, see Chapter 2, Figure 2.9.

Of the three types of innovation capabilities, technological capabilities are the most complex. Only a few very advanced economies that have diversified know-how can systematically generate technological capabilities. This can be seen by contrasting the Republic of Korea and Egypt. The former has a wide distribution of capabilities covering most domains and is specialized in all the fields related to semiconductors, ICTs and audiovisual technologies. The latter is specialized in domains where complexity is lower, such as the production capabilities of producing agrifood, minerals and fuel, and to a certain extent manufacturing and chemicals and in the scientific capabilities related to chemistry, applied and fundamental biology and engineering; it has no particular specialization in any technological capabilities.

Technological capabilities are the most complex

Figure 7 Share of capabilities in the top 100 complex fields, 2017–2020



Note: For complete notes and sources, see Chapter 2, Figure 2.8.

In general, developed economies are both more diversified and more complex than less developed ones, and more likely to see higher growth. In short, economies grow by transforming their production structure from one dominated by low-tech, ubiquitous activities to one with rare outputs that are more reliant on skilled human capital.

Relatedness

Diversification is vital for growth. But what is the best way to diversify? The evidence suggests that diversification is more likely to happen incrementally as economies develop activities that have similar skills to those they already have.

Diversification favors activities that are more closely related to each other – this is known as the principle of relatedness. Countries looking to gain new capabilities should therefore identify where the most rewarding opportunities can be found, rather than trying to develop complex technologies without solid foundations. The principle of relatedness can also work in the opposite direction: countries can lose capabilities that are isolated from their related skills.

For this reason, countries and regions tend to specialize in technologies and products that are closely related to their past capabilities: think of Stuttgart in Germany (automotive technologies) and Silicon Valley (ICTs) and Boston (health technologies) in the US.

In general, the more related, unique and sophisticated capabilities that an innovation ecosystem has, the more complex technologies it will be able to develop. China, for example, gained incrementally complex technological capabilities between 2001 and 2020 in the ICT domain, particularly in speech or audio coding or decoding, electronic circuitry, electric elements for telecommunications, and computing methods and technologies.

Different forms of development

In the domain of agricultural technology, several regions have shifted away from traditional agricultural production by building on local innovative capabilities, leading to ethanol production in São Paulo in Brazil, the production of maize varieties for the African region in Nairobi, Kenya and the global export of crop biotechnology varieties and other agricultural technologies in Colorado, US.

New opportunities can be leveraged from existing capabilities

Figure 8 **The agriculture sector has sourced in new know-how that builds on existing capabilities**

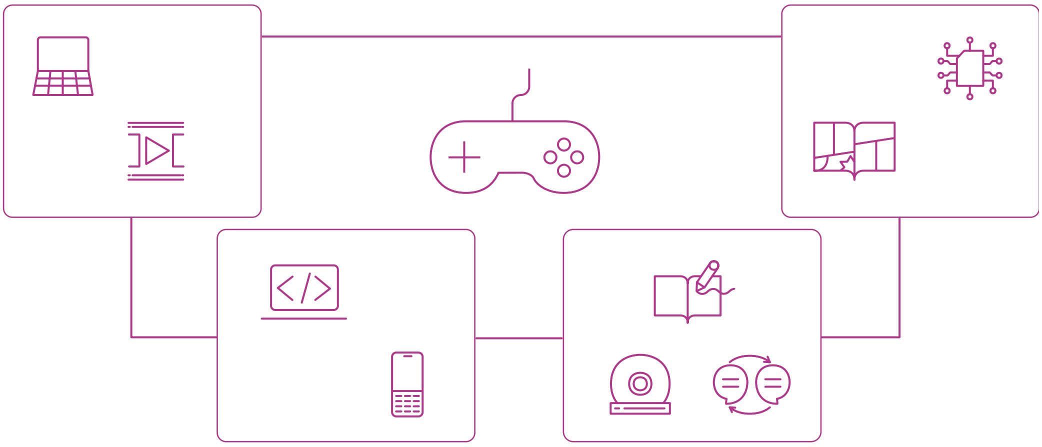
Note: See Chapter 3.

Similarly, the development of the motorcycle industry has been intrinsically tied to the capabilities cultivated in the closely related bike, aviation and automobile sectors. National motorcycle industries tend to chart courses shaped by their historical technological, institutional set-up and policy trajectories. In Italy, this has led to high performance and distinctive design; in Japan to advanced technologies and product reliability; and in India to cost efficiency and urban mobility features.

In some cases, new capabilities can develop based on several apparently unrelated existing capabilities. In the United States, for example, the video game industry was built on the robust computing sector combined with creative talent from Hollywood. Similarly, in Japan video games benefited from a strong electronic manufacturing base, which led to arcade games and later home console gaming, and artistic talent from the anime and manga industries. In Finland, teenage hobbyists led to the creation of the "demoscene," a subculture in which video game programmers and artists work together to create computer audiovisual demos despite limited hardware. The Polish videogame industry went to the next level by pairing game translation and distribution know-how with local literature and design talent.

New capabilities can develop from unrelated existing capabilities

Figure 9 **Video game capabilities developed from different pre-existing artistic capabilities**



Note: See Chapter 5.

Promoting industrial development

The concept of economic complexity and relatedness can help inform countries' industrial policy priorities: for example, advanced economies specializing in complex activities may be better able to diversify into other highly complex activities while less developed economies will only be able to diversify into less complex ones.

Science, technology and innovation (STI) ecosystems underpinned by solid innovation policies can promote investment in nascent technologies, which provide the foundation for future innovation and industrial development. Technological advances that benefitted from public funding, and which spawned new industries, include penicillin production, the Internet and autonomous vehicles.

In developing economies, a functioning STI ecosystem can also be instrumental in absorbing and adapting knowledge generated elsewhere. Universities and research institutes can lead the adaptation of new plant varieties and farming technologies to local conditions. Publicly funded research organizations have played a crucial role in the development of the pharmaceutical industry in India and the semiconductor industry in the Republic of Korea.

Government incentives to invest in innovation, such as R&D subsidies and tax credits and subsidized loans, as well as the intellectual property system, can incentivize the development of new technologies and production of innovative goods and services. Globally, most of the R&D in agriculture has been financed by the public sector. The Brazilian shift toward ethanol production, for example, was backed by public financial incentives for both the consumers as well as producers of ethanol.

Building an innovation ecosystem

The past few years have seen a revival of industrial policies, in response to challenges such as the global pandemic and climate change. For example, the European Green Deal of 2020 and the U.S. Inflation Reduction Act of 2022 provide incentives to promote the development and deployment of carbon-reducing technology. Many countries, including Italy and India in the case of motorcycles, are incentivizing the take-up of electric vehicles through subsidies and tax credits.

Analysis of economic complexity and relatedness can inform these policies by identifying missing links in the innovation ecosystem. For instance, it is possible to identify untapped technological potential by comparing scientific output and international patents, including through patent landscaping and other techniques. This can help policymakers to prioritize between domains and identify constraints in relations between academic institutions, industry and the IP system.

By managing innovation capabilities and mapping relatedness, countries can lay the foundations of long-term growth and competitiveness. Embracing principles such as complexity and smart specialization, as set out in the report, can help policymakers to make informed strategic decisions that deliver innovation, economic success and sustainability.

1 Economic development, economic complexity and industrial policy

Economic growth depends on sustained technological development, but capabilities can vary across the world from one region to another. In theory, technological knowledge could easily be shared and reproduced, but in practice it is not so straightforward. This chapter introduces the concept of economic complexity and explains how policymakers can facilitate knowledge diffusion to promote industrial growth.

Introduction

Sustained differences in economic growth between countries have led to vast differences in income per capita. When Adam Smith wrote *The Wealth of Nations* in 1776, the ratio of the highest to lowest income per capita was around 7 to 1. Today, this ratio is more than 250 to 1![1] The historical roots of these significant disparities in income date back to the Industrial Revolution, when per capita income growth accelerated in industrialized countries.[2] Since then, continued technological progress has enabled new industries to grow. This growth has transformed the face of economies everywhere, though not in the same way.

While the gap between the poorest and richest countries has grown overall, the growth experience of initially poor economies has been mixed. Up until around 1990, poorer countries, taken together, did not grow any faster than richer countries. Economists characterized this development performance as a continued process of divergence.[3] This trend has, however, flipped over the other way during the last three decades, with poorer countries seeing somewhat faster growth than richer ones.[4] In other words, divergence has become convergence.

Despite this better news, it is important to realize that what holds true for poorer economies as a whole does not necessarily hold true for all such economies. Already by the 1970s and 1980s, certain less developed countries – notably, the Republic of Korea – had achieved economic convergence with developed economies. Conversely, despite there being a general convergence trend over the last three decades, a considerable number of poorer economies – including many of the least developed countries – have struggled to generate growth and have continued to fall behind. Across world regions, Asian economies – primarily those in East and South Asia – have, overall, seen a stronger growth performance than economies in Africa and Latin America. Yet even within different regions, the growth experience of the different economies has varied over time.

Economists have sought to explain such wide variations in development outcomes for as long as they have been observed. Robert Solow famously argued that long-run economic growth could only be achieved through sustained technological development.[5] Joseph Schumpeter as well as Philippe Aghion and Peter Howitt emphasized the importance of creative destruction, whereby new technologies and industries replace old ones.[6] Paul Romer devised a theory of so-called endogenous growth, in which technological progress attracts investments in both human capital and research and development (R&D).[7] Martin Weitzman argued that new ideas arise through the recombining of existing ones and that economic growth is constrained not by a lack of new ideas, but the inability to leverage existing ones.[8]

In principle, technological knowledge can be easily shared and replicated, but in practice it does not flow seamlessly across space.[9] Some places have historically been more successful at acquiring knowledge and effectively converting it for industrial use than have others.

What explains their relative success and what can others learn from their experiences?

These questions are at the heart of this report. Drawing on new thinking in economic research, the report introduces the concept of economic complexity, which provides a framework for understanding how economies accumulate, diversify and apply knowledge. This task is performed in Section 2 of this chapter. Based on this understanding, Section 3 reviews what policymakers can do to promote industrial growth and reviews how both the practice and the intellectual thought behind so-called industrial policy have evolved over the past few decades. Section 4 offers concluding thoughts by highlighting the emergence of a new era of industrial policies.

The remainder of this report delves deeper into the industrial development process. Mirroring the notion of economic complexity, Chapter 2 employs data on trade, scientific publications and patents to develop indicators of so-called innovation complexity. Chapters 3 to 5, in turn, offer insights into successful industrial development approaches through three case studies: agricultural technology, motorcycles and videogames.

Understanding relatedness and economic complexity

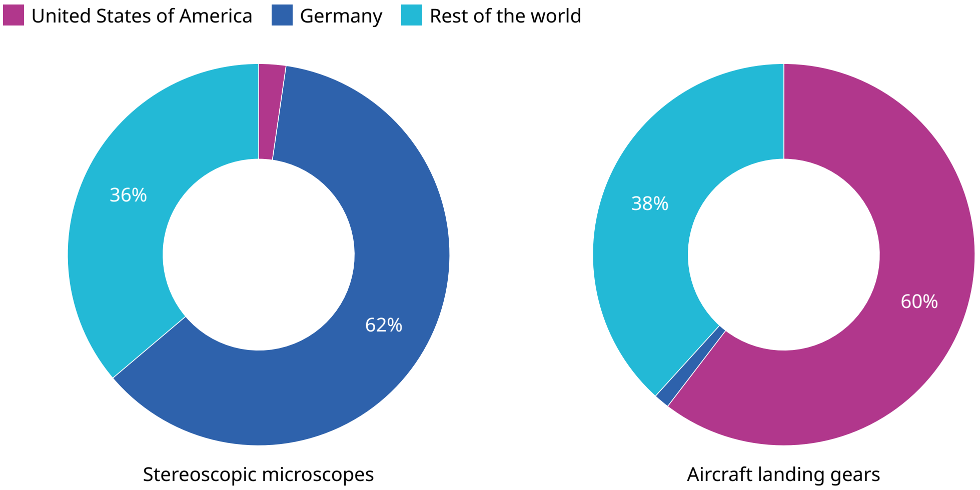
Technology represents the knowledge that we harness to reshape our physical and social environments. It has grown tremendously over the past few centuries, as demonstrated by the ever increasing volume of books, scientific papers and patents. Yet our individual capacity to comprehend it remains constrained. Hence, we increasingly become specialized as individuals and distribute knowledge to counterparts. Over time, this knowledge ends up in tools, machines and equipment – so-called embodied knowledge. In addition, we codify what we know and convert it into forms that can be shared through documentation, standardization and classification – so-called codified knowledge. Yet a large part of our knowledge is harder to codify; instead, it remains *tacit*.

Tacit knowledge is "stuck" in brains and does not easily move across the world. Even codified knowledge does not flow seamlessly from one individual to another, because it requires prior knowledge to absorb. As a result, knowledge becomes concentrated in certain places. In 2021, for instance, Germany exported 61.5 percent of the world's stereoscopic microscopes and the United States of America (US) 60.4 percent of the world's aircraft launching gear (Figure 1.1). Firms and workers in those industries are highly specialized and cannot easily switch from producing microscopes to aircraft gear or vice versa.

This concentration and specialization of tacit knowledge can also be observed within industries. For instance, companies that make jet engines typically do not produce other aircraft parts. To put all the parts of an aircraft together, somebody must think about the design of each part and how they will come together. Hence, the growth of knowledge at the product level requires an increase in the division of labor at the level of the individual.

How knowledge can concentrate in certain places

Figure 1.1 **Exporters of selected products in 2021**



Source: Harvard Growth Lab (2023).

The game of Scrabble as a metaphor

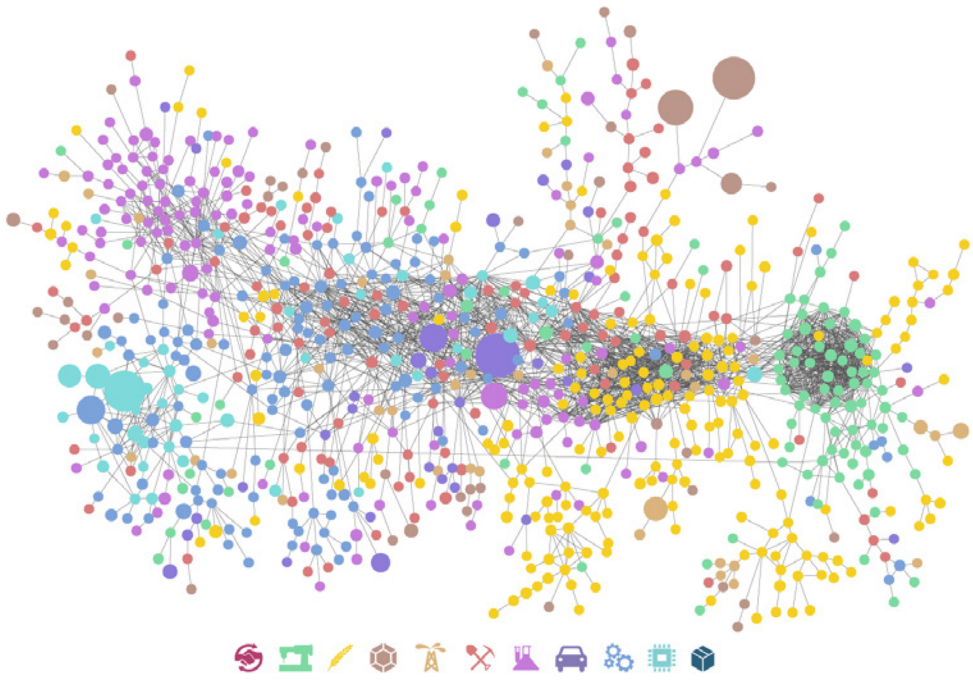
In this metaphor,[10] goods and services rely on productive capabilities, which we can call letters. Words then represent the combination of those productive capabilities that go into making a particular product. Not all combinations of letters are words: some sets of letters are words, but other sets of letters are just gibberish. So the products – words – can be defined by the set of capabilities needed to make them – the letters.

Continuing the metaphor, we can think of places as collections of words and letters and products as collections of letters. A place – whether a city, province or country – can be characterized by the letters it has, whereas a product can be characterized by the letters it requires.

Economic researchers have formalized these logical statements about the world and have tested them empirically.[11] Using international trade data, they found that the difference in the number of letters explains not only which products a given place is likely to diversify into but also the pattern of diversification. This holds true for countries and municipalities alike. They visualize this in what they call the product space (Figure 1.2). Each dot in this space represents a product. The proximity between the dots approximates the similarity in the know-how required to produce two products. Lines connecting two dots indicate the primary connections between products. The product space is irregular, with different products bunched together. For example, garment products are tightly clustered together, implying that the letters needed to make one kind of garment are similar to the letters needed to make other kinds of garments. The same goes for machinery. Then, some poorly connected products suggest that those words are short. For instance, oil requires making holes in the ground, but there are few products for which one needs to dig holes in the ground. By comparison, letters to make a microwave oven are similar to the letters to make a washer or dryer.

The world's product space

Figure 1.2 Exported products clustered and connected based on common related capabilities



Notes: Each dot represents a product category (based on the Harmonized System 1992 classification) and the size of each dot is proportional to the size of that product's world trade. The colors represent the 10 major sectors shown in the key (textiles, agriculture, stone, minerals, metals, chemicals, vehicles, machinery, electronics, and others). Products requiring related capabilities are clustered closer together in the network. The lines between dots indicate primary connections between products.

Source: Harvard Growth Lab (2023); an interactive version is available at https://atlas.cid.harvard.edu.

Each economy occupies its own product space. In order to diversify into new products, a country needs to find ways to reach other parts of the product space. And research has shown that diversification favors activities that are close together – known as the principle of relatedness.[12] For example, Venezuela has relatively few activities and most of them – such as oil and raw materials – are in peripheral positions.[13] Mexico has more and Austria – which is less than a 10th the size of Mexico – has even more, covering the entire product spectrum.

Further implications of the Scrabble metaphor

The Scrabble metaphor has further implications for industrial development. First, the more letters one has, the more words one can put together. The diversity of letters thus leads to a diversity of words. Second, the longer the word, the harder it is to make it. If one assumes that there is some distribution of letters among places, the longer the word, the fewer the places that can make it. We call the number of places that can make a product the *ubiquity* of the product. A place that has a lot of letters should be more diversified and specialized in less ubiquitous products. And by the same token, less ubiquitous products should be made in more diversified places. Accordingly, the term *economic complexity* seeks to capture the knowledge residing in an economy, as it is expressed in the diversity and ubiquity of the products it produces. Economic researchers have translated this concept into a formal economic complexity index that captures how diversified and ubiquitous an economy's export basket is.[14]

The economic complexity index correlates with economic output and income per capita. Poor countries have few letters, whereas rich countries have a lot of letters. More importantly, if – relative to other countries with the same GDP or income per capita – a country has fewer letters, it tends to grow more slowly. In some sense, the space of letters is more fundamental to growth prospects than the current income level. A greater endowment with letters enables economies to diversify more easily and especially into products that are less ubiquitous. This is discussed in more detail in Chapter 2.

The concept of economic complexity allows for a richer understanding of the economic growth process that emphasizes different dimensions of knowledge and how distributive knowledge needs to come together in order to make things. To sustain growth, countries need to move to new and more complex industries, while building on relevant local capabilities.

A key question therefore is how can a country acquire new letters to make new words and diversify into new activities, particularly toward the denser part of the product space, where more complex products are located. The country would need the knowledge to make such jumps. According to the economic complexity view, the key to economic development is productive knowledge. Such knowledge is distributed in different individuals' heads, tools and materials, and the process of economic growth entails the accumulation and expression of this knowledge in more goods. In the Scrabble world, this corresponds to more letters, more words and longer words. Development thus requires greater specialization at the level of individuals, which leads to greater diversification at the level of companies and industries.

One implication of this theory is that the tacit and complex knowledge embedded in specialized individuals is crucial for diversification. Due to its tacit and complex nature, such knowledge does not move freely across the world. Hence, countries may lack the knowledge to make jumps into new activities. How can they possibly overcome this barrier?

Diversification is a chicken-and-egg problem. For a place to diversify into new activities, it must learn to do things that it could not do in the past. But how does a place begin to make things if it does not know how they are made? For example, how does one become an experienced watchmaker in a place that does not make watches? The greater the number of missing letters, the more challenging it will be to diversify.

Countries generally need to benefit from a high level of basic skills to be able to absorb more complex and specialized capabilities from elsewhere.[15] Still, the accumulation of basic skills also faces the chicken-and-egg problem. In a location where most of the industries present do not use high-skilled or specialized labor, the incentives to invest in these skills are limited. Only once there are concrete prospects from acquiring new skills will these incentives change. In the complexity framework, we can think of letters as being shaped by the education system; if a letter has no word in which to be used, it will not emerge.

The complexity framework developed here is in line with the criticism by economists – notably Benjamin F. Jones – about how human capital stock is accounted for in studies of economic growth.[16] In particular, Jones highlights the importance of skills that are not perfect substitutes for one another. A heart surgeon, for instance, requires at least an anesthesiologist to operate effectively – without one, the surgeon's value would greatly decrease. The division of labor allows for the existence of collective know-how, which is greater than the sum of individual skills. In developed economies, the ubiquity of other highly specialized knowledge workers justifies the costly acquisition of specialized knowledge. Developing economies, in turn, may find themselves in a "knowledge trap," as an insufficient ecosystem for complementary skills undermines an individual's reward for investing in specialized skills.[17]

How then can the challenge of missing letters be overcome? One way is the presence of major organizations with diversified portfolios, which allows for internal diffusion and redeployment of capabilities. Particularly relevant here are those organizations with substantial resources – such as corporate conglomerates – that can re-deploy existing workers and even whole teams to new and related activities. Famous examples of such internal diversification are the *keiretsu* in Japan and the *chaebols* in the Republic of Korea. Research has shown how these organizations propelled diversification into new technological activities in these two economies.[18]

Labor mobility leading to knowledge transfer

Worker migration is another way of enabling diversification.[19] Take the case of East Germany, which has experienced a gradual revival of its industries after initially losing 60 percent of its manufacturing jobs following German unification. Research has shown that the pioneer plants in East Germany relied heavily on experienced workers from West Germany.[20] These well-paid workers from outside the region generated substantial employment opportunities for local workers and individuals entering the job markets. Pioneer plants, in turn, may train workers which may then be hired by follower plants, ultimately fostering the diffusion of specialized knowledge.

Pioneer plants also tend to drive the structural transformation of economies. Research has found that the greatest diversification steps are taken by entrepreneurs and existing firms from elsewhere that set up new plants in regions. They foster a process of knowledge diffusion across regions. During a period of 17 years of structural transformation in regions within Sweden, it is those pioneers that are shown most likely to survive and thrive.[21] By contrast, existing firms that try to jump into new activities are more likely to fail. They cannot draw on related local capabilities in the same way that pioneer companies can draw on internal capabilities acquired elsewhere.

Hence, for countries and regions to achieve structural transformation, it may be important to attract companies and workers from elsewhere. Economist AnnaLee Saxenian calls these workers the New Argonauts. She documents how foreign-born, highly skilled workers who have ventured back and forth between Silicon Valley and their home countries infused the latter with new knowledge. [22] Saxenian finds that such interactions proved crucial to emerging innovation hotbeds, such as the semiconductor industry in Taiwan, Province of China. More generally, these interactions are reflected in patterns of world trade. One study finds that a 10 percent increase in immigration from exporters of a given product leads to a two percent increase in the probability that the host country starts exporting the same product within the next 10 years.[23]

One driving force for labor mobility is foreign direct investment (FDI). When companies invest abroad, they often send experienced workers to their subsidiaries and transfer skills to local employees through formal training and mentoring. FDI can thus be a key steppingstone to acquiring new letters. One study, for example, found that when companies set up foreign R&D facilities in a particular region, that region sees subsequent growth in patenting activities.[24] More generally, research has shown that most structural change is induced not by domestic firms but by foreign ones.[25] That said, how the knowledge of multinational companies diffuses through the host economy depends critically on the pre-existing capabilities of local firms.[26] The benefits of FDI thus vary across industries and countries.

Diaspora networks can be another important channel of knowledge diffusion. They enable countries to tap into the knowledge of natives living abroad. For example, studies have traced the origins and growth of the information technology industries in China, India and Israel back to professional connections between domestic engineers, on the one hand, and diaspora engineers and entrepreneurs in Silicon Valley, on the other.[27] Similarly, the recent modernization of agriculture in Albania and its growth in exports of agricultural products can be traced back to returning migrants from Greece and Italy, who brought in advanced technological know-how.[28]

These various mechanisms focus on moving brains rather than moving knowledge across brains. As discussed above, the tacitness of knowledge makes the latter much harder to accomplish. One way it can still work is through business travel. Despite modern communication technology, in-person travel remains an important feature of global business activity. One study found that business travel networks predict which new economic activities will develop in a country and, inversely, which old activities will decline.[29] In particular, business travel from countries specializing in a specific industry causes growth in that economic activity in the destination country. In fact, the study finds that this effect, in statistical terms, has the most substantial impact on a range of bilateral relationships between countries, such as FDI, trade and migration.

The acquisition and accumulation of specialized knowledge usually result from market forces, with individuals and businesses identifying opportunities to maximize wages and profits. However, the diverse outcomes in industrial development observed across different parts of the world and over time indicate that the learning process enabling industrial diversification is not automatic. This raises the question of what preconditions need to be in place for successful learning to occur and, in particular, which public policies favor such success? We turn to this question next.

Policies to promote industrial development

From a broad perspective, a wide range of preconditions and policies matter for industrial development. For instance, overall macroeconomic stability, a functioning legal system, an effective educational system, and a financial system that efficiently turns savings into investment are all important. The complexity framework just discussed also highlights the importance of labor mobility, particularly openness to skilled immigration.

No doubt it is possible to point at countries that did not fully meet all the above conditions and yet still experienced industrial diversification. In addition, successful industrial development can be a self-reinforcing process, whereby initial success and the resultant economic growth promote the preconditions for subsequent success. Still, unfavorable overall preconditions in the above-listed areas will, on balance, hinder industrial development prospects.

Looking at it more narrowly, governments have long implemented policies aimed at directly promoting industrial diversification. The array of policy instruments employed for this purpose has significantly evolved over the past half-century. Traditionally, so-called *industrial policy* has been associated with a range of policy measures – notably, import tariffs, subsidies and subsidized loans – targeted at a limited set of industries.

An explicit or implicit aspect of these industrial policies was the selection of winners – the belief that certain industries held more promise for future development prospects compared to others. Starting in the 1950s, industrial policy centered on import substitution strategies, with many developing economies in Asia, Africa and Latin America pursuing such strategies.[30] The logic behind import substitution was that infant industries in less developed economies needed temporary protection that would enable them to learn and achieve scale, before becoming globally competitive.

The track record of import substitution is mixed, and in the 1990s many economists turned against it. While a theoretical case for import substitution exists, there were increasing doubts whether governments can reliably predict which industries hold the greatest promise. In addition, the acquisition of productive knowledge often proved more formidable than anticipated and perpetual infancy led to enduring import protection.[31]

The disenchantment with import substitution gave rise to a new industry policy paradigm: export-led growth. The impetus behind this strategy was the success observed in certain East Asian economies, most notably Japan, the Republic of Korea, Hong Kong, SAR and Singapore, collectively recognized as the East Asian miracle. These economies experienced simultaneous industrial diversification and a significant expansion of their export activities. This led to the idea that active engagement in global commerce played a pivotal role in fostering knowledge acquisition and promoting industrial diversification. In principle, policies aimed at promoting export-led growth were intended to be neutral toward specific industries, avoiding the picking of winners. The emphasis was on flexible exchange rates, diminishing import protection, and, broadly, eliminating distortions in market incentives.[32] However, in reality, some government policies, such as offering special incentives within export processing zones, still favored certain sectors at the expense of others.

Many governments still subscribe to the export-led growth paradigm. However, economists' perspectives on its likelihood of success have significantly evolved. The outcomes of initial export-led growth policies exhibit a mixed track record. Despite the notable East Asian success story, many developing economies that adopted these policies did not experience substantial industrial growth.[33] At the very least, the track record suggests that these policies are insufficient to generate industrial diversification.

Economic research has also raised doubts about whether the East Asian model of export-led growth, which is focused on manufacturing, can be effectively replicated in today's vastly transformed global economy.[34] The manufacturing sector now contributes significantly less to both economic output and employment compared to the period when the East Asian miracle occurred. Modern industrial development strategies must encompass the growth of service sectors, as these sectors typically account for most economic output. Although technology has expanded the tradability of some services, a substantial portion of service activities remains non-tradable, with limited opportunities for learning through exporting.

A related question is whether all countries and regions share the same potential for industrial diversification. For example, advanced economies already specializing in highly complex activities may be in a better position to diversify into other highly complex activities, whereas less developed economies will only be able to diversify into less complex activities.[35] The potential for diversification may also change over time, as technological progress opens new opportunities for diversification and closes others.

Considering the insufficiency of the export-led growth paradigm, how has thinking on industrial policy evolved over the past two decades? And does the concept of economic complexity help in setting priorities for industrial policy? While a full review of the rich research on industrial policy is beyond the scope of this chapter, the remainder of this section focuses on two prevalent lines of thought that have defined more recent approaches to industrial policy: harnessing science, technology and innovation for industrial development, and effectively devising industrial policy.

Harnessing science, technology and innovation for industrial development

A country's science, technology and innovation (STI) system comprises all entities engaged in the creation and dissemination of knowledge, as well as the interactions between them. These entities include universities, training institutes, research organizations, regulatory institutions and companies, which can be publicly or privately owned and can operate on either a for-profit or non-profit basis.

Within the economic complexity framework, an STI system shapes the set of letters available in a place and, in turn, the number of words – or products – it can produce. While productive knowledge ultimately resides in the brains of skilled workers, these workers are often trained at local universities. In addition, when innovating, companies frequently collaborate with scientific organizations, drawing in expertise not available in-house. Scientific organizations – while seeking the advancement of scientific knowledge – are often expressly tasked to address the technological needs of the local economy, though some do so more successfully than others.[36]

Public policies and funding play a crucial role in sustaining an STI system that supports industrial development. Markets left to themselves would systemically underinvest in generating and diffusing knowledge. This is most evident for scientific research that does not have any immediate industrial application, but which provides the foundation for future innovations. Yet even where there are prospects for industrial applications, private markets may shun them. Technology may still be incipient, with a high risk of failure and uncertain commercial viability. There are numerous examples of technological advances initially benefiting from public funding that spawned entirely new industries, such as the pharmaceutical innovations developed during the Second World War, the internet and self-driving cars.[37]

Even when companies are willing to bear the risk of investing in innovation, economists contend that they often tend to underinvest compared to what is socially desirable, for two key reasons. First, companies may find it difficult to appropriate the returns on their innovations if others can readily copy them. This is why governments protect patents and other forms of intellectual property (IP), which offer companies timebound exclusive rights on their inventive and creative outputs. Second, even when companies are able to profit from their innovations, the private return on innovation is often substantially below its social return.[38] Take the example of COVID-19 vaccine innovation. One study compared the social return from the invention of these vaccines – in the form of saved lives and contained economic output losses – to the private profits accruing to vaccine makers. It estimated the former to exceed the latter by a factor of 887.[39] Higher social than private returns justify governments providing extra incentives for companies to invest in innovation. Such incentives take the form of R&D subsidies and tax credits, subsidized loans, prizes and other instruments.[40]

An STI system is not only important in fostering innovation that prompts the commercialization of technology that is new to the world. It can also be instrumental in enabling economies to absorb and adapt knowledge generated elsewhere. In fact, this will be the primary role of STI systems in developing economies, where industries do not operate at the world's technology frontier. For example, in many developing economies, universities and research institutes have led the adaptation of new plant varieties and farming technologies to local conditions. Studies have also documented the crucial role that publicly-funded research organizations played at the early stages of India's pharmaceutical industry and the Republic of Korea's semiconductor industry.[41] The support provided by these organizations included advice on technology deployment, the transfer of technology developed within such organizations, joint R&D, and other services.

Harnessing STI systems for development is a matter of mobilizing government revenue to fund universities and public research organizations and providing R&D support to companies. However, it is also a matter of providing policy incentives, building linkages within the STI system and offering advice. For instance, many universities have developed frameworks for transferring technology developed in academic labs to companies. These frameworks seek to promote such transfers, while also recognizing that the commercial deployment of university technology often requires substantial follow-on investment by companies. Managing IP rights is a critical component of such technology transfer frameworks.

In addition, STI institutions are important in matching the supply and demand for technology. Unlike many goods and services traded in the marketplace, technology is highly differentiated. Companies may not be aware of existing solutions to the technological challenges they face, while academic researchers may be insufficiently informed about the technological needs of companies. There is thus a role for platforms and industry fairs that can overcome such informational divides. Similarly, many IP offices provide so-called technology landscapes to industry stakeholders, based on the patents filed in different technology fields worldwide (Box 1.1).

Box 1.1 How patent landscapes offer insights for innovation stakeholders

Individuals, companies, universities and other entities applying for patent protection must disclose their inventions to IP offices, who evaluate whether these inventions meet the eligibility criteria for patentability. IP offices eventually publish patent applications, adding to an ever-growing patent literature that provides a wealth of information on innovation across all fields of technology. Many companies frequently consult patent literature in order to study the latest technological trends and learn about the innovative activities of their competitors.

Patent documents are a good example of codified knowledge that is theoretically accessible to anyone, but which in practice requires specialized skills in order to understand and use. To facilitate insights that emerge from the patent literature, many IP offices around the world regularly publish so-called patent landscapes. These landscapes typically focus on one or a selected group of technologies. They provide a classification of relevant technologies, highlight areas of growth and decline, and pinpoint the main actors and locations of inventive activity. WIPO maintains a global repository of patent landscapes compiled by national and regional IP offices.[42] In addition, WIPO also publishes its own patent landscape reports.[43]

Companies without their own in-house patent analytics capabilities can draw on these freely available reports to inform their innovative activities, including whether to seek licenses for patented technologies. Patent landscapes can also provide useful information to policymakers, as they reflect the capabilities of local innovators and their position in the broader innovation landscape. For example, in its 2021 Innovation Strategy, the Government of the United Kingdom (UK) partly relied on the patent landscaping work of the UK Intellectual Property Office in order to identify seven technology families that provide a starting point for prioritizing investment.[44] For these technology families, the UK was considered to have globally competitive R&D and industrial strength.

Finally, through the STI system, governments can prioritize the development and diffusion of technologies that societies value highly but for which private incentives to innovate are insufficient. One example is public health. The COVID-19 pandemic has highlighted the importance of an agile innovation system to respond to the spread of infectious diseases. However, in non-pandemic times, companies have little incentive to invest in vaccine R&D, as there is no market to sell vaccines. Public support can compensate for the lack of market incentives. Similarly, STI policies can prioritize technologies that reduce carbon emissions and better manage climate adaptation – beyond what market incentives can provide.

Devising industrial policy

As pointed out above, one criticism leveled at early industrial policies was the uncertain ability of governments to predict which industrial activities held the greatest promise in a particular location. There are, indeed, numerous examples of disappointing results from initiatives to build, say, local biotech or semiconductor industries from the ground up.[45] Policymakers arguably overestimated the capacity of local economies to build the knowledge base necessary to enable the production of globally competitive goods, especially in industries with rapid technological progress and fast product cycles. Indeed, the economic complexity framework emphasizes the key role of the existing capabilities available within a territory, which limit the possibilities of developing new technologies.[46] Knowledge diversification is typically a gradual path-dependent process, where one decision determines later ones. In the Scrabble metaphor, it is driven by exploiting adjacent opportunities to combine letters to form new words.

Industrial policy interventions may serve different purposes. They may amplify existing capabilities and thus accelerate industrial diversification. Alternatively, they may aim to disrupt the natural path dependence process if existing capabilities constrain industrial growth.[47] Either way, the formulation of industrial policies needs to rely on a careful understanding of existing skills and capabilities, their competitive strengths and opportunities for diversification and growth. New approaches to industrial policy have thus emphasized the need for industrial policies to be devised in a "bottom-up" rather than a "top-down" fashion, typically taking place at the level of specific economic regions rather than overall economies.

One approach – adopted in the European Union (EU) since 2014 – is called smart specialization.[48] This entails an inclusive process that involves stakeholders and is centered on "entrepreneurial discovery." The process seeks to identify priorities for investment by both governments and companies that build on local capabilities. For example, governments invest in physical infrastructure, research and educational institutes that address the specific needs of local entrepreneurs. Companies, in turn, invest in innovation that continuously sustains their competitive strength. The key principles of smart specialization policies include focusing on the most binding constraints to industrial growth and instituting constant evaluation and calibration. Smart specialization policies also acknowledge the important role of STI systems in fostering the acquisition and diffusion of knowledge that enables industrial diversification.

How successful has smart specialization been? It is difficult – and perhaps too early – to provide a definite answer. The first phase of implementation in EU countries suggests that it is feasible but challenging to design and implement smart specialization strategies. In many cases, it proved difficult to identify a relevant priority area. Moreover, translating identified priorities into specific goals and finally moving toward transformational roadmaps and activities requires supporting institutions, which often proved to be weak.

Assessing economic outcomes is complicated by the fact that smart specialization strategies entail numerous interventions over time with long-term objectives, which do not allow for straightforward "before" and "after" assessments.[49] While recent evidence suggests that EU cities with the largest gains in complex and related technologies have enjoyed an economic performance premium, it remains an open question to what extent smart specialization policies can actually foster such gains.[50]

A new era of industrial policies

In summary, economists have long held ambivalent views about the effectiveness of industrial policies. This arguably reflects the mixed historical record of industrial policies centered on import protection and subsidizing specific industries. Beneath this ambivalence, however, there arguably is a more widespread consensus on the types of policy intervention that promote industrial development. Most economists would endorse governments investing in an STI system that facilitates the acquisition and diffusion of new knowledge.[51]

STI policies may not always fit neatly within narrow definitions of industrial policy, and they typically fall outside the purview of industrial development ministries. However, STI systems invariably shape industrial development and are usually designed with this purpose in mind. To be clear, STI policy choices still entail taking tough decisions. For example, which fields of scientific research should receive support? Which incipient technologies deserve funding and when should such funding be withdrawn? Market mechanisms provide few, if any, signals to inform such decisions.

Recent years have seen a revival of industrial policies, including in economies that have traditionally shunned them, such as the United States. This revival was not prompted by economists having gained new insights into their effectiveness. Rather, they emerged as a response to various new challenges faced by governments. One such challenge is climate change and the need to reduce carbon emissions. Prominently, the European Green Deal of 2020 and the U.S. Inflation Reduction Act of 2022 provide incentives to companies and projects that promote the development and deployment of carbon-reducing technology. Another challenge is to address shortages of strategic goods in the face of global supply chain shocks – as happened during the COVID-19 pandemic. For example, the Government of Japan has made subsidies available to companies to support the re-shoring of production from overseas locations.[52] Finally, some governments have rolled out large-scale support to certain high-tech industries considered critical for national security, notably semiconductors.[53]

The industrial policy instruments employed by governments in this new era vary widely. They range from tax breaks, production subsidies and R&D subsidies to trade and regulatory measures.[54] Most policy measures are still being implemented, so it is too early to assess their overall impact. Moreover, while recent industrial policies may aim to foster industrial development as a complementary goal, their success must be evaluated in the context of the broader objectives these policies intend to achieve.

Nonetheless, and despite the difference in context, some of the choices in recent industrial policies reflect bets on which industrial activities will offer long-term benefits. For example, many governments around the world currently support the development of an indigenous battery industry, believing that batteries will be a critical input for electrical vehicles and, more generally, future mobility. However, economies of scale in the production of batteries may mean that production will only be efficient at a few locations. In addition, it is unclear whether hosting battery production will offer substantial spillover benefits to the local economy, or whether batteries will turn out to be a commoditized product that can be easily imported. Notwithstanding the strong imperative behind the new wave of industrial policies, evaluating the benefits and costs associated with different policy interventions will thus remain important.

Notes

1 See Bolt and Van Zanden (2020). Bolt, J. and J.L. Van Zanden (2020). Maddison style estimates of the evolution of the world economy: A new 2020 update. *Maddison-Project Working Paper No. WP-15.* University of Groningen.

2 For a more in-depth historical growth perspective, see Chapter 1 of WIPO (2015). *World Intellectual Property Report 2015: Breakthrough Innovation and Economic Growth.* Geneva: WIPO. Available at: www.wipo.int/publications/en/details.jsp?id=3995.

3 As famously noted by Pritchett, there was "divergence, big time." See Pritchett, L. (1997). Divergence, big time. *Journal of Economic Perspectives*, 11(3), 3–17. DOI: https//doi.org/10.1257/jep.11.3.3.

4 The seminal study pointing this out is Patel, D., J. Sandefur and A. Subramanian (2021). The new era of unconditional convergence. *Journal of Development Economics*, 152, 1026687. DOI: https//doi.org/10.1016/j.jdeveco.2021.102687.

5 Solow, R.M. (1956). A contribution to the theory of economic growth. *Quarterly Journal of Economics*, 70(1), 65–94. DOI: https//doi.org/10.2307/1884513.

6 Schumpeter, J.A. (1942). *Capitalism, Socialism and Democracy.* Harper and Brothers; Aghion, P. and P. Howitt (1992). A model of growth through creative destruction. Econometrica, 60(2), 323–351. DOI: https://doi.org/10.2307/2951599.

7 Romer, P.M. (1990). Endogenous technological change. *Journal of Political Economy*, 98(5, part 2), S71–S102.

8 Weitzmann, M.L. (1998). Recombinant growth. *The Quarterly Journal of Economics*, 113(2), 331–360. DOI: https//doi.org/10.1162/003355398555595.

9 Maskell, P. and A. Malmberg (1999). The competitiveness of firms and regions: 'Ubiquitification' and the importance of localized learning. *European urban and regional studies*, 6(1), 9–25. DOI: https//doi.org/10.1177/096977649900600102; Cohen, W.M. and D.A. Levinthal (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, 128–152. DOI: https//doi.org/10.2307/2393553; WIPO (2015). *World Intellectual Property Report 2015: Breakthrough Innovation and Economic Growth.* Geneva: WIPO. Available at: www.wipo.int/publications/en/details.jsp?id=3995.

10 See Haussmann, R., M.A. Yildirim, C. Chacua, M. Hartog and S. Gadgin Matha (2024). Innovation policies under economic complexity. *WIPO Economic Research Working Paper No. 77.* World Intellectual Property Organization.

11 Hidalgo, C.A., B. Klinger, A.-L. Barabási and R. Hausmann (2007). The product space conditions the development of nations. Science, 317(5837), 482–487. DOI: https//doi.org/10.1126/science.1144581; Haussmann, R., C.A. Hidalgo, S. Bustos, M. Coscia, A. Simoes and M.A. Yildirim (2014). *The Atlas of Economic Complexity: Mapping Paths to Prosperity.* The MIT Press.

12 Neffke, F., M. Henning and R. Boschma. (2011). How do regions diversify over time? Industry relatedness and the development of new growth paths in regions. *Economic Geography*, 87(3), 237–265. DOI: https://doi.org/10.1111/j.1944-8287.2011.01121.x; Boschma, R. (2017). Relatedness as driver of regional diversification: A research agenda. *Regional Studies*, 51(3), 351–364. DOI: https://doi.org/10.1080/00343404.2016.1254767; Hidalgo, C.A., P.-A. Balland, R. Boschma, M. Delgado, M. Feldman, K. Frenken, E. Glaeser, C. He, D.F. Kogler, A. Morrison, F. Neffke, D. Rigby, S. Stern, S. Zheng and S. Zhu (2018). The principle of relatedness. In Morales, A., C. Gershenson, D. Braha, A. Minai and Y. Bar-Yam (eds), *Unifying Themes in Complex Systems IX: Proceedings of the Ninth International Conference on Complex Systems*. Cham: Springer, 451–457. DOI: https://doi.org/10.1007/978-3-319-96661-8_46; Hausmann, R., D. Stock and M.A. Yildirim (2022). Implied comparative advantage. *Research Policy*, 51(8), 104143. DOI: https//doi.org/10.1016/j.respol.2020.104143; Li, Y. and F. Neffke (2023). Evaluating the principle of relatedness: Estimation, drivers and implications for policy. *CID Research Fellows and Graduate Student Working Paper Series No. 146*. Cambridge, MA: Center for International Development at Harvard University.Neffke and Henning apply this principle to job transitions, with people moving to jobs that have similar skill requirements. See Neffke, F. and M. Henning (2013). Skill relatedness and firm diversification. *Strategic Management Journal*, 34(3), 297–316. DOI: https//doi.org/10.1002/smj.2014.

13 See Figure 6 in Haussmann, R., M.A. Yildirim, C. Chacua, M. Hartog and S. Gadgin Matha (2024). Innovation policies under economic complexity. *WIPO Economic Research Working Paper No. 79.* World Intellectual Property Organization.

14 Hidalgo, C.A. and R. Hausmann (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences*, 106(26), 10570–10575; Haussmann, R., C.A. Hidalgo, S. Bustos, M. Coscia, A. Simoes and M.A. Yildirim (2014). *The Atlas of Economic Complexity: Mapping Paths to Prosperity.* The MIT Press.

15 Hanushek, E. and L. Woessman. (2015). *The Knowledge Capital of Nations: Education and the Economics of Growth*. MIT Press.

16 Jones, B.F. (2014). The knowledge trap: Human capital and development reconsidered. *Northwestern University Working Paper.* Available at: www.kellogg.northwestern.edu/faculty/jones-ben/htm/Knowledge%20Trap.pdf.

17 Jones empirically accounts for the specialized nature of and complementarities between skills and finds that an adjusted measure of human capital stock fully explains the large income variations between rich and poor economies. See Jones, B.F. (2014). The human capital stock: A generalized approach. *American Economic Review*, 104(11), 3752–3777. DOI: https://doi.org/10.1257/aer.104.11.3752.

18 Saxenian, A. (2006). *The New Argonauts: Regional Advantage in a Global Economy.* Harvard University Press.

19 See, for example, Miguelez, E. and A. Morrison (2022). Migrant inventors as agents of technological change. *The Journal of Technology Transfer*, 48, 669–692. DOI: https://dx.doi.org/10.2139/ssrn.4256518.

20 Hausmann, R. and F.M. Neffke (2019). The workforce of pioneer plants: The role of worker mobility in the diffusion of industries. *Research Policy*, 48(3), 628–648. DOI: https//doi.org/10.1016/j.respol.2018.10.017.

21 Neffke, F., M. Hartog, R. Boschma and M. Henning (2018). Agents of structure change: The role of firms and entrepreneurs in regional diversification. *Economic Geography*, 94(1), 23–48. DOI: https://doi.org/10.1080/00130095.2017.1391691.

22 Saxenian, A. (2006). *The New Argonauts: Regional Advantage in a Global Economy.* Harvard University Press.

23 Bahar, D. and H. Rapoport (2018). Migration, knowledge diffusion and the comparative advantage of nations. *The Economic Journal*, 128(612), F273–F305. DOI: https://doi.org/10.1111/ecoj.12450.

24 Crescenzi, R., A. Dyèvre and F. Neffke (2022). Innovation catalysts: how multinationals reshape the global geography of innovation. *Economic Geography*, 98(3), 199–227. DOI: https://doi.org/10.1080/00130095.2022.2026766.

25 Elekes, Z., R. Boschma and B. Lengyel (2019). Foreign-owned firms as agents of structural change in regions. *Regional Studies*, 53(11), 1603–1613. DOI: https://doi.org/10.1080/00343404.2019.1596254.

26 See Crescenzi, R., A. Dyèvre and F. Neffke (2022). Innovation catalysts: how multinationals reshape the global geography of innovation. *Economic Geography*, 98(3), 199–227. DOI: https://doi.org/10.1080/00130095.2022.2026766.

27 Smart, A. and J.-Y. Hsu (2004). The Chinese diaspora, foreign investment and economic development in China. *The Review of International Affairs*, 3(4), 544–566. DOI: https://doi.org/10.1080/1475355042000241511; Saxenian, A. (2006). *The New Argonauts: Regional Advantage in a Global Economy*. Harvard University Press; Pandey, A., A. Aggarwal, R. Devane and Y. Kuznetsov (2006). The Indian diaspora: A unique case? In Kuznetsov, Y. (ed.), *Diaspora Networks and the International Migration of Skills*. World Bank Institute Development Studies, 71–97.

28 Hausmann, R. and L. Nedelkoska (2018). Welcome home in a crisis: Effects of return migration on the non-migrants' wages and employment. *European Economic Review*, 101, 101–132. DOI: https://doi.org/10.1016/j.euroecorev.2017.10.003.

29 Coscia, M., F.M. Neffke and R. Hausmann (2020). Knowledge diffusion in the network of international business travel. *Nature Human Behaviour*, 4(10), 1011–1020. DOI: https://doi.org/10.1038/s41562-020-0922-x.

30 For a comprehensive review see Irwin, D.A. (2021). The rise and fall of import substitution. *World Development*, 139, 105306. DOI: https://doi.org/10.1016/j.worlddev.2020.105306.

31 Bruton, H.J. (1998). A reconsideration of import substitution. *Journal of Economic Literature*, 36(2), 903–936.

32 Striving for export-led growth was part of the so-called Washington Consensus, as summarized by Williamson, J. (1990). What Washington means by policy reform. In Williamson, J. (ed.), *Latin American Adjustment: How Much Has Happened?* Washington, DC: Institute for International Economics, 7–20.

33 Fink, C. and J. Raffo (2019). What role for intellectual property in industrial development? In Correa, C. and X. Seuba (eds), *Intellectual Property and Development: Understanding the Interfaces*. Springer Singapore, 119–136. DOI: https://doi.org/10.1007/978-981-13-2856-5.

34 See Juhász, R., N.J. Lane and D. Rodrik (2023). The new economics of industrial policy. *National Bureau of Economic Research Working Paper No. 3153*. Available at: www.nber.org/papers/w31538.

35 For evidence of such inequality-reinforcing feedback loops, see Pinheiro, F.L., P.-A. Balland, R. Boschma and D. Hartmann (2022). The dark side of the geography of innovation: Relatedness, complexity and regional inequality in Europe. *Regional Studies*, Special Issue. DOI: https://doi.org/10.1080/00343404.2022.2106362.

36 Balland and Boschma show how the match between scientific capabilities and technological needs varies across European regions. See Balland, P.-A. and R. Boschma (2022). Do scientific capabilities in specific domains matter for technological diversification in European regions? *Research Policy*, 51(10), 104594. DOI: https://doi.org/10.1016/j.respol.2022.104594.

37 For historical perspectives on the origins of various breakthrough innovations, see Mazzucato, M. (2015). *The Entrepreneurial State: Debunking Public vs. Private Sector Myths* (Revised edition). New York, NY: PublicAffairs; WIPO (2015). *World Intellectual Property Report 2015: Breakthrough Innovation and Economic Growth*. Geneva: WIPO. Available at: www.wipo.int/publications/en/details.jsp?id=3995; and WIPO (2022a). *World Intellectual Property Report 2022: The Direction of Innovation*. Geneva: WIPO. Available at: www.wipo.int/wipr/en/2022.

38 Jones, B.F. and L.H. Summers (2020). A calculation of the social returns to innovation. *National Bureau of Economic Research Working Paper No. 27863*. DOI: https://doi.org/10.3386/W27863.

39 Fink, C. (2022). Calculating private and social returns to COVID-19 vaccine innovation. *WIPO Economic Research Working Paper No. 68*. World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4595&plang=EN.

40 For an overview of these instruments, see Table 2.2 in WIPO (2022a). *World Intellectual Property Report 2022: The Direction of Innovation*. Geneva: WIPO. Available at: www.wipo.int/wipr/en/2022.

41 See Mazumdar, M. (2013). An overview of the Indian pharmaceutical sector. In *Performance of Pharmaceutical Companies in India*. Berlin: Springer, 17–44; and Kim, S.R. (1998). The Korean system of innovation and the semiconductor industry: A governance perspective. *Industrial and Corporate Change*, 7(2), 275–309. DOI: https://doi.org/10.1093/icc/7.2.275, respectively.

42 See www.wipo.int/patentscope/en/programs/patent_landscapes/plrdb.html.

43 See www.wipo.int/patentscope/en/programs/patent_landscapes.

44 The seven technology families are: Advanced Materials and Manufacturing; Artificial Intelligence, Digital and Advanced Computing; Bioinformatics and Genomics; Engineering Biology; Electronics, Photonics and Quantum; Energy and Environment Technologies; and Robotics and Smart Machines. See https://assets.publishing.service.gov.uk/media/61110f2fd3bf7f04402446a8/uk-innovation-strategy.pdf.

45 See Lerner, J. (2009). *Boulevard of Broken Dreams: Why Public Efforts to Boost Entrepreneurship and Venture Capital Have Failed – And What to Do About It*. Princeton University Press; and, as a specific example, Orsenigo, L. (2001). The (failed) development of a biotechnology cluster: The case of Lombardy. *Small Business Economics*, 17(1/2), 77–92.

46 Hidalgo, C.A., P.-A. Balland, R. Boschma, M. Delgado, M. Feldman, K. Frenken, E. Glaeser, C. He, D.F. Kogler, A. Morrison, F. Neffke, D. Rigby, S. Stern, S. Zheng and S. Zhu (2018). The principle of relatedness. In Morales, A., C. Gershenson, D. Braha, A. Minai and Y. Bar-Yam (eds), *Unifying Themes in Complex Systems IX: Proceedings of the Ninth International Conference on Complex Systems*. Cham: Springer, 451–457. DOI: https://doi.org/10.1007/978-3-319-96661-8_46.

47 Balland, P.-A., R. Boschma, J. Crespo and D.L. Rigby (2019). Smart specialization policy in the European Union: Relatedness, knowledge complexity and regional diversification. *Regional Studies*, 53(9), 1252–1268. DOI: https://doi.org/10.1080/00343404.2018.1437900; Pinheiro, F.L., P.-A. Balland, R. Boschma and D. Hartmann (2022). The dark side of the geography of innovation: Relatedness, complexity and regional inequality in Europe. *Regional Studies*, Special Issue. DOI: https://doi.org/10.1080/00343404.2022.2106362.

48 See Foray, D. (2015). *Smart Specialisation: Opportunities and Challenges for Regional Innovation Policy*. Abingdon: Routledge; and the European Union's Smart Specialization Platform at: https://s3platform.jrc.ec.europa.eu.

49 Foray, D. (2019). In response to 'Six critical questions about smart specialization'. *European Planning Studies*, 27:10, 2066–2078. DOI: https://doi.org/10.1080/09654313.2019.1664037.

50 Rigby, D.L., C. Roelser, D. Kogler, R. Boschma and P.-A. Balland (2022). Do EU regions benefit from Smart Specialisation principles? *Regional Studies*, 56(12), 2058–2073. DOI: https://doi.org/10.1080/00343404.2022.2032628.

51 In reviewing industrial policy carried out in the United States from 1970 to 2020, Hufbauer and Jung draw a similar conclusion. Hufbauer, G.C. and E. Jung (2021). *Scoring 50 years of US industrial policy, 1970–2020*. Peterson Institute for International Economics. Available at: www.piie.com/publications/piie-briefings/scoring-50-years-us-industrial-policy-1970-2020.

52 See www.jetro.go.jp/en/invest/attractive_sectors/manufacturing/government_initiatives.html.

53 See, for example, the U.S. Chips and Sciences Act of 2022.

54 Recent industrial policies implemented in a wide range of jurisdictions are documented in Evenett, S., A. Jakubik, F. Martín and M. Ruta. (2024). The return of industrial policy in data. *IMF Working Paper No. 2024/001*. International Monetary Fund. Available at: www.imf.org/en/Publications/WP/Issues/2023/12/23/The-Return-of-Industrial-Policy-in-Data-542828.

2 Innovation capabilities as a guide for successful policy design

The *World Intellectual Property Report* reveals a novel method that economies can implement to measure and leverage their innovation capabilities, assessing their scientific, technological and productive know-how. This chapter explores the concept of innovation complexity and the principle of relatedness to evaluate know-how.

Introduction

Recent years have seen a resurgence of industrial policies worldwide. These policies have mostly been driven not by new insights into their efficacy but by governments responding to challenges such as climate change, supply chain disruptions and national security concerns. In part, recent industrial policies reveal governments' expectations about which industrial activities are most likely to offer long-term benefits to the economy.

By employing a range of industrial policy instruments governments are also making (explicitly or implicitly) a wide range of scientific and technological choices. These choices shape the economic incentives for a stakeholder – whether individual or institutional – to facilitate the generation, acquisition and diffusion of new scientific, technological and production knowledge. As a result, industrial policies influence the innovation path taken by a region or country by choosing where to allocate human and financial resources through a range of public policy instruments.

As discussed in Chapter 1, economic thinking would endorse governments investing in those activities, individuals and institutions that facilitate the generation, acquisition and diffusion of new scientific, technological and production knowledge. Consequently, successful industrial policies should aim to develop new capabilities, nurture nascent ones and maintain any existing advantages over other countries.

But which are the correct scientific or technologically related capabilities to target with industrial policies? For instance, which fields of scientific research should government funding prioritize? Which promising embryonic technology should get government funding to achieve commercial viability? Answering such questions is not straightforward. It requires the conviction that supporting a nascent local industry today will generate critical input for other local industries at competitive prices in the future, or that it will generate substantial spillover benefits to the local economy.

Market mechanisms often provide signals that are too incomplete to inform such decisions. Evaluating the benefits and costs of such interventions is crucial in the evolving landscape of industrial policy. This is because the innovation that fuels progress, economic growth and competitiveness is a multidimensional force embodying various facets of human endeavor across nations, regions and industries. Among the many relevant dimensions of innovation are the people and institutions related to the production of science, technology and products.

The empirical approach undertaken in this chapter focuses on these three key dimensions of innovation: science, technology and products. At the macro level, advanced national economies typically perform in all three of these dimensions. Yet advanced economies may greatly differ in terms of the specialization, intensity and combination of and the subcategories within these three dimensions. Some economies excel in scientific research but struggle to translate scientific outcomes into technological advances, leading to an untapped potential. Others might exhibit exceptional ingenuity in one technological field, yet face challenges in transforming these advances into commercially viable products.

As will be discussed further in the next section, most economies show some production capabilities but only a far smaller group of economies are able to show scientific capabilities, and a still smaller group to show technological ones. Why is it that certain countries manage to create viable, competitive products with a role in global value chains but find it difficult to produce scientific discoveries and technological breakthroughs of their own?

This chapter focuses on innovation capabilities measured by the scientific, technological and production know-how – tacit or codifiable – existing in each country or region. Assessing capabilities in these three dimensions is crucial for evidence-based policymaking but is not straightforward. The chapter provides a novel empirical analysis of the current set of innovation capabilities in economies for international comparison. This relies on a body of economic literature focused on economic and technological relatedness and complexity that is applied to data on scientific publications, patent applications and international trade.[1]

The first section of this chapter defines innovation capabilities and discusses how they can be measured using data on scientific publications, international patents and international trade. The second section introduces the innovation complexity concept by exploring the qualitative differences between innovation capabilities, particularly with regards to diffusion. It also discusses how complexity can be a key factor in explaining economic growth. The third section introduces the concept of relatedness in order to shed light on how current capabilities can be leveraged to develop new ones. The last section concludes the chapter with takeaways, remarks and general policy implications.

Defining innovation capabilities

Innovation capabilities represent, in essence, the ability of a country to deliver competitive outputs in a certain field of the innovation process. In many cases, these outputs include the skills and knowledge embedded in tools, procedures or computer codes that can be easily shared or shipped around the world. However, often they are tacit, meaning that they are embedded in individuals but are not readily codifiable and hence not easily transferrable.[2] The fact that they are not easily transferrable makes their understanding and measurement crucial for innovation policymaking.

This section focusses on innovation capabilities in terms of the scientific, technological and production know-how – tacit or codifiable – that each country has.[3]

The scientific dimension: Scientific capabilities include the research, discovery and generation of knowledge. This is achieved through a culture of exploration and experimentation. Scientists and researchers push the boundaries of the world's scientific knowledge by discovering, perfecting and combining existing capabilities in each scientific field.

The technological dimension: This includes all the methods that transform existing scientific and technical knowledge into concrete processes and products. Engineers, applied scientists, developers and designers collaborate to bridge the gap between theory and practice. They translate what are usually abstract concepts into functional technological capabilities. These capabilities take the form of technical procedures and tangible tools that can be applied to different technological fields. For instance, engineers and developers relied heavily on the scientific fields of quantum mechanics and materials chemistry to develop semiconductor devices, lasers and optical technologies. Today, products and processes rely on these latter technologies to innovate and researchers use them to push further the frontiers of science.

The production dimension: This contains the whole spectrum of production capabilities; namely, all those capabilities needed to produce all the goods and services commercialized in an economy. To optimize the production of a given industry outcome, entrepreneurs combine production capabilities by hiring labor with specific skills, acquiring technologically advanced equipment and incorporating more sophisticated inputs. With varying degrees of sophistication, this happens at the scale of large corporations, as well as at the scale of small companies and start-ups. Ultimately, innovation is realized through efficient production methods, supply chain optimization and customer-centric offerings. Production stakeholders and their capabilities play a crucial role in ensuring that innovations reach end-users and drive economic value.

The innovation path

To a great extent, the path to successful and innovative products can be traced all the way back to some technological and scientific capabilities. Many of the most advanced innovations have originated from basic exploratory science. Scientific breakthroughs can open the door to ground-breaking capabilities, giving birth to new technological solutions that boost economic growth and, more importantly, assist in addressing societal challenges. The scientific and technological discoveries of penicillin and semiconductors, for instance, led to groundbreaking innovations. These innovations first boosted direct growth in the health and electronics industries, respectively, and later spread productivity growth throughout the economy.[4]

A relatively linear path from scientific discovery and technological development to industrial production is still noticeable in today's medical innovations such as novel medicines and medical implants. Typically, a pharmaceutical product new to the market can be linked to a scientific finding of a molecule and the technologies developed subsequently to synthetize it at scale. The same applies to advanced medical implants – such as pacemakers and artificial organs – that resulted from the synergy of a scientific understanding of human biology and technological capabilities in materials engineering and miniaturized electronics.

However, mastering scientific capabilities does not necessarily lead to product and process innovation. This is for several reasons. First, scientists may lack the incentives to link with other actors because innovation is not their primary goal. Second, scientific capabilities can be very theoretical and not easily applicable when related to the most fundamental science. Third, the specific settings of scientific institutions – for example, organizational practices and culture – may differ considerably from those of private institutions leading to barriers in establishing science–industry linkages.

In addition, a country or a company does not need to master all the scientific and technological capabilities required to successfully develop new production capabilities. Indeed, skilled workers often acquire production capabilities by systematically using advanced equipment rather than through formal scientific or engineering training. This is what is known in the economic literature as learning by doing.[5]

Similarly, not all technologies develop all the way to goods and services commercialized in the market. For instance, studies based on surveys of applicants find that between a third and a half of patents are never used commercially.[6] Moreover, several technologies are created from other technological capabilities without requiring the related scientific capabilities.[7] Technological advances can stem from creative combinations and applications of existing tools and concepts. For instance, 3D printing (i.e., additive manufacturing) is a technology that has evolved significantly in recent years. However, the basic principles have been known for decades. Innovations in 3D printing often involve the development of new materials and a refining of the printing process rather than any groundbreaking scientific advancements. The technology is widely used for rapid prototyping in various industries, allowing for the quick and cost-effective production of prototypes and customized products.

It is important to emphasize that innovation capabilities do not float in a vacuum. They are embedded in those individuals and organizations that facilitate the generation, acquisition and diffusion of new scientific, technological and production knowledge. These innovation stakeholders include firms and academic institutions (such as universities and public research organizations). They also include public institutions without a primary scientific or technological mission such as government agencies, financial institutions and intellectual property (IP) offices. The collection of all these stakeholders in a country, region or industry defines a living "innovation ecosystem."[8] The industrial and innovation policies explored in Chapter 1 influence the paths taken by innovation ecosystems and their capabilities by allocating human and financial resources through public policy instruments.

How can we measure innovation capabilities?

Scientific, technological and production capabilities have their own internal consistency, yet they are also interdependent in generating innovative ideas, technologies and products. The degree of sophistication and interconnectedness of these dimensions characterizes the innovation ecosystem of a given country, region or city.

How can these three capability dimensions be measured? Typically, economic literature estimates capabilities by using a different set of outputs for each dimension. Peer-reviewed scientific publications reflect advances in science, whether incremental or breakthrough discoveries, as they are a tangible, credible and easy-to-disseminate source of new scientific information. Patent applications capture the exclusivity requests for new technologies – either methods, products or both – that are novel and have an industrial application.[9] Like scientific publications, the patent application process requires public disclosure and therefore facilitates the dissemination of technical information.[10] Lastly, exports are considered to be an indicator of a country's ability to provide competitive goods and services, implying that there is an efficient mechanism behind their production.[11] Box 2.1 details the data used to measure capabilities in this chapter.

Box 2.1 International innovation-related data for global comparison

The report makes use of three datasets to measure innovation capabilities based on data relating to scientific, technological and industrial capabilities. The data sources employed are:

Scientific publication data

Scientific progress, the bedrock of human knowledge, is reflected in international scientific publications. The report uses the data on scientific articles published in internationally recognized academic journals and compiled in the Web of Science, Science Citation Index Expanded (WoS SCIE) collection, which are grouped into 169 distinct scientific subjects serving as scientific fields. These fields are grouped into 11 scientific domains. Countries are assigned scientific publications based on the university affiliation address. Fields in the social sciences and humanities were excluded from the analysis.

International patent data

Technological advancement is encapsulated in international patent family data sourced by combining WIPO patent databases and the European Patent Office's (EPO) PATSTAT. The report applies the definition of international patent families, which considers the first filings of those patent families that have sought protection in a country other than the applicant's country of origin. Patent data are grouped into 172 technology fields according to the international patent classification (IPC). Inventors' addresses provide the information to assign a country. These technology fields are grouped into 14 technological domains.

International trade data

Product innovation can find its expression in international manufactured exports. Products that are competing in the international market have assured a certain degree of competitiveness that can be related to an innovative product. We have used the UN COMTRADE database to trace the global journey of 274 distinct product fields for all countries and years. These fields are grouped into 15 production domains.

In the three datasets considered, the report analyzes data at country and field level for the period 2001–2020. The focus on countries is so as to describe global trends. But it must be acknowledged that the design of innovation policies may require analysis at a more disaggregated level, such as at the level of regions, clusters or cities. Moreover, the period studied is not large enough to allow us to understand all the stages of an innovation process, which in some cases may span many decades and require a more detailed assessment of how an individual idea is transformed into a final product. That said, it does allow us to assess the current state of scientific, technological and production capabilities, as well as providing insights into their geographical distribution, degree of sophistication, recent evolution and potential connections.

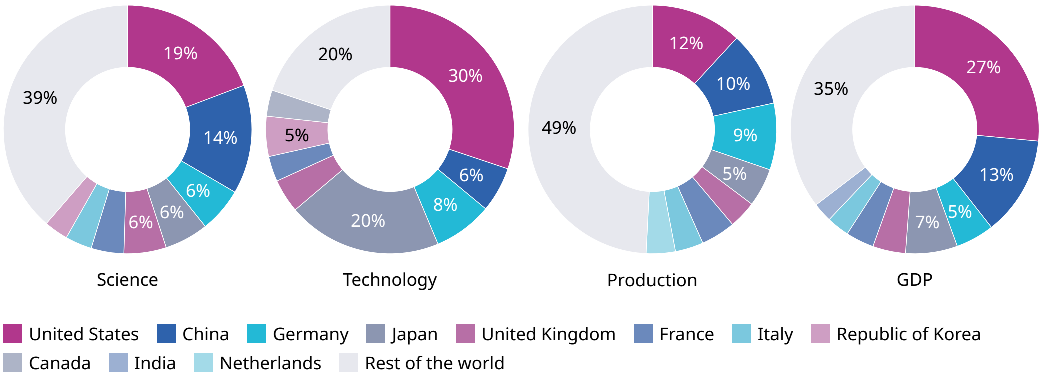
Innovative outcomes are highly concentrated in just a few countries. Over the past 20 years, the top eight countries (five percent of the countries covered in this analysis) account for 50 percent of exports, 60 percent of scientific publications and 80 percent of international patenting. Technological and scientific outcomes are significantly more concentrated than exports. As shown by the three indicators in Figure 2.1, today the world's scientific publications, international patent families and exports remain concentrated in large countries.

A few economies – namely China, France, Germany, Japan, the Republic of Korea and the United States – have been among the top countries in all three indicators for the last five years of available data. Not surprisingly, as Figure 2.1 shows, most innovation outcomes are concentrated in high-income economies. However, the size of any economy also matters. China and, to some extent, India are two notable exceptions to the high-income economies' concentration thanks to their large size.

However, income and size are not the whole story. There are notable differences across economies in terms of scientific, technological and production shares. For instance, Germany has a greater concentration of scientific articles, patents and exports than its share of GDP would predict (Figure 2.1). Brazil's shares of exports and scientific articles are above its GDP share but the share of international patents is not. Indonesia's share of exports is above its GDP share, whereas the shares of scientific articles and international patents are substantially below.

The vast majority of scientific, technological and production outcomes are concentrated in a few national innovation ecosystems

Figure 2.1 Share of innovation outputs vs. GDP share, 2017–2020

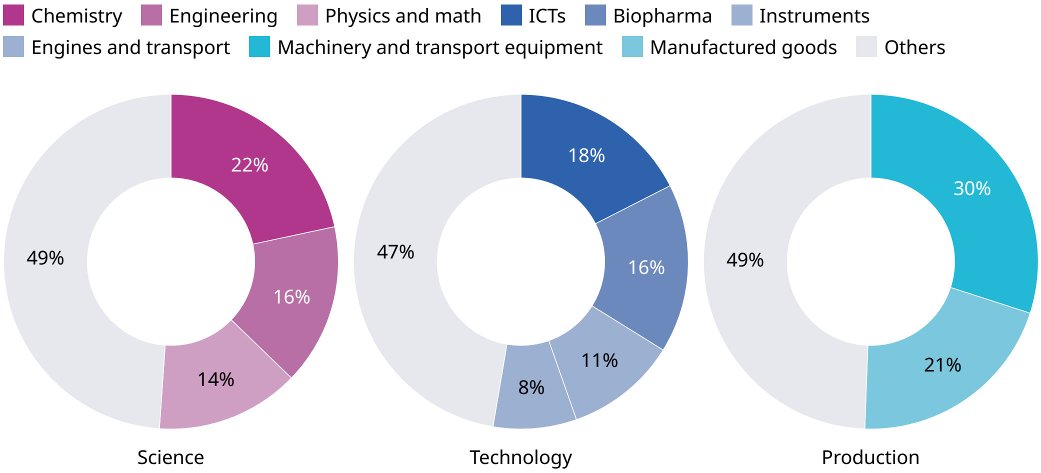


Notes: Innovation outputs include scientific publications, international patent applications and exports.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; World Bank World Development Indicators (WDI); WoS SCIE.

In addition to revealing notable differences across economies, the data on scientific articles, international patents and exports enables the exploration of innovation capabilities in much greater detail. These three indicators combined can shed light on more than 600 scientific, technological and product fields representing a wide range of innovation capabilities. We have grouped these product fields into 11 scientific, 14 technological and 15 production domains.

Scientific, technological and production outcomes are likewise concentrated in a few domains but to a lesser extent

Figure 2.2 World shares of 626 scientific, technological and product fields, 2017–2020



Notes: Innovation outputs include scientific publications, international patent applications and exports.
Sources: Sources: EPO PATSTAT; UN COMTRADE; WIPO; World Bank World Development Indicators (WDI); WoS SCIE.

Figure 2.2 illustrates the world's output for these capabilities according to their relative size in the period from 2017 to 2020. Among the 11 larger scientific domains, the chemistry domain accounts for 22 percent of all scientific outputs, while the engineering, and the physics and math domains account for 16 percent and 14 percent, respectively. This same trend applies to the 169 scientific capabilities identified. The engineering field accounts for 5.8 percent of all scientific publications, followed closely by the fields of chemistry (5.3 percent) and physics (4.3 percent).

Among the 14 technological domains summarized in Figure 2.2, two stand out. The information and communication technologies (ICTs) and biopharma domains account for 18 and 16 percent of all international patents, respectively. Within the 172 detailed technological capabilities, the medical and veterinary pharmaceuticals field accrued 8.6 percent of all the international patents from 2017 to 2020, followed by the computing technologies (6.6 percent) and electric digital communication (6.3 percent) fields.

Among the 15 production domains, the machinery and transport equipment domain accounts for almost 30 percent of all exports, followed by manufactured goods and articles (21 percent) and chemicals (10 percent). Among the 285 production capabilities, the motor vehicles field accounted for 3.6 percent of all international trade, followed closely by crude fuel minerals (3.14 percent) and telecommunications equipment (3.11 percent).[12]

Why do economies specialize?

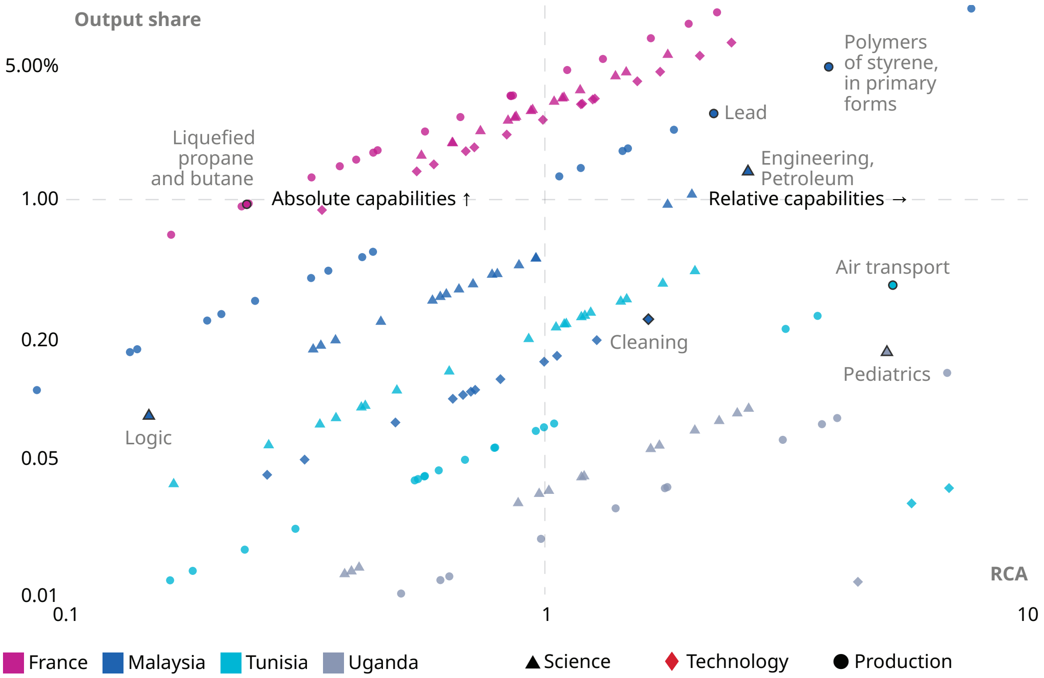
It is notable that countries do not produce the same share of outcomes across scientific, technological and production fields. Why do economies specialize in certain capabilities? Specialization offers a multitude of benefits that contribute to an economy’s growth and efficiency. By focusing on their strengths, countries and regions are able to achieve a higher level of productivity and innovation. Specialization encourages the development of expertise, leading to improved production processes and higher-quality outputs. This, in turn, fosters healthy competition, drives technological advances and enhances productivity and ultimately boosts overall economic performance.

In contrast, as discussed in Chapter 1, countries that are too specialized can be vulnerable to externalities such as global supply chain shocks. An over reliance on a particular set of industries can make them less resilient to external shocks, international market volatility and value chain disruptions, among other things. Many industrial policies implicitly apply a rationale in support of generating capabilities in strategically important industries – that is, diversification – by redirecting surplus resources toward such strategic industries and away from the most production industries. The same logic is applied to scientific and technological capabilities.

However, diversification and specialization are not necessarily opposing concepts. An orchestra, for instance, requires a set of specialized musicians in order to perform. Each musician is trained to play their instrument. Together they form a diversified group capable of playing the most sophisticated works. One-man bands that play many instruments but specialize in none are at the opposite end of the spectrum. By not being specialized in the way an orchestra is they are only able to produce simpler works. Furthermore, when individuals and firms specialize the innovation ecosystems of which they are a part can gain new, combined capabilities. This increases the ecosystem's diversity and the opportunities to combine different capabilities. Both make more sophisticated outputs possible.

Innovation ecosystems concentrate capabilities both in absolute and relative terms

Figure 2.3 **Share of innovation outputs vs. relative comparative advantage, by country and capability, 2001–2020**



Notes: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and exports data. See glossary for RCA formula.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

The lion's share of most innovation capabilities is enjoyed by only a few countries. Figure 2.3 shows how the presence of all 626 innovation capabilities varies between four selected countries, namely, France, Malaysia, Tunisia and Uganda. These four countries represent four different income groups.[13] The vertical axis shows a country's world share for each capability. Most of France's contribution to each capability surpasses one percent of the world's total outcome. In other words, for most capabilities, one or more out of 100 patents or scientific publications are produced by a French inventor or researcher. Similarly, a French company is responsible for at least 1 US dollar for every USD 100 exported for most products.

The same is true for the majority of high-income economies, which are together responsible for more than 65 percent of most outputs in each field. Indeed, any given capability has at least one country that has accumulated more than 10 percent of the total. In most cases, the countries in question are the United States (with a more than 10 percent participation rate in 70 percent of capabilities), Japan (22 percent of capabilities), China (53 percent), the Republic of Korea (11 percent) or Germany (19 percent).

These and other similar economies at the innovation frontier often accumulate a considerable diversity of capabilities, making them substantive players in the global innovation arena. For instance, Italy and Japan managed to build successful motorcycle hubs based on their advanced engine and mechanical capabilities (see Chapter 4). At the same time, these two motorcycle innovation powerhouses differed with regards to many other innovation capabilities, meaning that their products evolved along successful but different technological paths.

In such a skewed and concentrated landscape, other economies are hard to find. In Figure 2.3, the selected upper-middle income economy, Malaysia is seen to display several production capabilities above the one percent threshold, a handful of scientific capabilities and only one technological capability. Tunisia and Uganda have just a few production capabilities above one percent. Small high-income economies such as Singapore, the Republic of Ireland and New Zealand often also struggle to achieve capabilities above one percent, given the size of their economies.

This means that most non-large, non-high-income countries have limited absolute resources available to allocate to the production of outcomes in all capabilities. Often, such countries achieve an above average share of outcomes in a small set of capabilities. They therefore have to prioritize the distribution of resources in order to build specialization in those key capabilities in which their economy may have a natural or historical advantage. Choices such as these can be the result of long planned industrial policies, aimed at leveraging existing economic advantages from nature or history. They can also be aimed to completely change the existing capabilities.

Figure 2.3 (x-axis) shows how much countries have accumulated of each capability relative to world share.[14] Those capabilities on which countries concentrate relatively more than the world average have a value greater than one. Not surprisingly, France has a substantial number of scientific, technological and production capabilities above the world proportion. In respect to these capabilities, France is specialized in both absolute and relative terms. Similarly, most of Malaysia's absolute specialization production capabilities also appear with relative specialization. More importantly, Malaysia displays relative specialization in many scientific and technological capabilities also.

The above-mentioned small high-income economies appear quite often among those countries specializing in relative terms. This is in accord with anecdotal evidence. For example, Finland and Poland created new and successful video game industry capabilities based on their strong capabilities in relative terms in ICT technologies, computer science, imaging science, computer services and audiovisual services, among others (see Chapter 5).

Combining the two axes in Figure 2.3 captures the current state of the global innovation landscape, considering both absolute and relative capabilities of economies. Both absolute and relative specializations are essential if we are to understand how resources are allocated and what are the capabilities of a given economy. On the one hand, countries whose capabilities lie in the lower-left quadrant of the figure are not specialized, since they are not contributing enough to the field, yet, at the same time, they are not trying to do so either, relative to other countries. On the other hand, the remaining three quadrants show some level of specialization that allows a country's innovation capability to be identified.

In the rest of this chapter, innovation capabilities are measured as the combination of absolute and relative specialization exemplified by the remaining three quadrants in Figure 2.3. The top-right quadrant shows those economies that are concentrating larger shares of innovation capabilities, while also doing relatively more than the world average. Only a small set of economies – for example, France and to some extent Malaysia – can have a large set of innovation capabilities in terms of both absolute and relative specialization. The upper-left quadrant shows those capabilities where large and advanced economies – for example, China, France, Germany, Japan and the United States – show an absolute but not relative specialization.

A country making a prominent contribution in a given field is considered as specialized in that field, even if in that country the share is relatively low. Most of the other economies specialize mainly in relative terms (see the lower-right quadrant in Figure 2.3). Like most economies in the lower middle-income and low-income groups, Tunisia and Uganda share the fact that the majority of their capabilities are in the lower-right quadrant. These two economies are not considered to be specialized in all these relative capabilities. For instance, Tunisia and Uganda have fewer than five yearly patents per capability. Therefore, despite being specialized in relative terms, these capabilities cannot be considered comparable to those of other countries specialized in the same field.[15]

Distribution of capabilities around the world

How widespread is each of these scientific, technological and production capabilities globally? On average, 21 out of 154 countries specialized in every innovation capability in 2017-2020. This represents a moderate increase of five percent since 2001–2004 when it was 20 countries.

However, this average number hides the fact that economies vary in their capabilities all the time, sometimes incorporating capabilities and at other times dropping them. Figure 2.4 shows the scientific, technological and production capabilities for eight selected countries over a 20-year period. During these two decades, China, India and the Republic of Korea saw a big increase in capability diversification. China in particular had a remarkable increase in technological capabilities due to its boom in patenting. China jumped from being specialized in only 16 percent of all technological capabilities during the 2001–2004 period to being specialized in 94 percent by the 2017–2020 period. China’s technological capability diversification appears to have been preceded by an earlier diversification in scientific capabilities, which was already at 73 percent during the 2001–2004 period and jumped to 100 percent by the 2013–2016 period.

The Republic of Korea also saw a large increase in both scientific and technological diversification, as both scientific and technological capabilities were around 40 percent during the 2001–2004 period and then jumped to 66 percent and 83 percent, respectively, during the 2017–2020 period. In a similar way India saw its scientific and technological capabilities rise from 42 percent and nine percent, respectively, during the 2001–2004 period up to 68 percent and 21 percent, respectively, during the 2017–2020 period.

During the same period, Germany and Japan saw a reduction in capability diversification, as the two economies experienced a drop in all three capability dimensions. While the United States dropped production capabilities, it remained stable in scientific and technological capabilities at around the maximum diversification level. Mexico saw little change in the amount of scientific, technological and production capabilities in which it specialized. While Mexico is still one of the most diversified economies in Latin America, it has lagged in all innovation capabilities in terms of diversification when compared to China, India and the Republic of Korea. At the other end of the spectrum, the United Republic of Tanzania shows very little specialization in any of the three dimensions, although it has shown some progression in the diversification of production capabilities.

There is also substantial variation across capabilities. Figure 2.5 summarizes how common capabilities are by showing the number of countries specialized in at least one innovation capability grouped by 40 scientific, technological and production domains. There is a general pattern of technological domains being less common among countries than are scientific domains, which in turn are less common than production domains. However, the pattern does not apply across all domains or fields. For instance, during the 2017–2020 period more than a third of economies specialized in at least one capability related to the domain of exporting natural lipids (36 percent of countries in the data) or the travel services domain (38 percent); publishing scientific articles in the medical science domain (34 percent); or applied for patents relating to the machine technologies domain (36 percent). All these domains are almost six times more ubiquitous than the audiovisual technological domain (six percent).

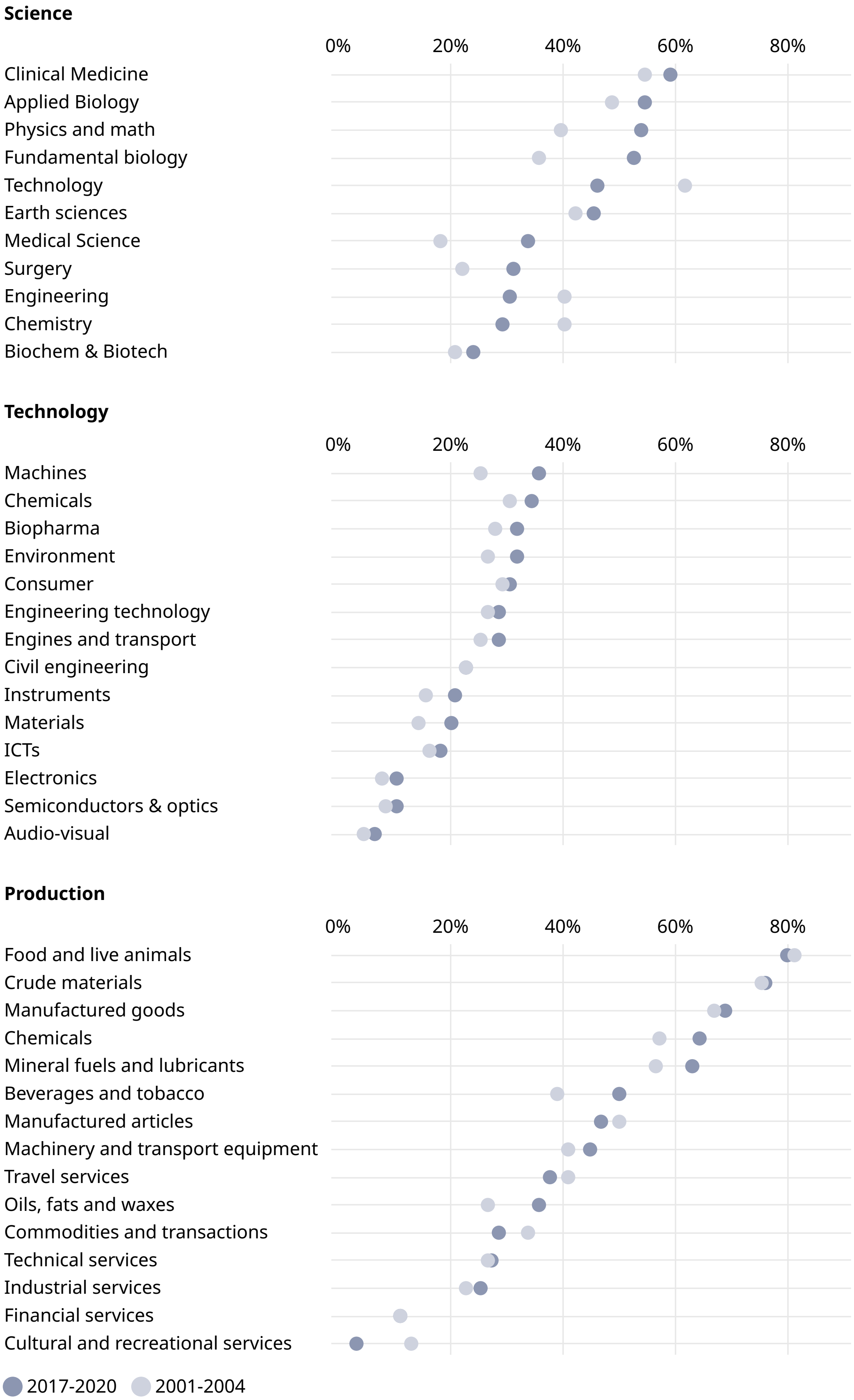
Specialization varies substantially across countries

Figure 2.4 Number of specialized capabilities by dimension, selected countries, 2001–2020

Note: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and exports data.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

Countries' specialization varies substantially across capabilities

Figure 2.5 Percentage of countries specialized in given capability group, 2001-2004 and 2017-2020



Note: 40 capability domains after grouping the 626 innovation capabilities (see Box 2.1).
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

In general, scientific domains show less variation in terms of ubiquity. The clinical medicine domain (59 percent) is the most ubiquitous, whereas the biochemical and biotechnological domain (24 percent) is rarer across countries. In the production and technological domains, the range is much wider. The less ubiquitous production domains are financial services (11 percent) and cultural and recreational services (three percent). The already mentioned audiovisual domain is the least ubiquitous technological domain, followed closely by the electronics (10 percent) and semiconductors and optics (10 percent) domains.

A quick inspection of Figure 2.5 also indicates that the rarity of capabilities – that is, a capability in which fewer countries are specialized – increases with the level of sophistication typically associated with the activities related to the field in question. For instance, in the production capabilities groups there is an increase in rarity as products and services come to require additional transformations and involve more technological equipment. The capability to export machinery and transport equipment, for instance, is rarer than miscellaneous manufactures, which in turn are rarer than most activities in the primary sector. That is not to say that the primary sector always lacks technology (see the discussion of the agricultural sector in Chapter 3).[16]

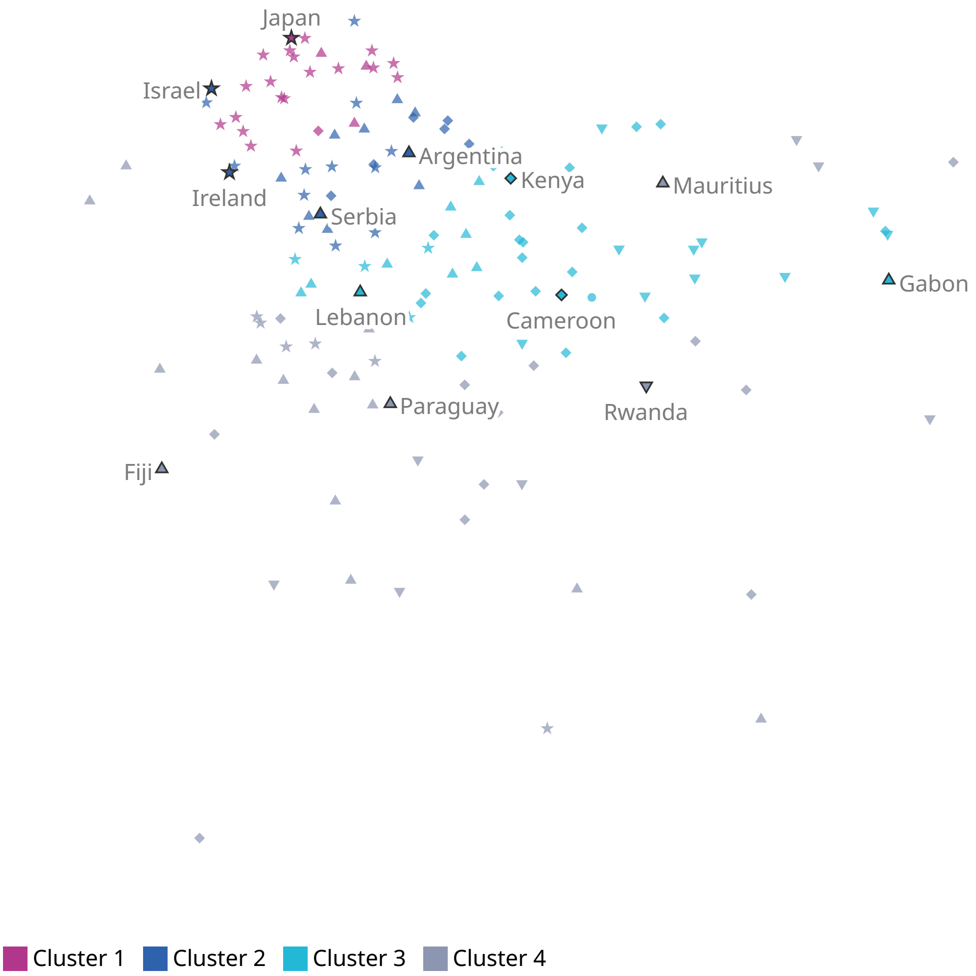
Furthermore, Figure 2.5 indicates a change in the rarity of capabilities over time. Overall, technological capabilities display a slight increase in the number of countries able to produce technologies during the last two decades. The two remaining dimensions display a more heterogeneous behavior. Most scientific domains have seen an increase in the number of countries specializing in at least one field within that domain. The three exceptions are the chemistry, engineering and technology scientific domains, which are much less ubiquitous today. Likewise, production has shown an increase in country ubiquity for the majority of its domains. The most notable exception is the domain containing capabilities in exporting cultural and recreational services, which has also seen a remarkable decrease in ubiquity.

Countries exhibit a heterogeneous distribution of capabilities. The diversification phenomenon becomes increasingly present as economies grow in terms of both population and income. Within the same income group, a country's size explains the number of capabilities in which it is specialized. For example, both Colombia and Republic of North Macedonia belong to the upper-middle income group. The large difference in the size of their respective populations explains to a large extent why Colombia is specialized in almost four times as many capabilities as the less populated Republic of North Macedonia. Conversely, higher income economies tend to have a larger set of capabilities when ecosystems from different income groups are compared. For example, the less populated Australia can match the diversification of larger, more populous countries such as India.

Having a similar number of capabilities is only one part of the story. High-income countries also tend to specialize in a different set of capabilities compared to the rest of the world. Figure 2.6 maps countries based on the proximities of their skills sets and groups them into four clusters. Cluster 1 includes the majority of high-income economies no matter their size. As countries move further away from this cluster their average income decreases. Countries such as the Republic of Ireland and Serbia show a similar level of population and capabilities. However, they have a great difference in terms of income and, despite both countries being clustered within the same group (cluster 2), the Republic of Ireland appears much closer to cluster 1.

High income economies share the closest sets of innovation capabilities

Figure 2.6 Proximity map based on the capabilities co-occurrence of 626 scientific, technological and product fields, 2017-2020, grouped in 4 clusters



Notes: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and exports data. Income: ★ High ▲ Upper-middle ◆ Lower-middle ▼ Low
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

This would imply is that some capabilities are more valuable than others. Countries eager to gain new capabilities ought therefore to consider carefully where to aim. Diversifying without a strategy could mean relocating scarce resources into fields that might not prove to be as beneficial. Therefore, it is important to determine the value of capabilities to find where the most rewarding opportunities are likely to be found. The next section focuses on the qualitative differences across innovation capabilities, regardless of dimension or domain.

Are all innovation capabilities equally important?

We have established that an economy's innovation capabilities are related in part to both its degree of development and size, and partly to the specialization choices that an innovation ecosystem makes to further improve its functioning.[17] But what about the qualities of these capabilities?

Assessing the worth of capabilities and their potential impact on a country's ability to innovate involves considering several factors. They include market demand, profitability, entry barriers, scalability, risk and uncertainty. Of course, compiling detailed data measuring all of these factors internationally is not easy.

Economists solve this issue partially by asking "who does what?" and "what is done by how many?". A first step is to assume that ubiquitous capabilities are easy to adopt, and that rare ones are harder. However, this is not always the case. Some capabilities can be rare just because the incentives to develop them are low. Likewise, there may be widespread capabilities whose rewards are so high that countries are motivated to develop them, even at a high cost.

Hence, a second step is to look at how diversified are those countries that have these capabilities. As mentioned above, a broad set of capabilities allows innovation ecosystems to create increasingly sophisticated outputs. Therefore, if a rare technology appears exclusively in diversified countries, then it is the result of this process; and for it to be developed, it must be leveraged with other capabilities. Conversely, if this same technology were to appear in non-diverse countries, it would mean that countries do not need extra know-how in order to develop it, making the process simpler.

The complexity concept

Combining the diversity of countries and the rarity of their capabilities is formalized as the complexity concept (see Chapter 1). Hidalgo and Hausmann designed the complexity indicator with the aim of measuring the level of know-how embedded in a given place.[18] Computing the complexity indicator involves an iterative process considering (a) how each country specializes in each capability and (b) the number of countries specializing in each capability. In other words, complex capabilities are those that are rare and only diversified innovation ecosystems are able to make use of them. Conversely, complex innovation ecosystems are those that specialize in capabilities that are rare and in which only other diversified innovation ecosystems are specialized.

Innovation complexity relates the rareness of capabilities with the diversification countries

Figure 2.7a Diversity vs. ubiquity, by country

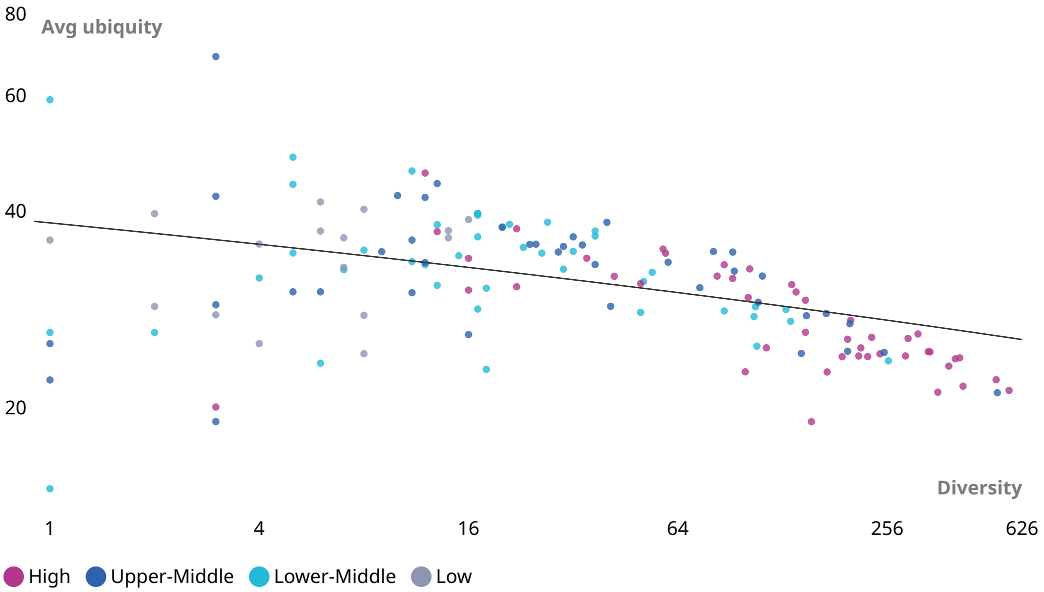
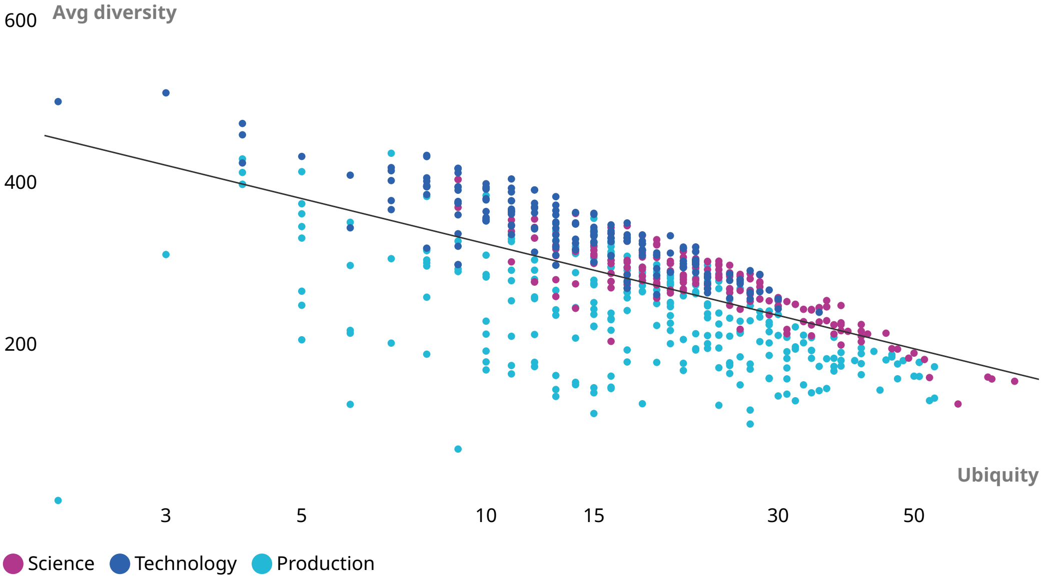


Figure 2.7b Diversity vs. ubiquity, by capability



Notes: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and exports data.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

Figure 2.7 illustrates the first step in computing the complexity indicator for all 626 innovation capabilities. This establishes a reciprocal relationship between the capabilities mastered by a country and the number of countries that master a capability. The countries panel (Figure 2.7a) plots the inverse relationship between how many capabilities a country is specialized in (diversity) against the average number of countries also specializing in this same set of capabilities (ubiquity). There is a clear downward trend shown.

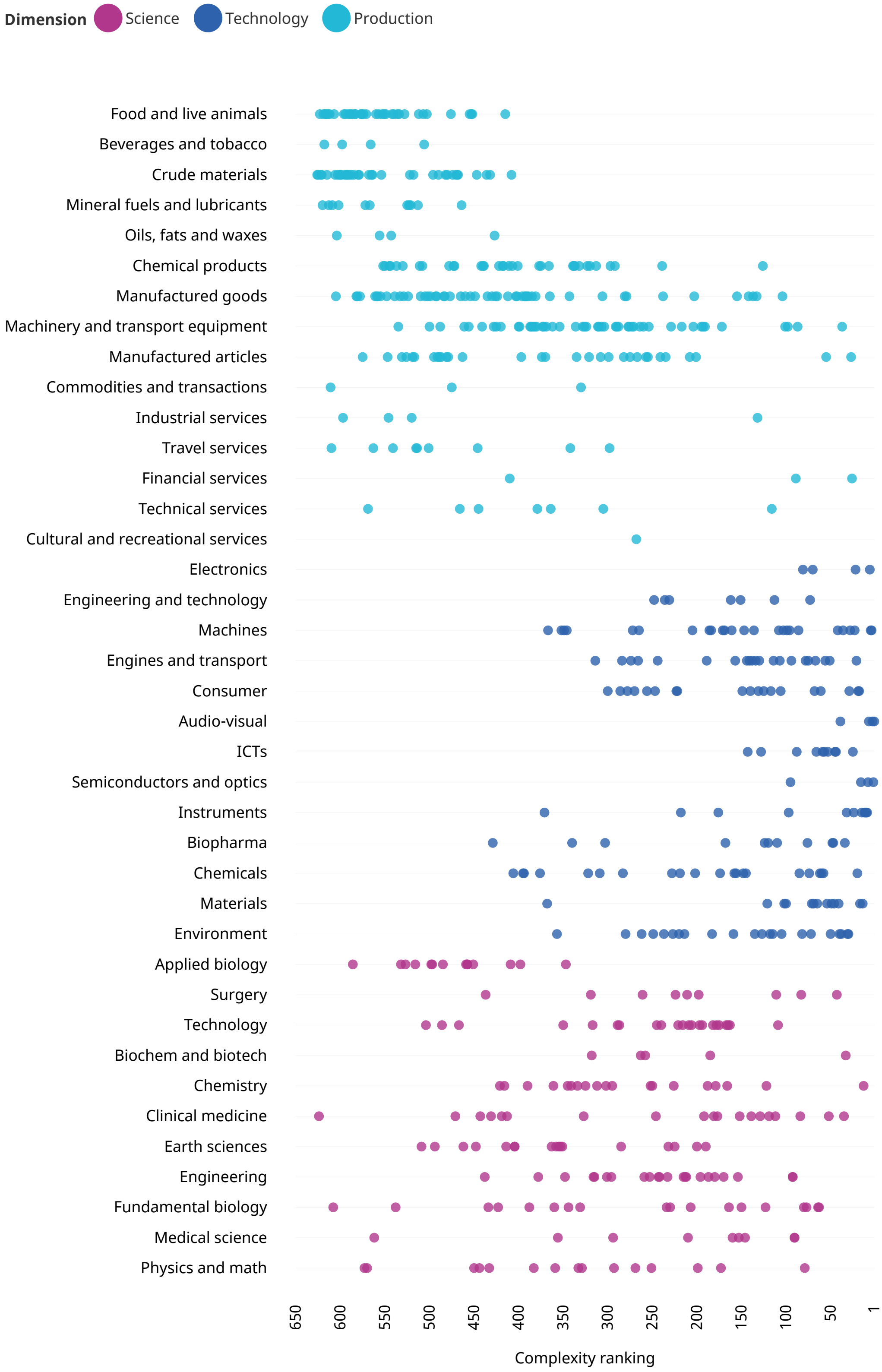
As countries become more diversified in general their capabilities become less common across other countries. For instance, Afghanistan is specialized in just two capabilities – fruit and nuts, and spices – which are very common, with on average about a quarter of countries specializing in them. Conversely, Germany specializes in more than 500 capabilities, and on average less than an eighth of other countries specialize in any one of them. Not surprisingly, virtually all high-income economies are to be found at the bottom right of the figure displaying both more diverse and also rarer capacities.

The capabilities panel (Figure 2.7b) plots the same relationship from the perspective of capabilities: how many countries specialize in each capability against the average number of specialized capabilities in those countries. This panel also shows an inverse relationship between the commonness of a given capability (ubiquity) and how diversified those countries that specialize in the same capability are. For instance, 59 countries (38 percent) specialize in the scientific capability tropical medicine but these same countries on average specialize in under a quarter of innovation fields. Conversely, a handful of countries specialize in the technological capabilities of audiovisual information storage and printing machines but on average these same countries specialize in 80 percent of all capabilities.

As a result, technological innovations in audiovisual information storage and printing machines are more complex innovation capabilities than the scientific production of tropical medicine. However, the inverse relationship is not straightforward. This is because the rarity of a capability is not the only criterion to determine its complexity. Some capabilities may be rare because they are not attractive enough to acquire or because they are located in specific places in the world. For example, a handful of countries specialize in the production capabilities ores and concentrates of uranium and thorium and rubber, although on average those same countries specialize in less than 10 percent of capabilities. Consequently, uranium, thorium and rubber are less complex than physics, particles and fields.

The complexity of innovation capabilities varies, but technological capabilities are among the more complex

Figure 2.8 Innovation capabilities ranked by complexity, grouped by domains



Note: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and exports data. Product complexity ranking from 626 (lowest) to 1 (highest).

Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

An iterative process following the same principles resolves these exceptions and produces an innovation complexity indicator that ranks the complexity of all innovation capabilities.[19] Complex capabilities are those that everybody wants but few know how to develop. Figure 2.8 ranks innovation capabilities according to their complexity level. Overall, production capabilities require a lower amount of know-how to be developed, followed by scientific and technological capabilities.

The complexity spectrum

Primary sector capabilities such as the mining or agrifood industries seem easier to adopt for those countries with lower levels of accumulated know-how and diversity. Goods and services, however, appear to include a wider spectrum of capabilities in terms of complexity. In the manufactured goods domain, for instance, the manufacture of lead goods is one of the 10 percent least complex, whereas the manufacture of machine tools is in the top 20 percent most complex. For services, manufacturing services come within the lower 10 percent of the complexity spectrum, whereas exports related to IP services is one of the top five percent of fields.

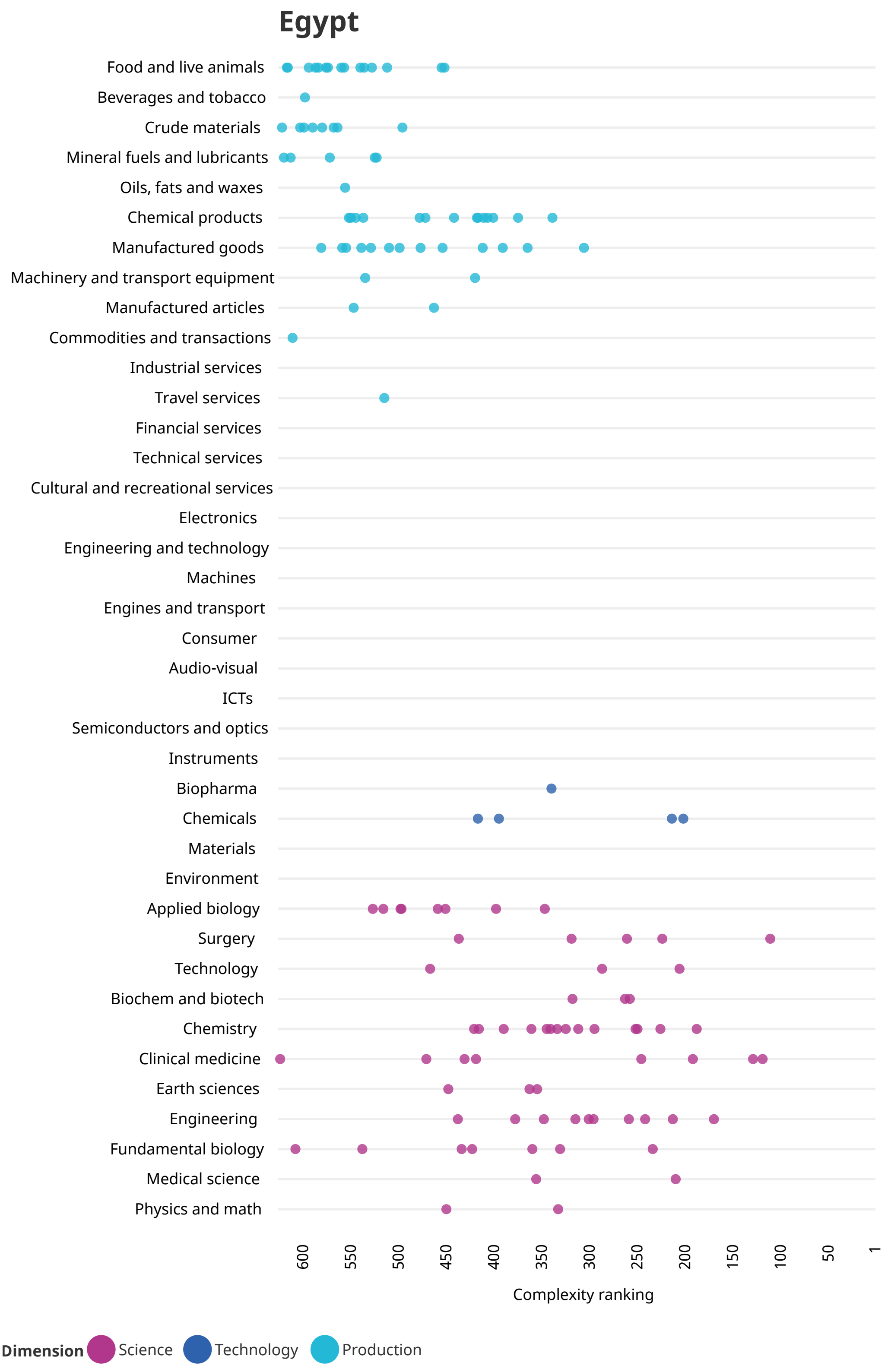
Scientific capabilities are usually the intermediate dimension in terms of complexity. These capabilities likewise show up at either end of the spectrum, much like manufacturing and services, but tend to require more know-how. Earth sciences, for instance, is a mid-tier domain with 15 fields that lie between the 20 percent and 70 percent range of complexities. At the lower end are the paleontology and marine biology fields, while at the higher end are the environmental and geological engineering fields.

In general terms, scientific fields get incrementally more complex as they start to depend on more sophisticated equipment and machinery. For example, despite being a sophisticated subject, theoretical physics has a relatively low dependence on laboratory infrastructure. Technically speaking, theoretical physicists can contribute to advances in their field armed only with a pen and paper. In contrast, in order for scientists to contribute in applied physics they must conduct experiments in labs and rely on machines maintained by engineers, and so on. An indication of such complexity can be found in the average team size of scientific subjects. For instance, scientific publications in theoretical physics have almost half the average number of authors per paper compared to those in applied physics.[20]

Technological capabilities are by far the most complex set of capabilities. All are among the 60 percent most complex fields. This across-the-board pattern indicates that the transformation of ideas – especially scientific ones – into patentable technologies is of itself a rare capability. As has been seen in Figure 2.1, concentration is much higher for patent outcomes than for scientific ones.[21] In addition, capabilities related to audiovisual, electronics and semiconductors are among the most complex ones. This pattern is in accord with the recent boom in innovation in ICTs and the even more recent boom in digital technologies. Only a few very advanced countries have managed to systematically generate technologies in these fields. These capabilities appear exclusively in diversified countries that have managed to collect know-how across different dimensions.

More diversified economies tend to have a more complex basket of capabilities

Figure 2.9 Republic of Korea and Egypt's innovation capabilities ranked by complexity, grouped by domains, 2017-2020



Notes: Innovation outputs include scientific publications, international patent applications and exports.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; World Bank World Development Indicators (WDI); WoS SCIE.

Figure 2.9 develops Figure 2.8 by contrasting two economies – the Republic of Korea and Egypt – with different innovation capabilities. In the first panel of Figure 2.9, the Republic of Korea shows a wide distribution of capabilities that covers most of the domains, including the most complex ones. For instance, and not surprisingly, the Republic of Korea is specialized in all fields related to semiconductors, ICTs and audiovisual technologies. The market evolution of world-leading Korean companies in these technologies – such as Samsung, LG Electronics, SK hynix and LG Display – is a concrete indication of the Republic of Korea's innovation capabilities in these fields.

In turn, the second panel of Figure 2.9 shows Egypt's innovation capabilities, which are mostly a subset of those displayed for the Republic of Korea. They are concentrated in domains where complexity is lower. In the case of production capabilities, Egypt is specialized in agrifood, mineral fuels, and to a certain extent manufacturing and chemicals capabilities. In the case of scientific capabilities, Egypt is specialized mainly in capabilities related to chemistry, applied and fundamental biology, and engineering. Nonetheless, Egypt shows no particular specialization in any one technological capability.

Why should an innovation ecosystem care about innovation complexity?

In the same way that capabilities can be ranked by complexity, an innovation complexity indicator can be produced in order to rank the innovation complexity of a given country (see Box 2.2). Conceptually, the country innovation complexity indicator ranks countries according to the level of sophistication of their innovation capabilities. High-complexity countries are specialized – in absolute or relative terms – in the most complex innovation capabilities. Figure 2.9 shows an example of the underlying difference in the complexity of countries – between the Republic of Korea and Egypt – a country's complexity being the average complexity of their capabilities.

Box 2.2 Basic definitions of relatedness plus complexity indicators and metrics

The report makes use of several indicators and metrics. These are founded upon the considerable economic literature on economic and technological complexity.

Innovation capabilities

Innovation capabilities are the scientific, technological and production know-how – tacit or codifiable – that exist in each country or region. They essentially represent the ability of a country to deliver competitive outputs in a certain field of the innovation process. In many cases, outputs include the skills and knowledge embedded in tools, procedures or computer codes that can be easily shared or shipped around the world. However, quite often they are tacit, meaning they are embedded in individuals and are not readily codifiable and hence not easily transferrable.

Country's specialization and diversification

This relates to the number of capabilities in which an economy specializes. The more innovation capabilities in which a country specializes, the more diversified is that country. Conversely, the fewer the innovation capabilities in which a country specializes, the more specialized is that country.

Capability ubiquity and rareness

This represents how many economies specialize in each scientific, technological and production field (i.e., capability). The more countries that specialize in a given capability, the more that capability is ubiquitous. Conversely, the fewer the countries that specialize in a given capability, the rarer that capability.

Capabilities proximity

This represents the connectedness between any pair of scientific, technological and production fields (i.e., capabilities). For any given pair of fields, proximity represents the probability that an average country will specialize in both fields at the same moment in time. It is based on the statistically significant co-occurrences of two capabilities in all countries.

Innovation complexity (capabilities)

This captures the amount and sophistication of know-how required to generate an outcome in each field (innovation capability). It ranks the diversity and sophistication of the know-how required to generate each field and is calculated based on how many other countries can generate outcomes in that field and the complexity of those countries. In effect, it captures the amount and sophistication of know-how required to generate an innovative outcome.

Innovation complexity (countries)

This captures the amount and sophistication of innovation know-how embedded in a country. It ranks a country based on how complex are its innovation capabilities. Countries that are home to a great diversity of know-how, particularly complex specialized know-how, can generate a great diversity of sophisticated innovation outcomes (i.e., science, technologies and products). High complexity countries specialize – in absolute or relative terms – in the most complex innovation capabilities.

Relatedness density (country)

This measures a country's ability to enter a specific field. It provides a distance (from 0 to 1) capturing the extent of a country's existing capabilities to generate outcomes in this field, and measures how close that field is to the country's current innovation outcomes. Moving to a "nearby" field has a greater likelihood of success, as it has more of the required related capabilities. Relatedness density measures the probability that a country generates outcomes in capability A given that it has a set of capabilities. Relatedness formalizes the intuitive idea that the ability to generate outcomes in scientific, technological or production fields can be revealed by looking at which other capability outcomes it can generate. Current capabilities can indicate where to go next. This is known as the principle of relatedness. Economies tend to diversify incrementally, moving into activities that have skills similar to the ones they currently possess.

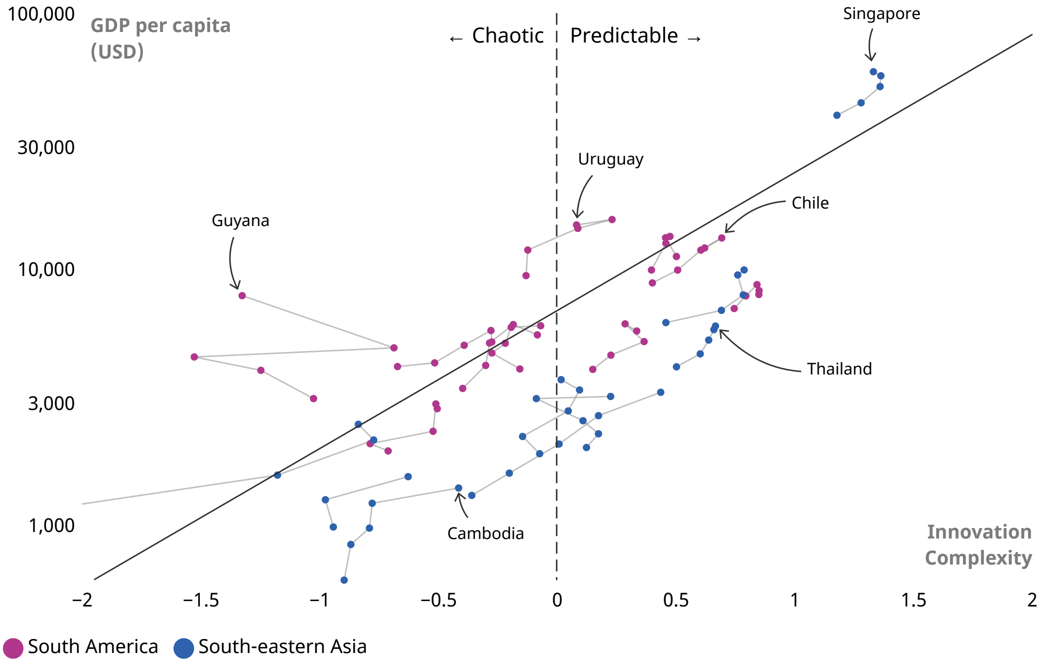
Untapped innovation potential

This refers to potential output in a capability given the current outcome on related capabilities. It is calculated using the proximity connections between scientific, technological and production capabilities in the economies from cluster 1 in Figure 2.6 (i.e., a selection of advanced innovation ecosystems). These proximities are used to estimate the transformation weights of outputs from scientific capabilities to outputs from the technological capabilities depicted in Figure 2.16.

Economic literature has found a strong relationship to exist between complexity and economic performance.[22] First, not only are developed countries more diversified they are also more complex. Vibrant innovation ecosystems can generate elaborate and unique technologies that lead to the creation of complex products. Second, studies find that economies attaining technologically complex production structures typically see higher economic performance. Countries with greater complexity are also more likely to have future economic growth.[23] Furthermore, these more complex economies are more likely to be resilient, by observing longer-run patterns of economic performance.[24] Moreover, the reward for higher complexity goes beyond economic growth. Higher complexity is found to correlate with less inequality, lower greenhouse gas emissions and more economic development.[25]

Innovation complexity correlates with economic performance and growth

Figure 2.10 Complexity vs. GDP per capita, South America and South-eastern Asia, 2017-2020



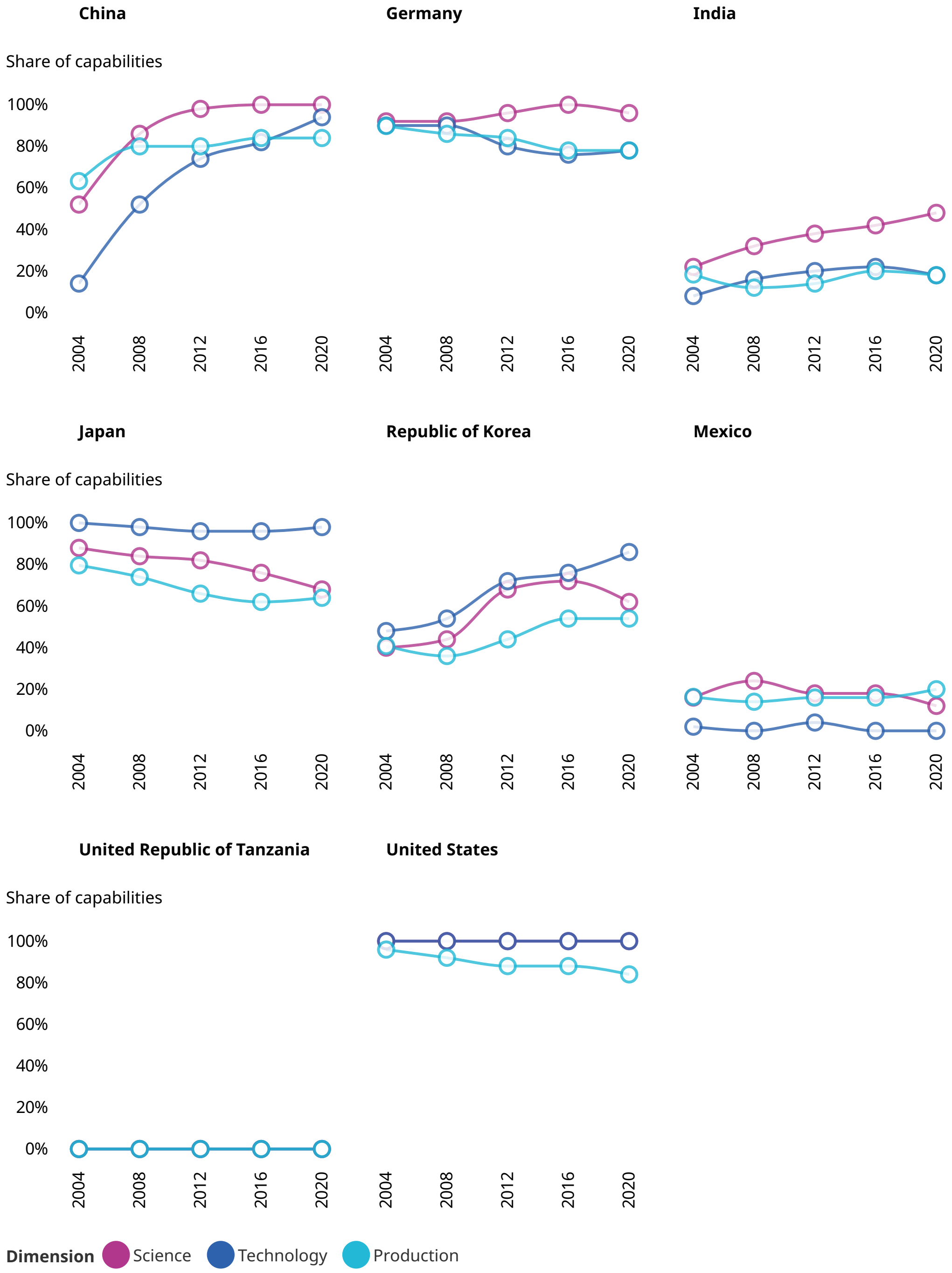
Notes: This figure mimics the results obtained by Cristelli et al. (2015). Lines summarize the 2001–2004 to 2017–2020 trajectory of economies in terms of GDP per capita and innovation complexity. Trajectories in the "predictable" frame are on average more convergent toward the fitted line; whereas trajectories in the "chaotic" frame are on average more divergent.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; World Bank World Development Indicators (WDI); WoS SCIE.

As a result, the complexity literature views economic development as a structural transformation process. Countries grow by transforming their production structure from one dominated by low-tech, ubiquitous activities (primary products) to a more advanced structure with rarer outputs that are more reliant on human capital (manufacturing and services).[26] Figure 2.10 shows how countries with a higher level of complexity typically have a higher GDP per capita. Additionally, countries with a higher complexity measure have a strongly predictable pattern of economic growth. Countries that have high complexity relative to their income level (below the trend line in Figure 2.10) grow faster than those that underperform in terms of complexity. It is in this underperforming group that the majority of Latin America and the Caribbean countries appear.

These results are in accord with recent economic research indicating that the economic and technological complexity of a country serves as a measure for intangible assets. This allows us to quantify the hidden growth potential of that same economy. A 10 percent increase in complexity is associated with a 0.45 percent increase in GDP per capita.[27] This is particularly true for those countries whose complexity is higher than their expected GDP per capita. As a result, country dynamics have very different patterns. Those economies with a lower complexity measure have a more turbulent economic growth path.[28]

Specialization in complex capabilities varies substantially across countries

Figure 2.11 Number of specialized top 50 complex capabilities by dimension, selected countries, 2001–2020



Note: 50 top complex innovation capabilities for each dimension, based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and exports data.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

Figure 2.11 builds on the results of Figure 2.4 by keeping only the top 50 more complex fields for each of the three dimensions – namely, scientific, technological and production – for the same eight selected countries over a 20-year period. From Figure 2.11, it is clear that the impressive economic performance of China correlates with a big increase in that country’s complex capability diversification. China has gained complex capabilities in all three dimensions, its jump in the technological dimension being the most impressive. In two decades, China went from being specialized in only seven out of the top 50 complex technological capabilities to 47 out of the top 50.

The same country's jump in complex scientific capabilities is also noteworthy. China's specialization in the top 50 complex scientific capabilities went from 26 out of 50 during the 2001–2004 period to 50 out of 50 by the 2013–2016 period. While Germany and Japan have seen a reduction in all capability diversification (Figure 2.4), Figure 2.11 shows that Germany has actually maintained its high degree of diversification in the top complex scientific capabilities, while Japan has done the same for the top complex technological capabilities. The Republic of Korea also shows a pattern of high diversification into complex capabilities. These results indicate that successful innovation ecosystems may drop less complex innovation capabilities but rarely drop the more complex ones.

In contrast, India shows progress in diversifying in the top complex scientific capabilities but less progress in the production and technological ones. Similarly, Mexico seems to have low diversification in all the top complex capabilities, particularly technological ones, while the United Republic of Tanzania has yet to specialize in a single top complex capability.

Leveraging capabilities to catch up

As was seen in the case of China, the Republic of Korea and to some extent India, these rankings are not fixed. As countries gain and lose capabilities their complexity levels change. China's new capabilities included technological know-how in ICT and transportation and scientific capabilities in medical science and clinical medicine. The addition of these complex capabilities mean that China's is now 18 positions higher in the complexity ranking than 20 years ago.

Such changes occur across all countries although often in a less dramatic fashion. Overall, countries have increased their diversity during the past 20 years. This rise is mainly driven by countries in East and Southeast Asia and to a lesser extent those in southern Europe and South America. Other regions have experienced a reduction in diversity. North America, eastern and western Europe all saw a reduction in the number of capabilities during the same period. This trend may partly explain why some Western countries – such as the United States and European Union (EU) countries – are adopting industrial and innovation policies designed to recover some of the capabilities they have lost.[29]

Several middle-income countries such as the Republic of Korea China and more recently India have consistently increased their level of know-how overall by adding more complex know-how to their capabilities. As the result, the Republic of Korea has succeeded in becoming a high-income economy.[30] While continuing to be a upper-middle income economy, China's impressive growth during the past two decades has left it on the verge of obtaining high-income status. More recently, India's continuous growth has put it on track to becoming a upper-middle income economy. Diversifying to more complex capabilities has helped, and continues to help, the economies in question move closer to the level of sophistication of the high-income economies.

Lower middle- and low-income countries alike are showing a decline in complexity levels, however. Rather than adding complexity, both groups have become "trapped" into focusing incrementally on less valuable capabilities thereby jeopardizing their ability to grow and exacerbating income inequalities around the world.[31]

How can countries choose which capabilities to pursue? Over the years there have been several unsuccessful efforts made by policymakers to "recreate Silicon Valley" in their respective regions and states.[32] The famous Californian hotspot was a small rural community at the beginning of the 20th century and is now recognized internationally as a major hub for technology and innovation, making it one of the places in the world with the most diverse and complex know-how. This success story resonates strongly in policymaking. However, other economies may be unable to replicate the multiple factors that made it possible.

Looking to develop high-complexity technologies where there are no solid foundations is like building a palace on an iceberg. Not only it will be hard to build but its inhospitable environment will make it hard to maintain and access. With no visitors nearby and nobody to fix it the structure will surely be abandoned and crumble at some point.

Related and unrelated capabilities

Knowledge gets incrementally diversified as it expands. Schools, for instance, start by teaching fundamental concepts such as mathematics and language in the early years of education and then later introduce physics, chemistry, literature and foreign languages. Some capabilities are building blocks or platforms to develop new ones.

Mapping the innovation capability space

Figure 2.12 Proximity based on country co-occurrence of 626 scientific, technological and product fields, 2001–2020

🟪 Science 🟦 Technology 🟦 Production

Note: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and export data.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

In this sense, innovation capabilities can be considered to be like a network connecting similar forms of knowledge. Figure 2.12 maps one such a network based on how often scientific, technological and production capabilities come to be found together in the same place. In this representation, the more complex capabilities appear in the lower right corner, as they are those that only advanced innovation ecosystems have developed these or adjacent capabilities. Most of the capabilities related to audiovisual, electronics and semiconductor technologies lie in that zone. In contrast, capabilities that require less accumulated know-how will appear more isolated, usually on the outskirts of the network on the upper left of the figure. This is the case for the production fields of many raw materials (iron and copper ores, cork, oils), food and live animals (cocoa, tea, rice), and some basic manufactured goods (such as those using tin or pearls and precious stones). Most of the intermediate complexity capabilities are at the center of the network.

As discussed in the previous section, capabilities differ in their level of complexity and which subset of these capabilities a country specializes in depends on many factors. In general, high-income countries have a rare set of skills that help them produce increasingly sophisticated outputs. These complex capabilities in turn boost productivity and wealth. Figure 2.13 reproduces the capability spaces in Figure 2.12 for Australia (top left), the Plurinational State of Bolivia (top right) and China (bottom-left and bottom-right quadrants). In all four, the non-grayed capabilities represent each country's current innovation capability specialization. Like any country with a more advanced level of innovation capabilities, Australia has innovation capabilities that are more centrally placed. In contrast, countries with a lower complexity – such as Bolivia – display a lower number of capabilities and these are located almost exclusively at the border of the network.

Entry to new capabilities is dependent on the portfolio of capabilities available in a given innovation ecosystem

Figure 2.13 **Australia, Plurinational State of Bolivia and China mapped in the innovation capability space**

Note: Countries' capabilities are represented in the co-occurrence mapping of 626 capabilities in Figure 2.2.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

This comparison raises two important questions: (1) How is it that Australia reached its current level of innovation capabilities? (2) How can Bolivia catch-up?

Some countries have been consistently adding innovation capabilities during the past two decades and have benefited from an increase in complexity. But how is it that countries gain new capabilities? Figure 2.13 shows the change in China's capabilities over the past two decades. During this time China has gained complex technological capabilities in the ICT domain, particularly in speech or audio coding or decoding, electronic circuitry, electric elements for telecommunications, and computing methods and technologies. More importantly, by 2020 China had gained most of the complex capabilities it was lacking in back the early 2000s.

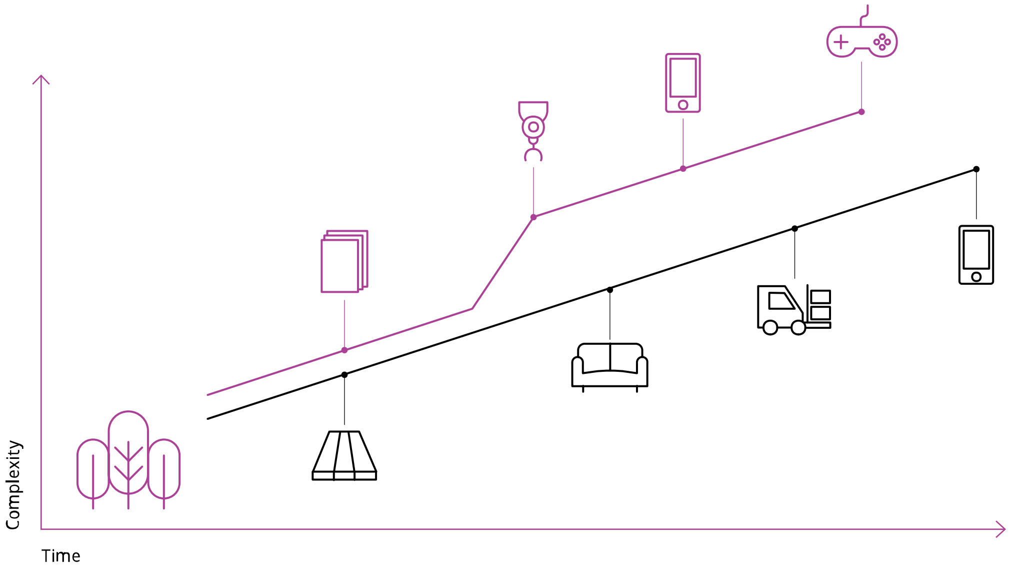
China’s experience suggests that a country’s current capabilities can indicate where to go next. This is known as the principle of relatedness.[33] Economies tend to diversify incrementally, moving into activities that have similar skills to those they currently possess.[34]

This behavior can be found in other contexts, too. For example, in the labor market people move between jobs that require a similar set of capabilities.[35] However, new positions will often require additional skills that can be learned on the job. This new set of capabilities then allows workers to move into positions that require a different set of skills from the first, performing tasks that were not present during their initial training.

Any structural transformation is a path-dependent process. However, there is room for agency. Due to related diversification, economies with similar capabilities can specialize in different areas. Finland and Sweden, for instance, have a relative abundance of forests in their territory. Such easy access to a particular resource has resulted in these two countries developing forestry capabilities during the late 19th and early 20th centuries. For both Finland and Sweden forestry is a vital part of the country's economy and related capabilities. In a simplified illustration, over time, Sweden’s move into related skills can be summarized as forestry capabilities being leveraged successively into wood treatments, furniture, designs, logistics and eventually telecommunications. Finland’s move into related skills can be summarized as forestry capabilities being leveraged successively into woodcutting and pulping equipment, heavy machinery, electronics and later telecommunications and video games. Nowadays, these paths can be illustrated by the business model successes of IKEA and Ericsson, for Sweden, and UPM, Nokia and Rovio, for Finland (see Figure 2.14 for a diagram on related and unrelated development paths).

Different capability paths can originate from a pre-existing portfolio of capabilities

Figure 2.14 Comparison of two capability strategies: maximum relatedness vs minimum time



Source: Modified from Hausmann et al. (2024) and Hidalgo (2022).

This example of a diverging evolution illustrates how relatedness can take two different paths. Sweden’s case is characterized by a maximum relatedness path (see the bottom line of the schematic diagram in Figure 2.14). The choice to stay in the realm of related skills has allowed it to build on its existing knowledge base and resources. It minimizes the risk associated with venturing into entirely new domains while capitalizing on established expertise.

However, Finland opted for a different path (represented by the top line in Figure 2.14). This required the country to develop skills and technologies that were less related to those it had at that time. This decision allowed Finland to quickly carve out a niche in a different sector, diverging from the path Sweden was taking. In contrast to Sweden, Finland did not limit itself to the immediate relatedness of the forestry sector. Instead, it pursued opportunities that provided a quicker transition to a new field. This approach is often associated with a "minimum time" strategy, as it aims to reduce the time required for economic transformation.

Both strategies can lead to successful economic development but they showcase different approaches to structural transformation based on relatedness and time considerations. Minimum time strategies rely on making a strategic leap into a less related, more complex capability. This move can open new opportunities if successful.[36]

Countries that managed to make such a move have consistently shown the ability to skip certain stages of traditional economic development and move directly to more advanced or modern stages. However, the question is can this be considered to be innovation leapfrogging? The well documented development boom undergone by several East Asian economies driven by the information technology industry shows how policies can play a big role in accelerating the process of acquiring less related capabilities.[37] Nonetheless, the related capabilities were eventually built, as illustrated in relation to the Republic of Korea and China (Figure 2.13), respectively.

Leapfrogging is therefore unlikely because the requisite new capabilities would have to be acquired first. As a result of related diversification economies tend to specialize in different areas. Any attempt to follow these kinds of strategies must be aware of timing. The window of opportunity to "leapfrog" is often narrow. Targeting an unrelated activity too late may miss the opportunity to fully benefit from such a risky move. Targeting it too early may lead to failure and wasted resources.

This is because the principle of relatedness also works in the opposite direction.[38] Countries often lose those capabilities that are isolated from their related skills. Countries that are related to a certain field are more likely not only to enter this new field but also to maintain the related capabilities they already possess. Indeed, innovation ecosystems exit certain capabilities – especially complex ones – if they do not maintain the related capabilities already in their basket.[39]

To make matters worse, many countries are unable to take such a risk. This is either because they have tried before, failed and no longer have the will to try again; or because a lack of resources restrains them from making such a risky leap.[40] As resources become scarcer there is usually a prevalence of conservative investments where the probability of success is much higher.

Looking for opportunities using relatedness and complexity metrics

Not every innovation direction is equally groundbreaking. Economists consider the concepts of innovation relatedness and complexity to be helpful policy tools in guiding the selection of priorities.[41] While the choices an economy could pursue are numerous, not all are equally related to pre-existing local capabilities. For example, given its ICT capabilities, a region such as Silicon Valley is more likely to innovate further in ICTs than in airplane technologies. The Toulouse region in France would likely be the opposite, as it is more related to airplane technologies than ICTs.

As discussed above, capabilities connect to each other according to their proximity and complementarity, which defines their relatedness. For example, autonomous vehicle technology requires technologies and expertise drawn from both the automotive and ICT industries. Consequently, automotive and AI technologies are both closely related to autonomous vehicles technology and, through it, they themselves are connected. In general, the more related, unique and sophisticated capabilities an innovation ecosystem has the more complex the technologies it will develop in the near future.[42]

The innovation capabilities of countries, regions and companies condition their ability to generate new outcomes. Countries and regions tend to specialize in technologies and products that are closely related to their past capabilities.[43] For instance, Silicon Valley's capabilities are more related to ICTs, whereas Boston's relate to health technologies and Munich's relate to automotive technologies. Similarly, countries and regions can only specialize in a higher complexity technology, once they have attained a higher relatedness to that technology.[44] For example, EU regions have been found more likely to specialize in a complex product if it was more related to their recent specialization.[45] In other words, the current relatedness of countries and regions influences their future specialization, especially for complex capabilities. This makes it hard for regions to leap to complex technologies without having first built the underlying capabilities. Therefore only a few regions and countries are able to attain more complex products and technologies. [46]

Smart specialization

In many respects identifying the relatedness and complexity of the top countries and regions of the world – such as Silicon Valley, Boston or Munich – is relatively straightforward. These regions already have high functioning innovation ecosystems that lead the way in transforming ideas into science and technologies that nurture the complex products of today and those of the future.

However, an understanding of potential specialization and diversification strategies based on relatedness and complexity tools can be extremely important for the design of innovation policies for middle-income economies and less developed regions. This process has been paired with the concept of smart specialization, as mentioned in Chapter 1.[47] Smart specialization is an industrial and innovation framework that aims to illustrate how public policies, framework conditions and especially R&D and innovation investment policies can influence the economic, scientific and technological specialization of a region and consequently its productivity, competitiveness and economic growth path.[48]

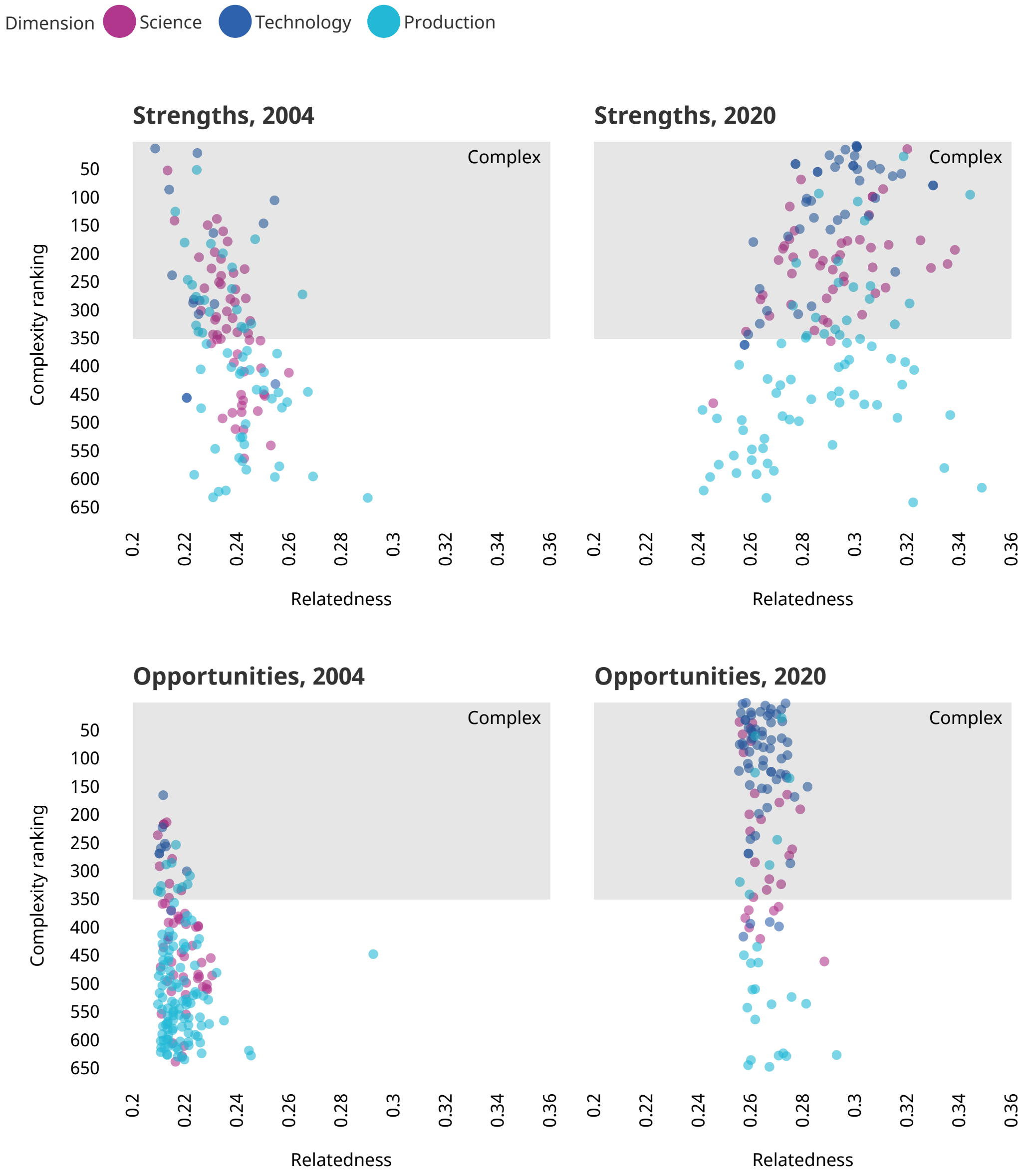
Companies or regions differ in their production capabilities. Hence the direction they should follow will vary accordingly. Innovation economists therefore advocate for countries and regions to pursue a smart specialization strategy. Such a strategy aims to encourage investments that complement the existing local production or technological assets, so as to create future local capability and competitive advantage.[49] Given the importance of priority selection in smart specialization strategies and regional innovation policy more broadly, scholars assert the need to develop better tools for informing a given region's priority choices.[50] In other words, how can policymakers prioritize technologies or industries when designing innovation and industrial policies that build on the local innovation ecosystem?

Some regions are becoming increasingly able to produce scientific research at the international level but fail to transform this research into patented technologies.[51] Despite not being able to contribute scientific outputs, yet other regions contribute to international trade but fail to transform that production capacity into the technological learning that leads to innovation. Such regions can benefit greatly from guidance as to where to focus their limited resources in order to remove the innovation roadblocks between science, technology and production. This guidance could also inform what role the IP system can play in assisting innovation policies.

Economists are increasingly suggesting that the complexity and relatedness framework is a useful toolbox for informing innovation policymaking, notably in support of smart specialization policies.[52] By combining these metrics policymakers are able to understand which capabilities countries or regions possess and how rewarding they are in terms of complexity. Additionally, policymakers can explore which of the not-yet-developed capabilities can be more easily attained, given pre-existing capabilities.

Singapore's path to fulfilling innovation opportunities

Figure 2.15 Singapore's complexity and relatedness metrics for specialized and not specialized capabilities, 2001-2004 and 2017-2020



Notes: Strengths = specialized capabilities; and Opportunities = not specialized capabilities.
Sources: WoS SCIE, EPO PATSTAT, WIPO, UN COMTRADE.

Fulfilled opportunities and untapped potential

Figure 2.15 plots the complexity of all innovation capabilities against their relatedness density in Singapore over two periods. The top-left quadrant shows the capabilities for which Singapore was specialized in 2001–2004, while the top right shows the same for 2017–2020. The change from 2004 to 2020 indicates that Singapore successfully developed more complex capabilities. In 2001–2004, Singapore was mostly specialized in capabilities with a lower complexity (the bottom-right quadrant). By 2020, Singapore had managed to become specialized in capabilities with a higher complexity (the top-right quadrant).

How did Singapore do this?[53] The process is at least partly explained by the bottom-left quadrant of Figure 2.15, which shows the opportunities that Singapore had in 2001–2004. By 2004, despite being not yet specialized, Singapore had a set of highly related capabilities (opportunities), the majority of which were low in complexity. Singapore focused on the uppermost opportunities and by 2020 it had managed to transform that high relatedness potential into concrete complex specialization. As a result, with its new set of capabilities, the bottom-left quadrant shows a handful of new opportunities, most of which are now in the high complexity spectrum. This current scenario is beneficial for the country, as it can continue to improve its complexity level and benefit from the rewards.

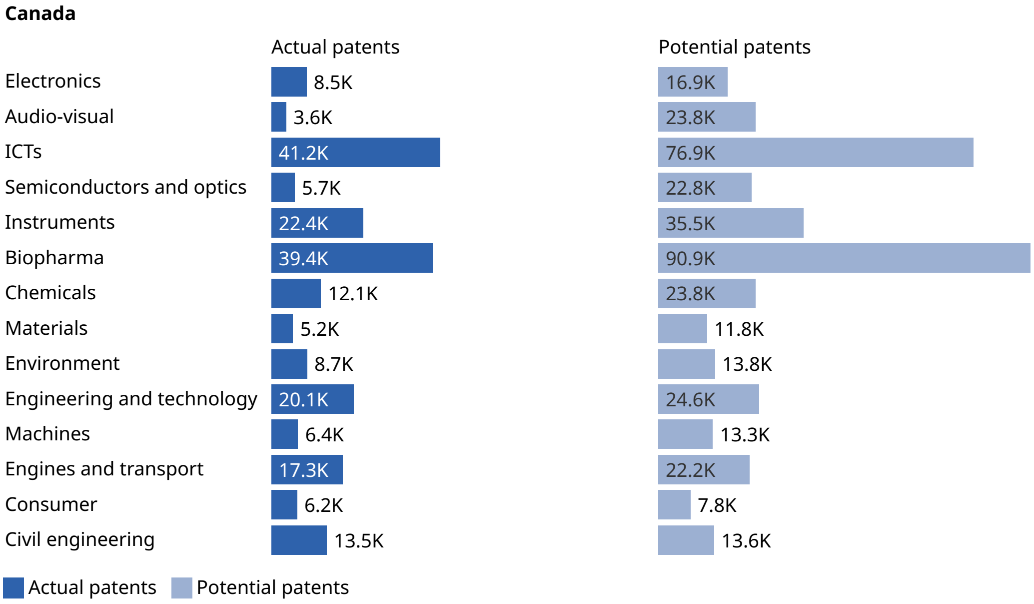
National and regional innovation policies can also exploit the relatedness between capabilities of different dimensions. Indeed, countries or regions are specialized in very different areas when it comes to trade, patents and scientific publications. How do these areas relate to one another? Can scientific capabilities for example translate into economic or technological capabilities?

Capabilities might not be directly related and may not co-evolve together, although the indirect effect of scientific capabilities on the absorptive capacity of countries, regions and companies has been documented in the economic literature. Studies have shown that patenting activity across countries correlates with scientific publications but not every scientific publication necessarily leads to patenting.[54] Similarly, other studies find that regional scientific capabilities in given scientific fields predict the development of related new technologies in the corresponding technological fields in the same regions. Recent studies find that countries are more likely to diversify in technologies that are related to existing scientific capabilities.[55] A similar rationale follows the link between trade capabilities and the probability of entering new technological fields.[56]

These connections can shed light on the untapped innovative potential of countries. The interplay between the three dimensions in the innovation frontier can help countries identify latent capabilities.[57] Figure 2.16 contrasts the untapped technological potential of a medium-sized high-income economy (Canada) with the untapped technological potential of a middle-income economy (Colombia). Figure 2.16 uses the proximity connections between scientific and technological capabilities in the economies from cluster 1 (in Figure 2.6) to estimate the number of patents that could be expected to be seen in a country based on its scientific publications if it were the average country in cluster 1. It refers to potential output in a capability given the current outcome on related capabilities.

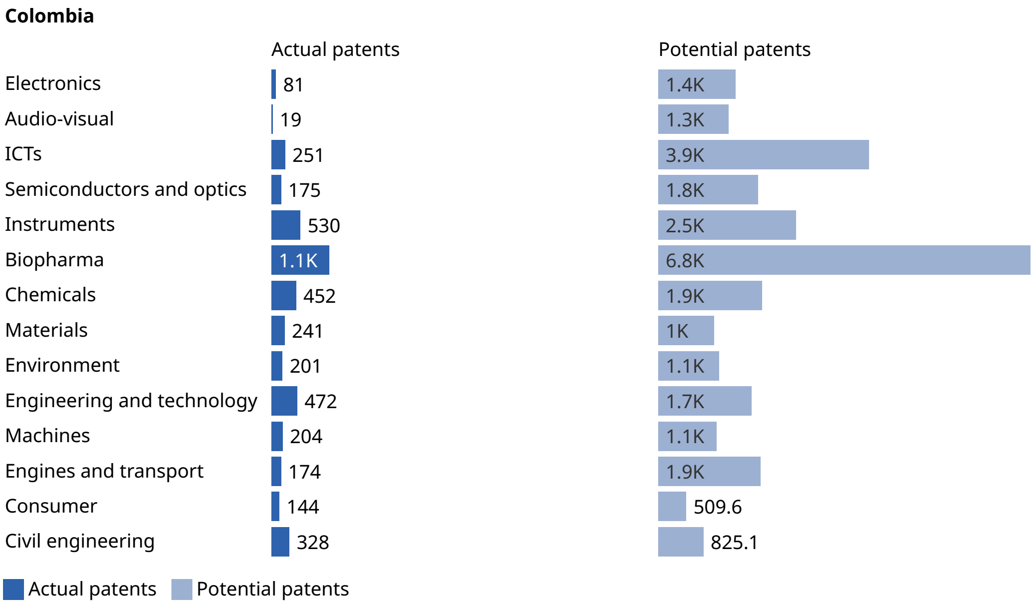
The tapped and untapped technological potential of Canada and Colombia

Figure 2.16 **Canada and Colombia estimated number of patents based on scientific publications, 2001–2020**



Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

Figure 2.16 *(continued)*



Both countries have domains where, based on their scientific outputs, there is untapped technological potential. For Canada (Figure 2.16a) there is room for improvement in three of the most complex domains – audiovisual, electronics, and semiconductors and optics. The average economy in cluster 1 would produce more patents if it had the same scientific outputs as Canada. For example, given its scientific production, Canada produces half as many patents in audiovisual technologies and two-thirds as many in chemical technologies compared to the average cluster 1 economy. In contrast, with the same scientific output, Canada produces 16 percent more patents in civil engineering technologies than the average cluster 1 economy in Figure 2.6.

This insight can be powerful when it comes to identifying missing links between the stakeholders in an innovation ecosystem. By looking into how these dimensions interact in a well-functioning ecosystem policymakers can prioritize between domains and zoom into the relations between academic institutions, industry and the IP system, so as to identify the particular constraints that are stopping the economy from reaching its full potential. For less diversified economies such as Colombia technological capabilities are less present at the international scale, and its observed patents are far from reaching their potential. Indeed, Colombia's transformation of scientific publications into international patents is in all fields less than 50 percent of that of the average cluster 1 economy. This is particularly relevant for biopharma and ICTs where Colombia produces a considerable related scientific output but realizes no more than 18 percent and six percent, respectively, of the technological transformation potential.

Conclusion: the key to successful development

This chapter has explored the empirical literature on innovation capabilities and presented new evidence based on data drawn from scientific publications, international patents and exports. In doing so, it has explored the potential relevance of using measures of innovation capabilities to inform the design of innovation and industrial policy.

First, the chapter has studied the need for a multidimensional measurement and an analysis of innovation capabilities. Categorizing innovation capabilities according to whether they are scientific, technological or production capabilities – measured by scientific publications, patents and trade data – seems to be a useful approach to mapping the different innovation ecosystems that exist around the world.

Second, to further understand the implications of a country's specialization in certain innovation capabilities it is crucial to comprehend the quality of those capabilities. The complexity metrics illustrated add deeper insights that go far beyond how ubiquitous or rare any particular scientific, technological or production field might be. The empirical evidence shows that the development of more complex scientific, technological and production capabilities correlates with economic growth. Furthermore, the chapter has identified differences in the level of complexity of capabilities between dimensions in general, highlighting the fact that the ability to produce technological innovations is, overall, the most complex and rewarding of the three dimensions analyzed.

Third, the chapter documents the capabilities that exist in each innovation ecosystem that are predictors of new capabilities. The dynamics of innovation capabilities, relatedness and complexity present a framework for understanding the progression toward the economic and technological development of an innovation ecosystem – either local, regional or national. These interconnected concepts and metrics can help policymakers to adopt a strategic approach that encompasses the co-evolution of different domains and their interdependencies. By doing so, economies can address binding constraints, stimulate positive externalities and promote a resilient innovation ecosystem.

Lastly, the chapter has documented the importance of innovation diversification for countries and the relationship between science, technology and production. The ever-changing landscape of capabilities and their relatedness underscores the need for strategic diversification. This evolution is not a one-size-fits-all process. Instead, it allows countries to choose from diverse paths based on their unique circumstances. Some may opt for a strategy that builds progressively on existing skills, while others may aim to accelerate the transition to a new field by targeting less related domains, known as leapfrogging. The choice of strategy should be well-timed and align with a country's specific goals and resource availability. The timing of a venture into unrelated activities is of vital importance. Pursuing such a venture either too early or too late can result in missed opportunities and a waste of resources. Policymakers need to be able to recognize a narrow window of opportunity when it opens and have the related capabilities in place.

There are also some limitations to note. While very important, the scientific, technological and production dimensions are not the only dimensions related to innovation capabilities. For instance, non-patentable technologies and non-tradable goods also make a contribution to the innovation capabilities of an ecosystem. Yet, these two dimensions are poorly measured by scientific publications, patents and trade data. Moreover, country level analysis of these two dimensions might be too aggregated, confounding regional capabilities of countries with large territories. For example, it cannot be assumed that the aggregated capabilities of Silicon Valley and New York City apply to each other, and that they apply even less to many areas in the center of the United States. Lastly, some caution is needed when interpreting the results of the complexity and economic growth correlation. In most cases, economic research has found a strong correlation without a strong empirical setting to test causation. Moreover, there is still a limited conceptualization and understanding of the mechanisms through which these relationships are working, which limits the potential empirical tests.

Some of these limitations can be at least partially addressed by an analysis that is more qualitative and focused. With this in mind, the next chapters explore innovation capabilities and related concepts, such as relatedness and complexity, as they apply to three case studies: agricultural technologies (or “AgTech”) (Chapter 3), motorcycles (with a focus on e-bikes) (Chapter 4) and video games (Chapter 5). While most of the general findings of this chapter are there to be seen in these case studies, they take a much deeper and intuitive dive into innovation capabilities.

In sum, managing innovation capabilities and their relatedness is pivotal for those countries seeking long-term growth and competitiveness in an ever-evolving global economic landscape. By embracing the principles of complexity and smart specialization, comprehending related and unrelated capabilities, and making well-informed strategic decisions, countries can position themselves for success and sustainability in economic and technological development.

Notes

1. For a summary of this literature see Box 2.2, and Balland, P.-A., T. Broekel, D. Diodato, E. Giuliani, R. Hausmann, N. O'Clery and D. Rigby (2022). The new paradigm of economic complexity. *Research Policy*, 51(3), 104450. DOI: https://doi.org/10.1016/j.respol.2021.104450.
2. For a seminal discussion on tacit knowledge, see Polanyi, M. 1966. *The Tacit Dimension*. Chicago: University of Chicago Press, 4.
3. This chapter's definition and measurement of innovation capabilities follows closely the work of Pugliese, E., G. Cimini, A. Patelli, A. Zaccaria, L. Pietronero and A. Gabrielli (2019). Unfolding the innovation system for the development of countries: Coevolution of Science, Technology and Production. *Scientific Reports*, 9, 16440. DOI: https://doi.org/10.1038/s41598-019-52767-5.
4. For a discussion on the discovery and development of penicillin and semiconductors and their contribution to economic growth, see WIPO (2015). *World Intellectual Property Report 2015: Breakthrough Innovation and Economic Growth.* Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=3995.
5. Arrow suggests that learning is the product of experience and hence hypothesizes that innovation (technical change) can be related to experience. He defines experience as "the very activity of production which gives rise to problems for which favorable responses are selected over time." See Arrow, K.J. (1962). The economic implications of learning by doing. *The Review of Economic Studies*, 29(3), 155–173. DOI: https://doi.org/10.2307/2295952.
6. Using an extensive Pat-Val survey, Torrisi and colleagues and Giuri et al. found that between a third and a half of the patents surveyed were used only strategically or not at all. Other studies have found even lower results due to other regulations – such as medicine approval – preventing patented products from being commercialized. See Torrisi, S., A. Gambardella, P. Giuri, D. Harhoff, K. Hoisl and M. Mariani (2016). Used, blocking and sleeping patents: Empirical evidence from a large-scale inventor survey. *Research Policy*, 45(7), 1374–1385. DOI: https://doi.org/10.1016/j.respol.2016.03.021; and Giuri, P., M. Mariani, S. Brusoni, G. Crespi, D. Francoz, A. Gambardella, W. Garcia-Fontes, A. Geuna, R. Gonzales, D. Harhoff, K. Hoisl, C. Le Bas, A. Luzzi, L. Magazzini, L. Nesta, Ö. Nomaler, N. Palomeras, P. Patel, M. Romanelli and B. Verspagen (2007). Inventors and invention processes in Europe: Results from the PatVal–EU survey. *Research Policy*, 36(8), 1107–1127. DOI: https://doi.org/10.1016/j.respol.2007.07.008
7. Balland and Boschma find that many EU regions specialize in technologies without mastering the related scientific capabilities. See Balland, P. and R. Boschma (2022). Do scientific capabilities in specific domains matter for technological diversification in European regions? *Research Policy*, 51(10), 104594. DOI: https://doi.org/10.1016/j.respol.2022.104594.
8. For an introduction to the notion of innovation ecosystems and the strands of the economic and social sciences literature discussing it, see Chapter 1 of WIPO (2022a). *World Intellectual Property Report 2022: The Direction of Innovation.* Geneva: World Intellectual Property Organization. Available at: www.wipo.int/wipr/en/2022.
9. To be granted, a patent must be for an invention that is novel, have a sufficient inventive step and which is susceptible of industrial application.
10. For an example of using scientific articles and patents as proxies for scientific and technological capabilities, see WIPO (2019). *World Intellectual Property Report 2019: The Geography of Innovation*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4467.
11. For an example of using scientific exports as proxies for production capabilities, see Hidalgo, C.A. and R. Hausmann (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences*, 106(26), 10570–10575.
12. The field "Special transactions and commodities not classified according to kind" accounting for 4.2 percent of the international trade between 2017–2020 is ignored in this list. Non-crude fuel minerals account for 3.09 percent, making crude and non-crude fuel minerals, combined, the top field in terms of concentration.
13. A very similar chart can be achieved by selecting almost any other four countries from each income group.
14. This indicator is the relative comparative advantage (RCA), expressed by the formula:share of capability x in country y / share of capability x in world total.
15. The final method considers a country to be specialized in a given innovation field if (1) its absolute specialization is within the top two times inverse Herfindahl–Hirschman Index (HHI); or, (2) its relative specialization (i.e., RCA) is greater than unity and its absolute specialization is above the bottom two times HHI. The method is inspired by Hausmann et al. (2024) and detailed in Moscatelli et al. (2024). Hausmann, R., M.A. Yildirim, C. Chacua, S. Gadgin Matha and H. Hartog (2024). Global Trends in Innovation Patterns: A Complexity Approach. *WIPO Economic Research Working Paper No. 80*. World Intellectual Property Organization; and Moscatelli, F., C. Chacua, S. Gadgin Matha, H. Hartog, E. Hernandez Rodriguez, J.D. Raffo and M.A. Yildirim (2024). Can we map innovation capabilities? *WIPO Economic Research Working Paper No. 81*. World Intellectual Property Organization.
16. For a thorough analysis of innovation in the mining sector, see Daly, A., D. Humphreys, J. Raffo and G. Valacchi (eds). (2022). *Global Challenges for Innovation in Mining Industries*. Cambridge University Press. DOI: https://doi.org/10.1017/9781108904209.
17. See WIPO (2022a). *World Intellectual Property Report 2022: The Direction of Innovation*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/wipr/en/2022.
18. The economic development literature has used Hidalgo and Hausmann's economic complexity indicator (ECI) extensively. The ECI allows a reduction in the dimensionality of the problem of understanding why economies grow. Previous efforts had aggregated data on firms, households, government and customs in order to build national accounts indicators, such as gross domestic product (GDP), investments, consumption and trade indicators. Aggregation loses much of that information by collapsing the different entries. By adopting a network analysis approach, the complexity methodology preserves more information by transforming the data into an indicator that still captures what it is that countries do. For a discussion, see Hidalgo, C.A. and R. Hausmann (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences*, 106(26), 10570–10575; and Hidalgo, C.A., B. Klinger, A.L. Barabási and R. Hausmann (2007). The product space conditions the development of nations. *Science*, 317(5837), 482–487. For a summary of the literature, including similar metrics such as the Fitness concept, see Balland, P.-A., T. Broekel, D. Diodato, E. Giuliani, R. Hausmann, N. O'Clery and D. Rigby (2022). The new paradigm of economic complexity. *Research Policy*, 51(3), 104450. DOI: https://doi.org/10.1016/j.respol.2021.104450.
19. See Box 2.2 for a summary of the main metrics relating to the complexity economic literature applied to innovation complexity. For more details on the complexity indicator and algorithm, see Hausmann, R., M.A. Yildirim, C. Chacua, S. Gadgin Matha and H. Hartog (2024). Global Trends in Innovation Patterns: A Complexity Approach. *WIPO Economic Research Working Paper No. 80*. World Intellectual Property Organization; and Moscatelli, F., C. Chacua, S. Gadgin Matha, H. Hartog, E. Hernandez Rodriguez, J.D. Raffo and M.A. Yildirim (2024). Can we map innovation capabilities? *WIPO Economic Research Working Paper No. 81*. World Intellectual Property Organization.
20. Wuchty and colleagues find that theoretical physics has an average of 2.33 authors per paper against 4.08 authors per paper in applied physics. See Wuchty, S., B. F. Jones and B. Uzzi (2007). The Increasing Dominance of Teams in Production of Knowledge. *Science*, 316(5827), 1036–1039. https://doi.org/10.1126/science.1136099.
21. For a discussion of the evolution of scientific and technological concentration – both at country and regional level – in

further detail, see WIPO (2019). *World Intellectual Property Report 2019: The Geography of Innovation*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4467.

22 See Balland, P.-A., T. Broekel, D. Diodato, E. Giuliani, R. Hausmann, N. O'Clery and D. Rigby (2022). The new paradigm of economic complexity. *Research Policy*, 51(3), 104450. DOI: https://doi.org/10.1016/j.respol.2021.104450.

23 Hidalgo and Hausmann find that the measures of complexity correlate with a country's level of income and that the relation is predictive of future growth. They suggest that development efforts should focus on generating the conditions that would allow complexity to emerge and thus generate sustained growth and prosperity. See Hidalgo, C.A. and R. Hausmann (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences*, 106(26), 10570–10575.

24 Balland and Rigby find that in US cities technological complexity correlates strongly with longer-run patterns of economic performance. See Balland, P.A. and D. Rigby (2017). The geography of complex knowledge. *Economic Geography*, 93(1), 1–23.

25 Hidalgo and colleagues find that economic complexity correlates with higher economic growth, less inequality, less greenhouse gas emissions and more economic development. See Hidalgo et al. (2022).Still, some caution is needed when interpreting these results, as in most cases economic research has found a strong correlation without a strong empirical setting to test causation, see Kogler, D.F., E. Evenhuis, E. Giuliani, R. Martin, E. Uyarra and R. Boschma (2023). Re-imagining evolutionary economic geography. *Cambridge Journal of Regions, Economy and Society*, 16(3), 373–390.

26 See Hausmann et al. (2024).

27 Mewes and Broekel find that technological capabilities (and their complexity) are a strong predictor of economic growth for European NUTS 2 regions from 2000 to 2014. See Mewes, L. and T. Broekel (2022). Technological complexity and economic growth of regions, *Research Policy*, 51(8), 104156. DOI: https://doi.org/10.1016/j.respol.2020.104156.

28 Using a metric equivalent to complexity (fitness metric), Cristelli and colleagues find that the predictive power of complexity (fitness) to explain economic growth depends on the level of the former. Economies with a lower complexity (fitness) will have a "chaotic" path to growth, whereas those with a higher complexity will have a "laminar" (i.e., more predictive) path to growth. See Cristelli M, A. Tacchella and L. Pietronero (2015). The heterogeneous dynamics of economic complexity. *PLoS ONE*, 10(2), e0117174. Available at: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0117174.

29 As discussed in Chapter 1, recent years have seen a revival of industrial policies in response to a variety of new challenges faced by governments. These include a need to reduce carbon emissions to mitigate climate change (e.g., the European Green Deal and the US Inflation Reduction Act), avoid shortages of strategic goods due to global supply chain shocks (e.g., during the COVID-19 pandemic) or to support those high-tech industries critical for national security (e.g., semiconductors).

30 Soh and colleagues document how the Republic of Korea is today a highly industrialized global leader in innovation and technology. Their report focuses on the Republic's transition from a middle-income to a high-income economy. They indicate that the Republic of Korea has succeeded by focusing on building global capabilities in innovation and technology among others that they consider to be the foundations of long-term growth. See Soh, H.S., Y. Koh and A.Aridi (eds) (2023). *Innovative Korea: Leveraging Innovation and Technology for Development*. Washington, DC: World Bank. Available at: http://hdl.handle.net/10986/40234.

31 Pinheiro and colleagues find that EU regions and countries at an intermediate level of income can be "trapped" in low complexity activities because they the lack relevant capabilities required to move into more complex ones. See Pinheiro, F.L., D. Hartmann, R. Boschma and C.A. Hidalgo (2021). The time and frequency of unrelated diversification. *Research Policy*, 51(8), 104323; and Pinheiro, F.L., P.A. Balland, R. Boschma and D. Hartmann (2022). The dark side of the geography of innovation: relatedness, complexity and regional inequality in Europe. *Regional Studies*, 1–16. DOI: 10.1080/00343404.2022.2106362.

32 For a discussion of the geography of innovation and the unsuccessful attempts to create "cathedrals in the desert", see Chapter 1 of WIPO (2019). *World Intellectual Property Report 2019: The Geography of Innovation*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4467; and Crescenzi, R., S. Iammarino, C. Ioramashvili, A. Rodríguez-Pose and M. Storper (2019). The Geography of Innovation: Local Hotspots and Global Innovation Networks. *WIPO Economic Research Working Paper No. 57*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4471.

33 The principle of relatedness establishes that greater past relatedness predicts current specialization. In other words, the capability (product or technological) space conditions the future specialization and complexity of countries or regions. See Hidalgo, C.A., B. Klinger, A.L. Barabási and R. Hausmann (2007). The product space conditions the development of nations. *Science*, 317(5837), 482–487; Boschma, R., P.A. Balland and D.F. Kogler (2015). Relatedness and technological change in cities: the rise and fall of technological knowledge in US metropolitan areas from 1981 to 2010. Industrial and corporate change, 24(1), 223–250; Boschma, R. (2017). Relatedness as driver of regional diversification: A research agenda. *Regional Studies*, 51(3), 351–364; and Hidalgo, C.A., P.A. Balland, R. Boschma, M. Delgado, M. Feldman, K. Frenken and S. Zhu (2018, July). The principle of relatedness. In *International Conference on Complex Systems*. Cham: Springer, 451–457. In particular, Boschma (2017) provides a comprehensive analysis.

34 Yet, regions or countries do sometimes diversify into unrelated fields. See Pinheiro, F.L., D. Hartmann, R. Boschma and C.A. Hidalgo (2021). The time and frequency of unrelated diversification. *Research Policy*, 51(8), 104323; and Pinheiro, F.L., P.A. Balland, R. Boschma and D. Hartmann (2022). The dark side of the geography of innovation: relatedness, complexity and regional inequality in Europe. *Regional Studies*, 1–16. DOI: 10.1080/00343404.2022.2106362.

35 See the work by Frank Neffke on this topic, Neffke, F., M. Henning and R. Boschma (2011). How do regions diversify over time? Industry relatedness and the development of new growth paths in regions. *Economic geography*, 87(3), 237–265; Neffke, F. and M. Henning (2013). Skill relatedness and firm diversification. *Strategic Management Journal*, 34, 297–316. DOI: https://doi.org/10.1002/smj.2014; and Neffke, F., M. Hartog, R. Boschma and M. Henning (2018). Agents of structural change: The role of firms and entrepreneurs in regional diversification. *Economic Geography*, 94(1), 23–48.

36 See Boschma, R. (2022). Designing Smart Specialization Policy: Relatedness, unrelatedness, or what? In Anderson, M., C. Karlsson and S. Wixe (eds), *Handbook of Spatial Diversity and Business Economics*. Oxford: Oxford University Press, forthcoming.

37 See a detailed discussion in WIPO (2022a). *World Intellectual Property Report 2022: The Direction of Innovation*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/wipr/en/2022.

38 Neffke et al. (2011) was the first paper to show that entries are related to existing capabilities within regions, whereas exits are unrelated to such capabilities. See Neffke, F., M. Henning and R. Boschma (2011). How do regions diversify over time? Industry relatedness and the development of new growth paths in regions. *Economic Geography*, 87(3), 237–265.

39 Hausmann and colleagues formalize this in "density regressions," where density measures the extent to which there is activity present within a country that is related to a certain activity. A country's existing technological portfolio is strongly predictive of not just the entry of new technologies but also their exit and growth. Entry and growth are

more likely when related technologies are present, whereas technologies with few related technologies around them are more likely to disappear. See Hausmann, R., M.A. Yildirim, C. Chacua, S. Gadgin Matha and H. Hartog (2024). Global Trends in Innovation Patterns: A Complexity Approach. *WIPO Economic Research Working Paper No. 80*. World Intellectual Property Organization.

40 Balland and colleagues showed that these kinds of policies have no certainty of success, making them very risky despite the potential high reward. See Balland, P.A., R. Boschma, J. Crespo and D.L. Rigby (2019). Smart specialization policy in the European Union: Relatedness, knowledge complexity and regional diversification. *Regional Studies*, 53(9), 1252–1268.

41 See Hidalgo, C.A. (2022). The policy implications of economic complexity. arXiv preprint arXiv:2205.02164. Available at: https://arxiv.org/ftp/arxiv/papers/2205/2205.02164.pdf; Rigby, D.L., C. Roesler, D. Kogler, R. Boschma and P.A. Balland (2022). Do EU regions benefit from Smart Specialisation principles? *Regional Studies*, 1–16; Deegan, J., T. Broekel and R.D. Fitjar (2021). Searching through the haystack: The relatedness and complexity of priorities in smart specialization strategies. *Economic Geography*, 97(5), 497–520; and Balland, P.A., R. Boschma, J. Crespo and D.L. Rigby (2019). Smart specialization policy in the European Union: Relatedness, knowledge complexity and regional diversification. *Regional Studies*, 53(9), 1252–1268.

42 See Hidalgo, C.A., B. Klinger, A.L. Barabási and R. Hausmann (2007). The product space conditions the development of nations. *Science*, 317(5837), 482–487; and Boschma, R., P.A. Balland and D.F. Kogler (2015). Relatedness and technological change in cities: the rise and fall of technological knowledge in US metropolitan areas from 1981 to 2010. *Industrial and Corporate Change*, 24(1), 223–250.

43 Hidalgo, C.A., P.A. Balland, R. Boschma, M. Delgado, M. Feldman, K. Frenken and S. Zhu (2018, July). The principle of relatedness. In *International Conference on Complex Systems*. Cham: Springer, 451–457; Balland, P.A., R. Boschma, J. Crespo and D.L. Rigby (2019). Smart specialization policy in the European Union: Relatedness, knowledge complexity and regional diversification. *Regional Studies*, 53(9), 1252–1268; and Deegan, J., T. Broekel and R.D. Fitjar (2021). Searching through the haystack: The relatedness and complexity of priorities in smart specialization strategies. *Economic Geography*, 97(5), 497–520.

44 See Balland, P.A., R. Boschma, J. Crespo and D.L. Rigby (2019). Smart specialization policy in the European Union: Relatedness, knowledge complexity and regional diversification. *Regional Studies*, 53(9), 1252–1268.

45 See Deegan, J., T. Broekel and R.D. Fitjar (2021). Searching through the haystack: The relatedness and complexity of priorities in smart specialization strategies. *Economic Geography*, 97(5), 497–520.

46 Balland and Rigby find that only a few US metropolitan areas are able to produce the most complex technologies. See Balland, P.A. and D. Rigby (2017). The geography of complex knowledge. *Economic Geography*, 93(1), 1–23.

47 Foray, D., P.A. David and B. Hall (2009). Smart specialisation: The concept. In *Knowledge for Growth: Prospects for Science, Technology and Innovation*, EUR 24047 EN. European Commission. Available at: https://ec.europa.eu/invest-in-research/pdf/download_en/selected_papers_en.pdf; and Foray, D. (2014). Smart Specialisation: Opportunities and Challenges for Regional Innovation Policy, *Regional Studies*. London: Routledge.

48 See OECD (2013). *Innovation-driven Growth in Regions: The Role of Smart Specialisation*. Organisation for Economic Co-operation and Development. Available at: www.oecd.org/sti/inno/smartspecialisation.htm.

49 See WIPO (2019). *World Intellectual Property Report 2019: The Geography of Innovation*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4467.

50 See Deegan, J., T. Broekel and R.D. Fitjar (2021). Searching through the haystack: The relatedness and complexity of priorities in smart specialization strategies. *Economic Geography*, 97(5), 497–520; and Marrocu, E., R. Paci, D. Rigby and S. Usai (2023). Evaluating the implementation of Smart Specialisation policy. *Regional Studies*, 57(1), 112–128. DOI: 10.1080/00343404.2022.2047915.

51 See WIPO (2019). *World Intellectual Property Report 2019: The Geography of Innovation*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4467. Conversely, some regions may develop technologies without possessing the related scientific capabilities, as shown in Balland, P. and R. Boschma (2022). Do scientific capabilities in specific domains matter for technological diversification in European regions? *Research Policy*, 51(10), 104594. DOI: https://doi.org/10.1016/j.respol.2022.104594.

52 Balland and colleagues define their smart specialization policy framework as four quadrants summarizing the cost–benefit trade-off of prioritizing specialization in a given technology instead of another one. In this approach, an attractive smart specialization policy will prioritize those potential technologies with a high relatedness and a high complexity (low risk and high reward) and oppose the "dead-end" policy scenario of prioritizing low relatedness and low complexity (high risk and low reward). Additionally, they describe a risky but potentially high-benefit strategy of developing new technologies from scratch (low relatedness but high complexity). Last, they point to a "slow-road" policy, which is where there is a relatively low-risk but also a low reward (high relatedness but low complexity). See Balland, P.A., R. Boschma, J. Crespo and D.L. Rigby (2019). Smart specialization policy in the European Union: Relatedness, knowledge complexity and regional diversification. *Regional Studies,* 53(9), 1252–1268. The report mimics this approach in Figure 2.15.

53 See WIPO (2022b)*Global Innovation Hotspots: Singapore's Innovation and Entrepreneurship Ecosystem*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4623.

54 See Pugliese, E., G. Cimini, A. Patelli, A. Zaccaria, L. Pietronero and A. Gabrielli (2019). Unfolding the innovation system for the development of countries: Coevolution of Science, Technology and Production. *Scientific Reports*, 9, 16440. DOI: https://doi.org/10.1038/s41598-019-52767-5.

55 These studies have explored the extent to which technology classes are related to scientific publications by analyzing citations of patent families in various technology classes to scientific fields, finding that countries are more likely to diversify in technological classes that are often citing specific scientific fields. See Furman, J. L., M. E. Porter, and S. Stern (2002). The determinants of national innovative capacity. *Research Policy*, 31(6), 899–933. DOI: https://doi.org/10.1016/S0048-7333(01)00152-4; Balland, P. and R. Boschma (2022). Do scientific capabilities in specific domains matter for technological diversification in European regions? *Research Policy,* 51(10), 104594. DOI: https://doi.org/10.1016/j.respol.2022.104594; Shin, H., D. F. Kogler and K. Kim (2023). The relevance of scientific knowledge externalities for technological change and resulting inventions across European metropolitan areas. *Review of Regional Research*, 1–17. DOI:10.1007/s10037-023-00190-9; and Hausmann, R., M.A. Yildirim, C. Chacua, S. Gadgin Matha and H. Hartog (2024). Global Trends in Innovation Patterns: A Complexity Approach. *WIPO Economic Research Working Paper No. 80*. World Intellectual Property Organization.

56 Hausmann et al. (2024) explores this in a similar way as Shin et al. (2023) do for scientific fields. See Hausmann, R., M.A. Yildirim, C. Chacua, S. Gadgin Matha and H. Hartog (2024). Global Trends in Innovation Patterns: A Complexity Approach. *WIPO Economic Research Working Paper No. 80*. World Intellectual Property Organization; and Shin, H., D. F. Kogler and K. Kim (2023). The relevance of scientific knowledge externalities for technological change and resulting inventions across European metropolitan areas. *Review of Regional Research*, 1–17. DOI:10.1007/s10037-023-00190-9..

57 In practical terms, this report defines as frontier innovation ecosystems those in cluster 1 of Figure 2.6.

3 The importance of local capabilities in AgTech specialization

Agriculture plays a vital role for society as the global population relies on this industry for food, nutrition and to address sustainability concerns. Innovation in agriculture varies depending on the context of the country, including its agroecological conditions. This chapter highlights the role of the public sector in building innovative capabilities in agriculture, and illustrates how Brazil, Kenya and the US have successfully specialized in specific AgTech fields.

Introduction

Every economy has an agricultural sector.[1] It is vital to ensuring food security and nutrition for a growing population.

Today's agricultural landscape has evolved significantly from the traditional farming methods dating back millennia. Advances in scientific foundations and technological progress have led to higher agricultural yields achieved by using better agricultural inputs such as improved crop breeds, fertilizers and pesticides. They have also lessened the need for the hard manual labor traditionally associated with farming by employing machines powered first by steam and then combustion engines.

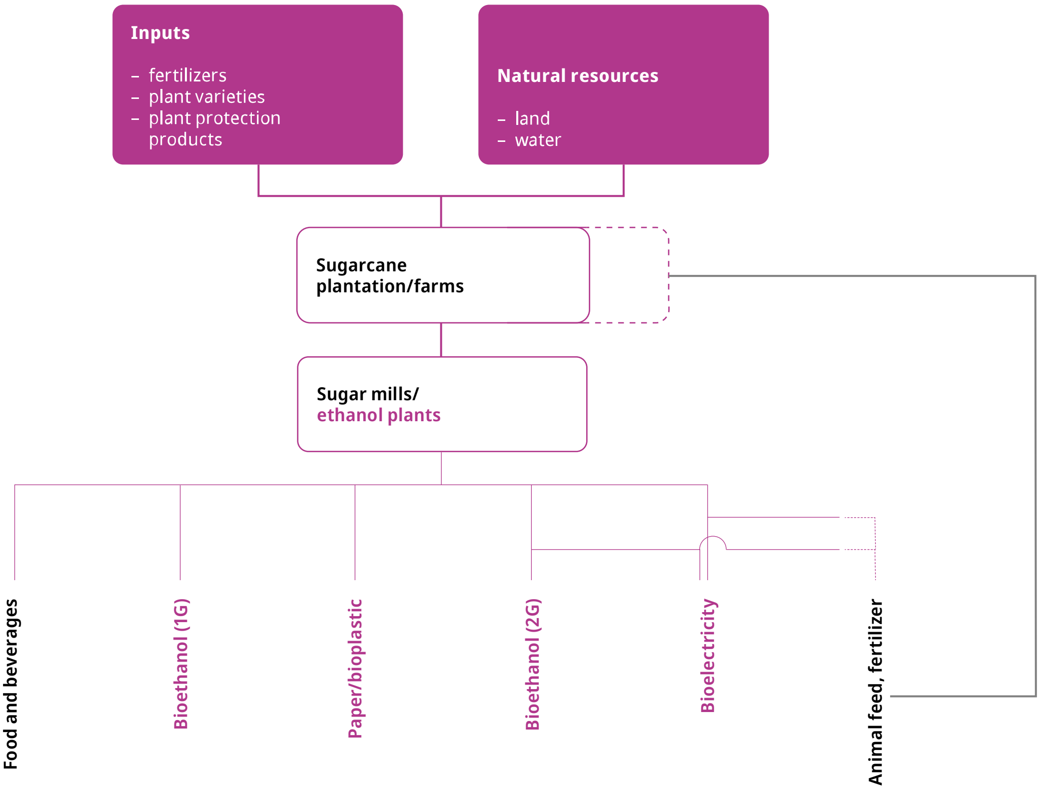
The current agricultural value chain is increasingly complex in terms of vertically and horizontally differentiated value segments, economic agents and intermediate and final products. It includes more than 200 industry subsectors and ranges from agricultural inputs such as fertilizer, seeds, farm land, irrigation and labor, to processing, manufacturing and packaging, all the way up to the final point sale of products and services to consumers. Innovation arises at many points along the agricultural value chain often drawing on technological advances in other sectors of the economy such as molecular biology, computing, satellite imaging or materials science.

Figure 3.1 illustrates an agricultural value chain, using the Brazilian sugarcane as an example. It shows how each segment of the value chain may consist of different economic agents with the potential to innovate and transform the sector. The end use for sugarcane products has diversified over time. Traditionally, sugarcane was used primarily for the food and beverage industry while its waste was used for animal feed and fertilizer. Today, sugarcane can end up as a source of renewable energy. Each sugarcane value segment requires different sets of skills and specialties, and each final category is governed by separate standards, rules and regulations.

The agricultural value chain has strong internal connections; a change in one value segment can impact another further along the chain. In the case of sugarcane, the government's program to produce ethanol increased the demand for raw sugarcane and induced many sugar mills to install ethanol plants. Innovation and developments in these segments help build the innovation ecosystem's local innovative capabilities and may shift its agricultural technology (AgTech) innovation trajectory.

Innovation can happen at different points in the value chain

Figure 3.1 The diversification of the traditional sugarcane industry in Brazil



Source: Adapted from Machado and Abreu (2024) and Neves et al. (2010).

Most of the productivity improvements in the agricultural sector are sourced from knowledge outside the sector.[2] Scientific and technological breakthroughs from the chemical, biological and biotechnology fields have led to better agricultural inputs such as fertilizers, pesticides and crop varieties, as well as better livestock genetics, medicines, vaccines and veterinary care for animal health. The mechanical innovations such as the steam engine and internal combustion engine, that led to significant labor savings in agriculture were adapted from technologies introduced elsewhere. Engineering achievements, such as irrigation, railroads, data infrastructure, and new digital technologies, such as the Global Positioning System (GPS), precision agriculture and technologies providing real-time access to weather information, water use and land surveillance are also transforming the industry. Even advances in the packaging, storage and manufacturing of agricultural products feed into the sector's general productivity improvements.

The increasing complexity and diversity of the agricultural sector, in addition to its global presence in every world economy, make it a useful case study in understanding how local capabilities can influence a country's technological trajectory.

This chapter traces the evolution of three AgTech innovation hubs; namely, São Paulo in Brazil, Nairobi in Kenya, and Denver, Colorado, in the United States of America (US). This provides important insights into the importance of local capabilities in shaping AgTech specializations. It also illustrates how these three hubs were able to shift from being traditional agricultural producers to leading ethanol producers (Brazil), major producers of maize varieties for Africa (Kenya), and global exporters of biotechnology crop varieties alongside other AgTechs (United States).

There are three takeaways from this chapter. First, innovation in agriculture is context-specific. This implies that for AgTech to be beneficial to different countries it must be adapted to specific agro-ecological conditions relating to the soil, landform and climatic characteristics of the growing region, as well as other cultural, political and market factors that shape regional farming systems. Second, the public sector is one of the main drivers of AgTech specialization. And third, the appropriability conditions, market opportunities and general innovative capabilities of an innovation ecosystem explains how countries can shift their AgTech innovation trajectories. The innovation ecosystem is a concept that links different innovation stakeholders loosely categorized into the private sector, government and universities, as well as research institutions, and provides a framework in which to describe how their interaction and complex relationship can give rise to new innovation.

The chapter is structured according to its key takeaways. The section that follows explains why agricultural innovation is agroecologically and regionally specific. It emphasizes how market failures resulting from its public good traits requires public sector involvement in driving agricultural sector innovation. The third section highlights the role of governments and the public sector in creating the conditions necessary to initiate and build innovative capabilities in agriculture. The penultimate section focuses on how the capabilities of a country's innovation ecosystem determine the innovation trajectory of its agricultural sector. The final section concludes by looking toward the future of agricultural technology and sets out some policy implications.

Box 3.1 Defining AgTech

For the purpose of this chapter, the term AgTech refers to technological-based solutions that address challenges in agriculture. It includes innovations that increase land productivity through higher crop yield per hectare or through irrigation, labor-saving through employing mechanization tools, cost-saving through better and more efficient use of scarce resources, for example, by using precision agriculture tools, and drought- and pest-resistant plant varieties adapted to climate change or to prevent disease. Institutional innovation, such as agricultural cooperatives or intermediaries that facilitate the coordination and knowledge-sharing platforms between government, farmers, agribusinesses and non-governmental organizations (NGOs), are not included.[3]

Preparing the ground: importance of soil and context

Innovation in agriculture is different from other sectors.

First, without government support, the incentives to innovate in the agricultural sector are not sufficiently attractive to generate enough interest from private sector primary producers, namely, farmers to invest in the activity. This is largely because of the agricultural industry's highly diffused structure wherein many small producers face narrow and uncertain profit margins. While profitability in farming depends on many factors, studies show that larger farms tend to have larger profit margins, partly due to economies of scale. However, the sector is highly skewed, with 70 percent of all farms worldwide operating on less than one hectare of land.[4]

In addition, farmers face risk and uncertainty when deciding which crops or livestock to produce. This is because they have to take decisions and make investments with only limited information and then wait for a payoff sometime in the future, if at all. Moreover, profits are tied to yields, which can be adversely affected by factors outside a farmer's control such as the weather, pests, disease, conflict and global market prices. For instance, the cost to Kenyan rose growers of choosing the "wrong" type of flowering rose to plant can be up to USD 160,000 per hectare.[5]

Second, agricultural commodities and activities tend to have the economic properties of a public good. Benefits such as ensuring food safety and security, adequate nutrition for public health, and environmental sustainability require public sector support. Recognizing such public needs early, the US Department of Agriculture (USDA) and the Land Grant agricultural research universities were established in 1862.[6]

Third, the agricultural sector needs an ongoing and consistent level of innovation. Constantly evolving pests and diseases, rising production costs from higher agricultural input prices, and extreme weather events are some of the factors that threaten industry producers. For instance, a 2023 report co-authored by the Organisation for Economic Development (OECD) and the

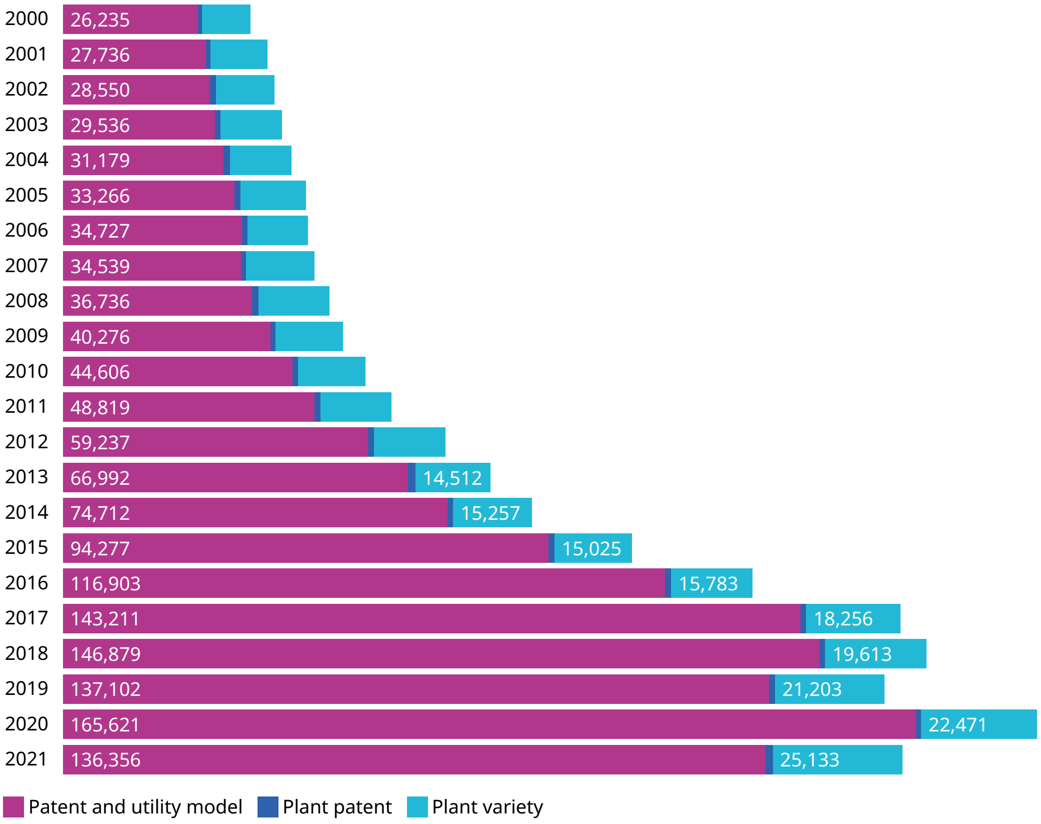
United Nation’s Food and Agriculture Organization (FAO) estimated that agricultural commodity prices would be likely to increase by 0.2 percent for every one percent increase in fertilizer prices.[7] Moreover, weather – including the frequency and severity of extreme events, such as heat waves, droughts, floods, tropical storms and wildfires – can reduce food production yields and quality.

Investments into innovation for agriculture must be long term as well. This is because it takes time for research to become commercialized and for technology to be adapted to meet multiple regions’ needs, as well as meet national guidelines before being adopted and planted in a farmer’s fields. For instance, it took at least 60 years from the introduction of hybrid corn technology before its adoption became widespread.[8]

Fourth, agricultural innovation has to be adapted to local agroecological conditions. According to the FAO, regions sharing the same agroecological zones have “similar combinations of climate and soil characteristics and similar physical potentials for agricultural production.”[9] This means that an agricultural innovation developed for the specific agroecological conditions of one region is not easily transferred and used in another region with different agroecological conditions. Instead, the innovation would have to be adapted to the specific conditions of that other region and respect its biodiversity and environmental requirements and guidelines. Some such adaptations can be seen through the steadily increasing number of plant varieties protected under the plant variety protection instrument administered by the International Union for the Protection of New Varieties of Plants (UPOV) in Figure 3.2.[10]

IP-protected agricultural innovation is booming

Figure 3.2 **Total number of applications filed under patent, utility model, and plant varieties equivalent protection systems, 2000–2021**



Note: See Technical Notes for explanation.
Source: EPO PATSTAT, UPOV Plant Variety Database and WIPO.

Figure 3.2 illustrates how innovators are increasingly coming to rely on intellectual property (IP) protection for their inventions, as seen in the total number of patents, utility models and plant varieties equivalent protection systems applied for on agricultural innovation worldwide. Box 3.2 outlines the different IP instruments that protect inventions in the agricultural sector.

Box 3.2 IP instruments protecting AgTech inventions

Innovation in the agricultural sector is wide-ranging. It includes novel farming implements, machines and digital technologies adapted to improving plants and plant varieties, farming methods, as well as irrigation.

The IP instruments that could protect these AgTech include patents, utility models, trademarks, geographical indications and trade secrets For plant varieties, the *sui generis* system also exists in many jurisdictions.

For example, in the case of crop genetic innovations made either by conventional or by genetic plant-breeding technologies the original innovation would need to be incorporated into the locally optimized germplasm and/or cultivars in the target region. This means that the genetic innovator may need to either license to germplasm or cultivars owners or otherwise collaborate with them to develop and adapt the technology to local conditions. This adaptation requirement leads to extra costs and hurdles for those innovation stakeholders who have limited budgets or restricted access to supporting institutions.[11]

AgTech evolution is hub dependent

The three AgTech hubs of Denver, Colorado (United States), São Paulo (Brazil) and Nairobi (Kenya) illustrate how AgTech evolution depends on context. Each hub has distinctive starting conditions, constraints and challenges. They also have different levels of public sector support and face different market opportunities. Moreover, each hub has nodes of innovation activities, innovators and relevant institutions that facilitate the knowledge sharing that feeds their respective innovation ecosystems. These factors, together with local innovative capabilities, determine how AgTech trajectories evolve.

The role of agriculture in Brazil, Kenya and the United States varies according to income level. In Kenya, agriculture accounts for 33 percent of the total workforce and contributes around 21 percent of the country’s gross domestic product (GDP). In Brazil, the sector employs almost 10 percent of the total workforce, and accounts for seven percent of GDP. Meanwhile, in the United States, fewer than two percent of workers are employed in the agricultural sector, which accounts for less than one percent of GDP.[12]

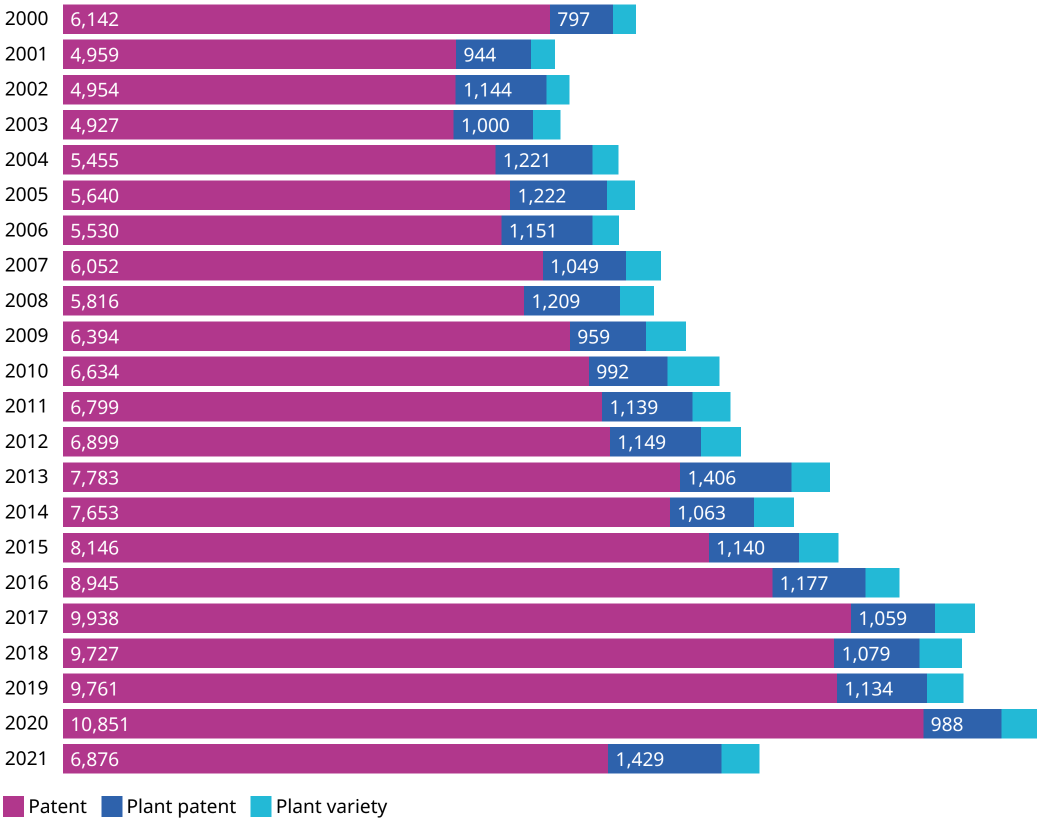
Colorado, United States: an AgTech hub because of water irrigation infrastructure

As the United States is the largest exporter of agricultural commodities worldwide, US AgTech producers enjoy global market opportunities. It is therefore not surprising that the United States has been innovating significantly in the sector and filing for patent protection on its AgTech inventions both at home and abroad.[13]

Figure 3.3 shows the total number of applications filed through patent, plant patent, and plant varieties equivalent protection systems filed for AgTech inventions in the United States.

The United States is one of the top five patent application filers in AgTech

Figure 3.3 Total number of applications filed through the patent, plant patent, and plant varieties equivalent protection systems in the United States, 2000–2021



Note: See Technical Notes for explanation.
Source: EPO PATSTAT, UPOV Plant Variety Database and WIPO.

Colorado is the second biggest agricultural innovation hub in the United States, tied with New York and second to Silicon Valley.[14] Its rise to prominence as an AgTech hub coincided with early private investments into water resource infrastructure for irrigation and transportation infrastructure, primarily railroads, in the late 19th and 20th centuries. Colorado is known for its beef cattle, dairy products and wheat. The largest city between Chicago and San Francisco, Denver, the capital of Colorado, became a major hub for the transportation and processing of agricultural commodities. It was later a key location for the establishment of federal research laboratories, in addition to several state universities. This enabled research to be undertaken into the needs of agriculture and related industries in the region and facilitated the technology transfer of innovations developed in adjacent fields.[15] Moreover, major research institutions were located within a one-hour drive of each other, fostering collaboration and knowledge exchange. In addition, there is a thriving agribusiness in the region. This includes innovators in water technology and infrastructure, soil fertility and pest control, plant genetics and new crop varieties, animal health, nutrition and health management, bioenergy, commodity processing and food manufacturing, and even natural, organic and local foods and marketing services.[16]

One of Colorado's biggest constraints is access to water. Innovations in irrigation technology in the state that began a century ago include the Parshall fume and the center-pivot irrigation system, both of which are now used worldwide. Colorado ranchers were among the first to develop the concentrated feedlot system for the more efficient fattening of beef cattle before slaughter. And Colorado became a major region for aerospace, satellite and atmospheric research, due to the regional concentration of US military facilities and federal laboratories, such as the National Oceanic and Atmospheric Administration (NOAA) and the National Center for Atmospheric Research (NCAR), which model and predict weather for agriculture and develop applications, such as remote sensing.

The farming industry is one of the biggest consumers of water resources in the state. Technological advances in improving irrigation, developing plant varieties to withstand weather conditions, such as lack of water, and those that optimize water use are readily adopted in Colorado. For example, Colorado experienced a severe drought in 2012. This adversely affected its farming outputs. So when a genetically-engineered (GE), drought-tolerant corn variety was introduced in 2012 and made available in 2013 Colorado was one of the states that adopted it. By 2016, 20 percent of corn planted in Colorado was of the GE corn variety.[17]

Innovators have also emerged in the processing of agricultural commodities, with some of the region's agribusinesses becoming global leaders in food and beverage manufacturing.[18] These corporate leaders have more recently been followed by a sort of counter revolution led by consumer-driven food and beverage companies focused on quality, health and environmental attributes.

Colorado's robust innovation ecosystem is what enables it to be a technology-frontier AgTech hub. The interface between agricultural production, commodity processing and food manufacturing close to urban and high-tech consumers, and increasingly sophisticated retail markets has created a unique set of challenges, tensions and opportunities for this hub.

Colorado's climate and access to new talent brings many agribusinesses and seed companies to the region. A number of global agricultural and food companies have set up headquarters for their US operations in Colorado, including Nutrien, the world's largest potash producer from Canada; JBS, the world's largest meatpacker from Brazil; and Danone, one of the world's largest dairy manufacturers from France.

São Paulo, Brazil: becoming a leader in ethanol production

São Paulo's status as an AgTech hub is due to the region's agribusiness growth and its sugarcane and ethanol production, as well as its range of specialty crops such as coffee and citrus fruits. Its biome is classified as Atlantic Forest, making it a fertile ground for growing coffee and sugarcane.

Since the introduction of Brazil's National Alcohol Program (Programa Proálcool), in 1975, São Paulo has evolved from a mainly coffee and sugarcane-producing agricultural state to become a world leader in ethanol production. Some of the ethanol produced is categorized as a biofuel and used as a renewable energy source. One of the catalysts for Brazil's quick shift to sugarcane production was due to the severe frost of coffee crops, known as the Black Frost (*Geada Negra*), in Paraná and São Paulo states in 1975.[19] This frost wiped out almost all of coffee crops on plantations from the region.

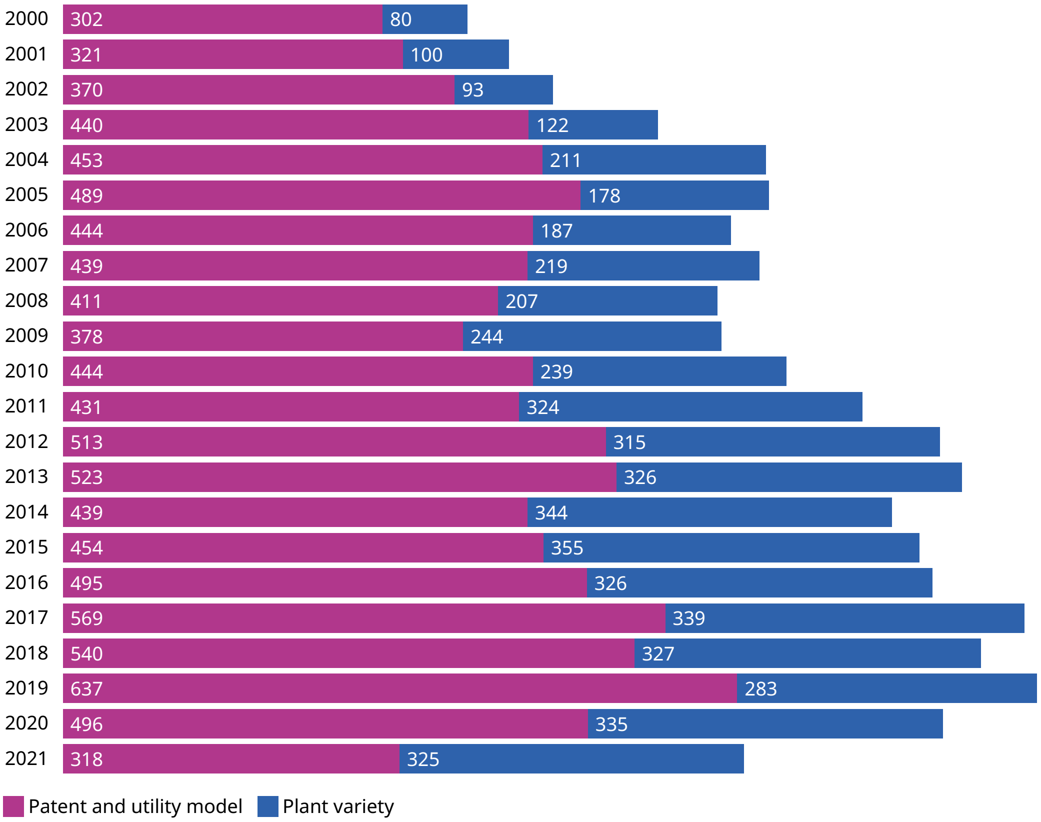
As Brazil is one of the world's largest and most competitive ethanol producers, its exporters cater to the global market demand for biofuel. In fact, producing sugarcane ethanol costs 50 to 60 percent less than producing corn ethanol.[20] And sugarcane produces more ethanol per hectare than corn. Brazilian biofuels produced from ethanol are far superior to those produced by the United States from maize or sugar beet.[21]

A recent increase in environmental awareness, especially in the European Union market, has prompted industry leaders to shift ethanol production toward second-generation (2G) ethanol production. One of the biggest drivers of this is the European consumer's willingness to pay premium prices for 2G ethanol. In addition, environmental awareness has prompted industry leaders to become more willing to adopt precision agriculture in order to optimize the use of natural resources.

Figure 3.4 shows how Brazilian innovators are steadily relying on patent and utility model protections for their agricultural inventions. In addition, their use of plant varieties protection system to protect their AgTech innovation is equally practiced.

Brazil has steadily been coming to rely on IP instruments to protect its AgTech innovation

Figure 3.4 Total number of applications filed through the patent, utility model and plant varieties' protection systems, 2000–2021



Note: See Technical Notes for explanation.
Source: EPO PATSTAT, UPOV Plant Variety Database and WIPO.

Strong agricultural research centers investing in agricultural innovation and the growing strength of the private sector are two of the factors that have contributed to the sector's development. São Paulo state is home to the largest number of agricultural research institutions in Brazil, some of which are the most prolific in publishing agricultural research.[22]

Two of the biggest challenges and constraints that Brazilian ethanol producers face is the lack of proper road infrastructure and government intervention in setting national prices for fossil fuels.[23] Regarding the latter, because domestic demand for ethanol depends upon the oil price, a low oil price reduces demand for ethanol. This in turn adversely affects producers' returns, making it riskier for producers to invest in new ventures.

At the same time, São Paulo hosts the headquarters of some of the world's largest agribusinesses. And this has given rise to a thriving agricultural start-up scene within the region. Indeed, São Paulo is known as the largest innovation and entrepreneurship center in Latin America. Moreover, it has a relatively mature financial and banking system, which provides much needed capital to start-ups.[24]

Nairobi, Kenya: innovation built on plant breeding and in collaboration with an international AgTech network

Agricultural production in Kenya is diversified, with the main products for domestic consumption being maize, wheat, rice and beans and the main products for export being tea, coffee, sugar and horticultural crops such as cut flowers, fruits and vegetables.

Its fair weather conditions, soil fertility and adequate sun exposure, and proximity to Europe have all made it the largest producer of flowers in Africa. Kenyan floriculture exports grew by 300 percent between 1995 and 2003 in spite of stagnation within the rest of the economy.[25]

Kenya has a long history of plant breeding and has built its innovative capability in this field. In 2013, four of Kenya's agricultural research institutes were merged into the Kenya Agricultural and Livestock Research Organization (KALRO). The four institutes in question were the former Kenya Agricultural Research Institute (KARI), the Coffee Research Foundation (CRF), the Tea Research Foundation of Kenya (TRFK) and the Kenya Sugar Research Foundation (KESREF). The Government's public support programs, investments into R&D and infrastructure, and its collaboration with regional and international agriculture research centers together work toward fostering innovation tailored to local needs.

A survey undertaken by the FAO in 2007 showed how Kenya possessed some capabilities in developing conventional and transgenic plant varieties.[26] In fact, it is one of the few African countries to have a research agenda in biotechnology. However, it has still to develop sufficient capacity to provide technological solutions to its agricultural problems.[27]

Instead, Kenya has been able to take advantage of the developments in the Africa region to develop its AgTech synergies. In building its capabilities as a plant varieties producer, KALRO collaborated with the world's primary international agricultural innovation network, known as the Consultative Group on International Agricultural Research (CGIAR) research centers to create the plant varieties that it needs.

One example of this regional synergy is when Kenya's maize crop was devastated by the maize lethal necrosis (MLN) disease. The disease led Kenyan farmers to lose between 30 and 100 percent of maize crop production in 2011. This disease was equally disastrous for other maize producers in the Africa region. In response, CGIAR's International Maize and Wheat Improvement Center (CIMMYT -*Centro Internacional de Mejoramiento de Maíz y Trigo*) research center was able to derive four MLN-tolerant hybrid varieties. It distributed these varieties among private and public sector partners in East Africa to be released. In 2012, CIMMYT collaborated with the Kenyan KALRO, national plant protection organizations and commercial seed companies in stopping the spread of the disease across sub-Saharan Africa. Other collaborators included the International Institute of Tropical Agriculture (IITA), the Alliance for a Green Revolution in Africa (AGRA) and the African Agricultural Technology Foundation (AATF), and advanced research institutions in the United States and Europe. After national performance trials in Kenya, several hybrids of the second-generation variety were released over the course of a five-year period from 2013 onwards.

In addition, funding from these non-profit organizations helped to train, diffuse and share the benefits of new plant varieties to its farmers.

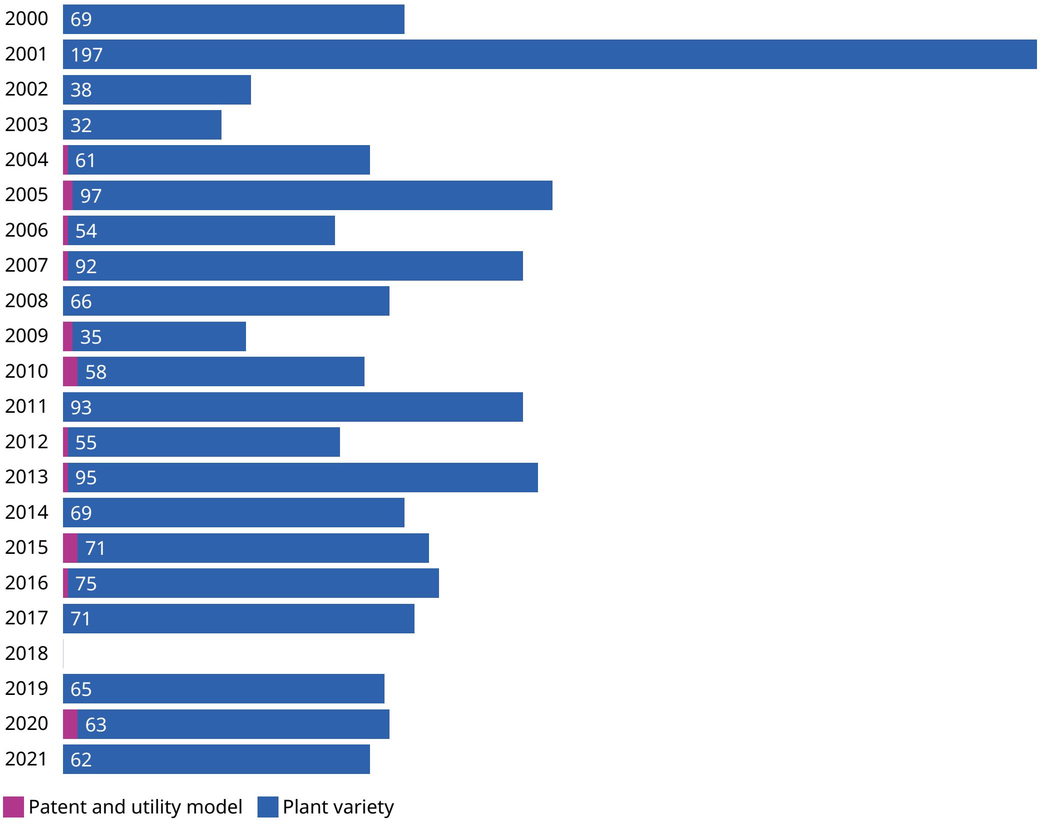
Kenya's collaboration with CGIAR explains how this AgTech hub has been able to build its local capabilities as a plant varieties breeder for the African region. First, its capital, Nairobi, hosts two research center campuses. One of the research centers is the Center for International Forestry Research and World Agroforestry (CIFOR-ICRAF) and the other is the International Livestock Research Institute (ILRI). Second, Nairobi's central location makes it a natural trade and distribution hub for agricultural products for the country, as well as the continent.

Third, the challenges and constraints that this AgTech hub faces can be overcome through its collaboration with CGIAR research centers. The challenges that Kenya faces include limited access to irrigation, the high cost of agricultural inputs, including seeds and fertilizers, and limited access to financing. About 83 percent of Kenyan land is arid or semiarid and unsuitable for rain-fed farming or intensive livestock production. Only seven percent of the land is irrigated.[28]

International public institutions like CGIAR, backed by NGOs such as the AATF, help Kenyan plant breeders to breed abiotic stress- and drought-resistant crops. For example, maize is a major food crop in the country. It accounts for 40 percent of the crop area and a majority of the staples grown. However, maize yields are low. To overcome this problem, KALRO collaborated with CIMMYT to develop, test and then convince Kenyan farmers to farm a drought-tolerant maize variety.[29]

Kenyan innovators rely more on plant varieties protection than patent or utility models for their AgTech innovation

Figure 3.5 Total number of applications filed through the patent, utility models, and plant varieties protection systems, 2000–2021



Note: See Technical Notes for explanation.
Source: EPO PATSTAT, UPOV Plant Variety Database and WIPO.

However, Kenyan AgTech innovators do not rely on IP protection to the same extent as those in the United States and Brazil.

Figure 3.5 shows that Kenyan innovators have only applied for a few patents and utility models over the last few years. This is partly owing to CGIAR's reluctance to allow innovators to file for patent protection on innovation it has co-developed. However, this stance is slowly changing. Separately, the Kenyan innovators' reliance on plant varieties equivalent protection has been relatively consistent since Kenya signed the UPOV Convention back in 2000.

Sowing the seeds: how public support propels AgTech development

The market failure argument based on the public goods characteristics of agricultural innovation explains why the public sector is still the largest contributor to agricultural R&D worldwide.

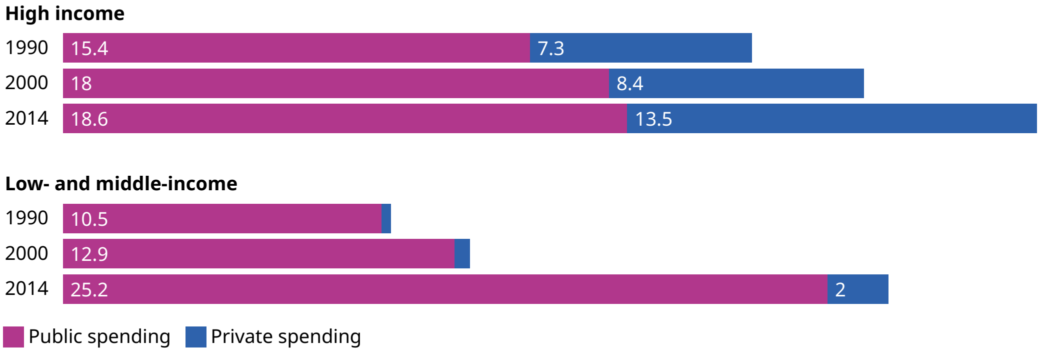
Governments that invest heavily in agriculture see stronger economic growth, declining poverty rates and better nutritional status.[30] A study conducted by the USDA found that between 1900 and 2011, every dollar spent on public agricultural R&D generated USD 20 for the United States economy.[31]

According to the International Food Policy Research Institute's Agricultural Science and Technology Indicator (ASTI) Global Report (2020) report, global R&D spending on AgTech totaled nearly USD 47 billion in 2016.[32] This number excludes private sector for-profit expenditure. The public sector in high-income countries accounted for 40 percent of global spending. Since 2011, however, the share of agricultural R&D undertaken by the public sector in high-income countries has either declined or stagnated. In its place, the private sector is spending more on agricultural R&D. In most low and middle-income countries (except Brazil and China), the public sector still funds the vast majority, if not almost all, of agricultural R&D.[33]

Figure 3.6 provides a snapshot of the public versus private sector share of spending on R&D across different income levels in 1990, 2000 and 2014.

The public sector accounts for the majority of R&D spending worldwide

Figure 3.6 **Agricultural R&D spending (in billions 2011 PPP) by the public and private by country income-levels, 1990, 2000 and 2004**



Notes: R&D spending is in billion 2011 PPP dollars. Public spending includes spending by governments, higher education institutions, and non-profit organizations. Private spending includes for-profit firms.
Source: Fuglie (2016).

There are three main ways government support is vital to building local innovative capabilities in agriculture. First, governments fund or conduct the research and help disseminate the findings through education, extension, training collaboration with and technology transfer to the private sector. Second, governments create the enabling conditions that provide incentives and support to innovative activities undertaken by the private sector. And third, governments can set policies or mission-oriented targets to boost innovative capabilities in agriculture.

Conducting AgTech research

Across all three regions profiled in this chapter, governments have been vital in funding and conducting agricultural research, including research that may not have an immediate payoff.

Colorado's rise as an agricultural innovation hub was rooted in the United States Government's investments into agriculture that began in the 19th century with the establishment of agricultural state universities and agricultural experiment stations. The Government provided reliable research funds to those universities, together with each of the state governments, such as Colorado, and also established federal agricultural research institutions, carrying out its own research through the USDA.[34] For example, the United States Government funded much of the basic research extending applications of molecular biotechnology into agriculture.[35] Most of the research results generated by government-funded universities and USDA research labs were transferred to the private sector in the early years through publication of results or through extension services, and more recently through collaborations and partnerships with private sector companies, through licensing of technologies or through the creation of technology start-ups.

In Brazil, the Government is the largest source of agricultural innovation funding. Its national agricultural research institution and research arm of the Brazilian Ministry of Agriculture, the Brazilian Agricultural Research Corporation (EMBRAPA –*Empresa Brasiliera de Pesquisa Agropecuária*), carries out research into the country's vast and diverse biomes. EMBRAPA consists of multiple research centers across Brazil focused on the agricultural needs of each region.[36] This research institution has developed over 9,000 technologies and over 350 cultivars. Most of these have been transferred directly to Brazilian farmers.[37]

Universities and government-sponsored research institutions were crucial to São Paulo's agricultural productivity gains. They contributed to São Paulo's rise as an agricultural innovation hub, initially for sugar and ethanol production. Two of the first research institutions to receive sugar and ethanol production funding were the University of Agronomy in Campinas (IAC – Instituto Agronômico de Campinas) and the São Paulo State Research Foundation (FAPESP – Fundação de Amparo à Pesquisa do Estado de São Paulo). The Government also established the National Sugarcane Improvement Program (PLANALSUCAR – Programa Nacional de Melhoramento da Cana-de-Açúcar), a government program to develop sugarcane varieties and improve crop yields.

It also led the work on seed development, while the Interuniversity Network for the Development of the Sugar-Energy Sector (RIDESA – Rede Interuniversitária para o Desenvolvimento do Setor Sucroenergético) developed various sugarcane crop varieties to fit Brazil's needs.[38]

Finally, EMBRAPA invested heavily in educating and training its workforce in order to build up the country's innovative capabilities. Between 1974 and 1982, EMBRAPA allocated approximately 20 percent of its budget to education.[39]

Kenya's agriculture research center, KALRO, aims to generate and disseminate food crop knowledge, innovative technologies and services. Despite the country's long experience with plant breeding, it still required collaboration with CGIAR research centers, backed by funding, for instance from AATF and the Bill & Melinda Gates Foundation, for the country to build its innovative capabilities.

One of those CGIAR research centers is CIMMYT referred to earlier. CIMMYT has access to a global innovation network of agricultural researchers worldwide. It also maintains a connection to private seed companies by working on the development of abiotic stress hybrids in 17 countries over nine years.[40]

Governments also play a key role in coordinating, collecting and disseminating valuable information about agricultural innovation. In Kenya, for instance, KALRO and CIMMYT trained the agribusiness actors along the value chain as part of convincing Kenyan farmers to farm drought-tolerant maize varieties. They were able to reach over one million farmers in Africa, partnered with 28 seed companies (four Kenyan) and established nearly 550 field demonstrations in Kenya. This effort led to 4,500MT of climate-smart varieties of maize being sold, and seed packs distributed to 10,000 Kenyan farmers.

Enabling innovation

Private investments into agricultural innovations are influenced by government policies and market demand, both in the producing country and those countries that might potentially import the commodities in question. Policies, in addition to the market's own price-based decisions, can affect the allocation of resources. Like farmers, the private sector decides which crop to plant and what technologies to adopt today, based on projected future prices of agricultural commodities.

Thus, governments must try to create incentives that align the private sector's interests with their own in order to induce changes or the adoption of new technologies. There are multiple policy levers by which governments can achieve this including:

- IP protection to create an important precondition for the private sector to begin investing in agricultural innovation. In the United States, IP protection was one of the factors that incentivized the private sector to invest in innovation in agriculture. The other was when the Government enacted the Bayh-Dole Act allowing universities to take title to IP over technologies developed using federal funding.
- Providing access to credit to facilitate adaption and adoption of new AgTech since it can be expensive for farmers. Brazil established the National System of Rural Credit providing finance to commercial agriculture to promote the use of new technologies, such as fertilizers, pesticides and agricultural machinery.[41]
- Investments in infrastructure such as road, rail and port transportations can significantly reduce the cost of moving agricultural commodities from the farm to the market, as well as facilitate the growth of the sector. One study examining Brazil's so-called "Cerrado Miracle" found that a one percent increase in paved roads led to an increase in crop production by slightly over one percent and livestock production by 1.11 percent.[42]

Implementing targeted agricultural policies

As mentioned above, the United States agricultural mission implemented in the 19th century set the stage for building its innovative capabilities in the sector. Targeted policies were intended to promote research into solutions to agricultural challenges in the region and to train researchers and farmers on how to use AgTech. Today most of the innovation in agriculture in the United States is undertaken by the private sector.[43]

São Paulo's relatively fast building of local capabilities in sugarcane production and ethanol biorefining was supported by the public spending. The country's National Alcohol Program (*Programa Proálcool*) provided financial incentives to encourage companies to produce ethanol for fuel, and subsidized the price of ethanol fuel and reduced taxes for those consumers who purchased ethanol for their cars.[44] The program boosted the country's sugar production by 20-fold over the course of 16 years.[45] It also built Brazil's capacity in producing flexible-fuel vehicles able to run on either gasoline or ethanol.[46] By 2017, nearly nine out of 10 vehicles sold in Brazil were flexible-fuel cars.[47]

Kenyan AgTech specialization in plant breeding is likely to expand after the Government lifted its ban on importing genetically-modified foods in 2015. This ban was in place partly because many of the richer economies that buy Kenyan exports ban the importation of transgenic crops. The Government has also allowed research into genetically-modified and engineered crops. In addition, the Kenya Government has enacted several agricultural-specific laws aimed at further transforming the country's agricultural sector.[48]

At the same time, non-agricultural government policies in both agriculture-producing as well as agriculture-importing countries influence agricultural innovation both at home and on the global market. Standards and policies that relate to sanitary and phytosanitary measures and sustainability initiatives (including biofuels and food safety) play a significant role in the types of agricultural innovation that are adopted in farmlands.[49]

Bearing fruits: when appropriability conditions, local capabilities and market opportunities drive the path

Although governments may be the biggest supporters of AgTech development, they are not necessarily the main commercial users or producers of AgTech. This is where the private sector has a role to play in identifying and exploiting market opportunities in the agricultural sector. Market opportunities are what drive the private sector's investments and commercialization efforts into AgTech development. However, its ability to do so varies according to the specific conditions and constraints faced by each hub. It also depends on the co-existing and related capabilities available locally.

First, local appropriability conditions have to provide sufficient incentives for the private sector to innovate in agriculture. In the United States, together, the Bayh-Dole Act and various IP protection instruments have encouraged private companies to accept the risk involved in adopting and commercializing new technological innovations. This was how start-ups and large seed companies collaborated with public research institutions and universities to commercialize transgenic crops.

Second, the presence of strong agriculture research centers, thriving farming communities and entrepreneurial businesses operating alongside enabling institutions and infrastructures contribute to a robust local innovative capability. The co-location of such innovative activities as these in AgTech hubs leads to knowledge and know-how spillovers in the sector, either from other value segments along the agricultural value chain or in a related or adjacent field.

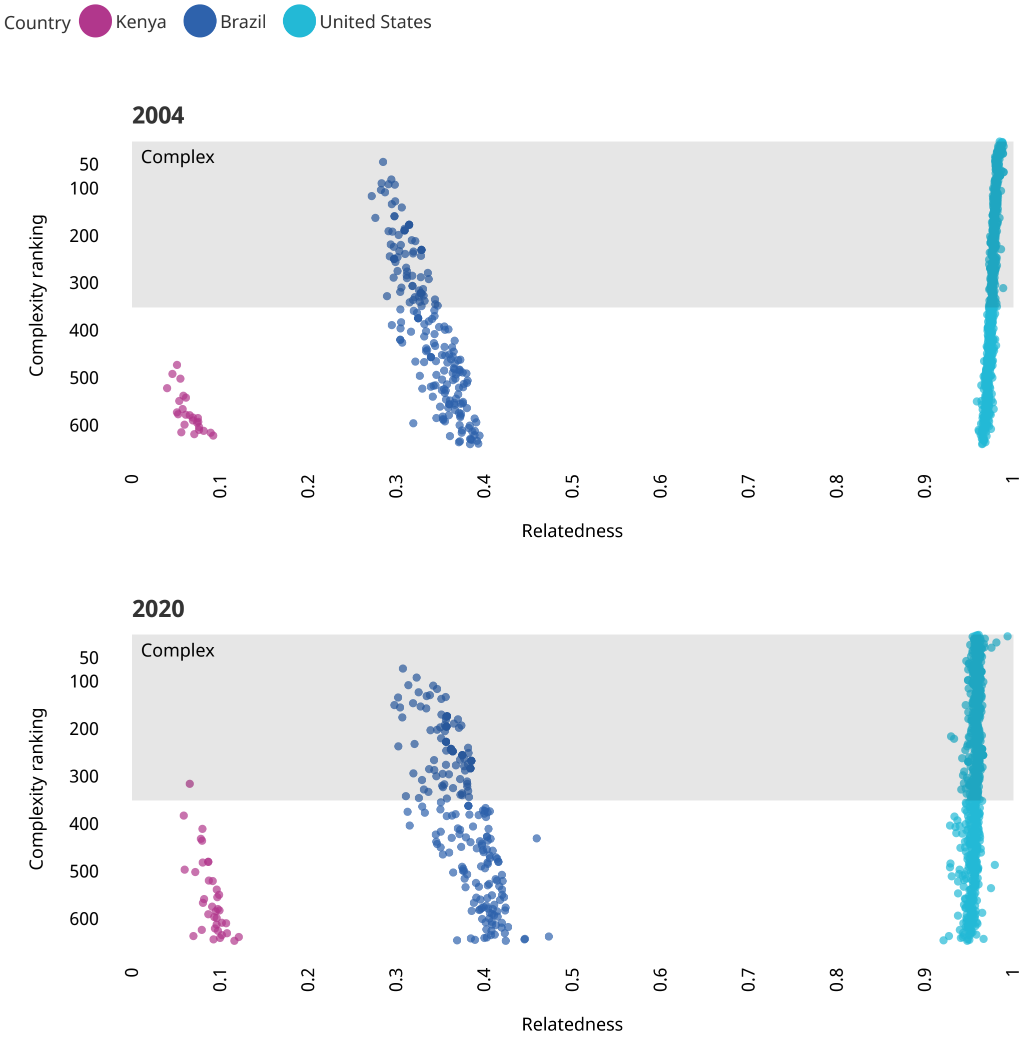
Third, the ability of the local innovation ecosystem to exploit local capabilities in response to market opportunities is dependent on many factors. The main one is the diversity, complexity, relatedness and rarity of its local capabilities.

As explained in Chapter 2 of this report, countries with greater opportunities to shift their technological path tend to have highly complex innovation ecosystems. This can be seen across all three AgTech hubs under discussion.

Figure 3.7 compares the different innovation capabilities of these three AgTech hubs for the years 2004 and 2020. This is measured using the three capability dimensions introduced in Chapter 2, namely, trade, scientific publications, and patent applications. The figure illustrates how the United States leads through having the highest level of capabilities in highly complex fields, followed by Brazil and Kenya. Kenya and Brazil have both built on their innovative capabilities and because of this display some level of complex capabilities.

The United States displays the highest level of capabilities among the three AgTech hubs

Figure 3.7 Innovation capabilities of Kenya, Brazil and the United States, 2004 and 2020



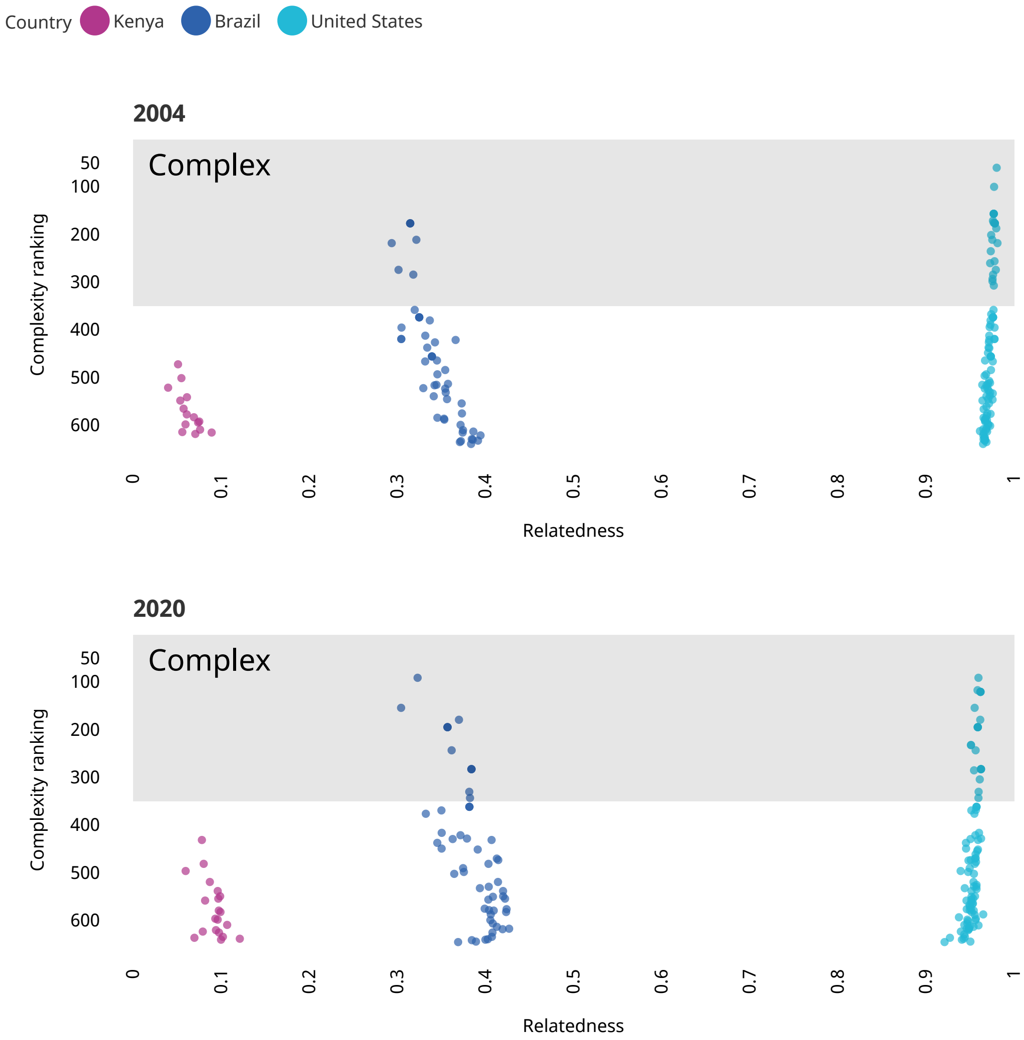
Note: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and export data.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

These general levels of innovation capabilities are similarly mirrored in the AgTech specialization of each hub.

Figure 3.8 maps the AgTech-related capabilities and shows how the distribution differs between simple to complex capabilities. Kenya has most of its AgTech capabilities within the simple range, implying that the capabilities it has managed to acquire are also present in other countries. Between 2004 and 2020, Brazil was able to build more complex capabilities in AgTech. The United States has the most complex capabilities, even in AgTech-specific fields.

The United States innovation capabilities in AgTech are at the frontier

Figure 3.8 **Innovation capabilities in the AgTech sector for Kenya, Brazil and the United States 2004 and 2020**



Note: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and export data.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

Colorado is an AgTech frontier producer

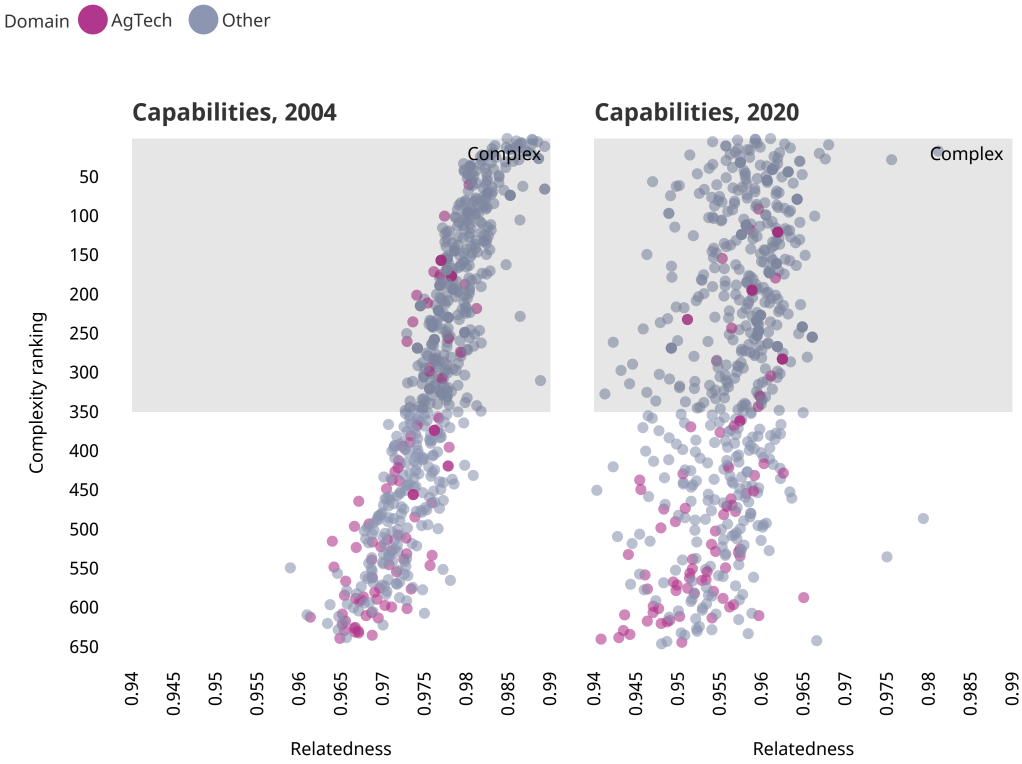
The United States economy is at the frontier of innovation, both generally and in respect to AgTech specialization.

Figure 3.9 compares that economy's capabilities across the scientific, technological and production dimensions between 2004 and 2020 and shows how specialized fields are related and concentrated together. The United States has the know-how necessary to develop rare and sophisticated technologies, which helps to explain why that country is the largest agricultural exporter in the world.

Consider the Colorado AgTech hub. Colorado is per capita the largest research performer under USDA funding in the United States. In 2011, it received the third highest total of USDA funding, trailing just California and Texas. The region is home to several USDA branch laboratories. Universities in Colorado have major programs in biosciences, water resources, agricultural science and food science, making the state one of the regional leaders in agricultural and food knowledge. According to a recent inventory, Colorado is also home to 550 agricultural innovators of which 460 are private sector (corporate and start-up) companies and 90 are public (federal, state and local) organizations.[50]

The United States has a model innovation ecosystem with highly complex innovation capabilities

Figure 3.9 Innovation capabilities of AgTech and other sectors in the United States, 2004 and 2020



Note: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and export data. Strengths = specialized capabilities; opportunities = not specialized capabilities.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

As a biotechnology hub, the United States was able to build its local capabilities based on the interactions between its strong public research center and institutions, on the one hand, and incentivized private sector, on the other. Appropriability conditions, such as through IP protection, have also helped facilitate the private sector's investments into agricultural R&D.

Two factors facilitated the commercialization of agricultural biotechnology from the 1980s onwards. The first of these was the granting of patents on genetically-engineered plants. The second was the passing of the Bayh-Dole legislation allowing for the filing of patent protection on publicly-funded research. Soon, start-ups from research labs were applying biotechnology to the agriculture field. Then, seed, chemical, fertilizer and pesticide companies started adopting the technology.

São Paulo is capitalizing on its capabilities and premium prices to transition toward producing sustainable ethanol

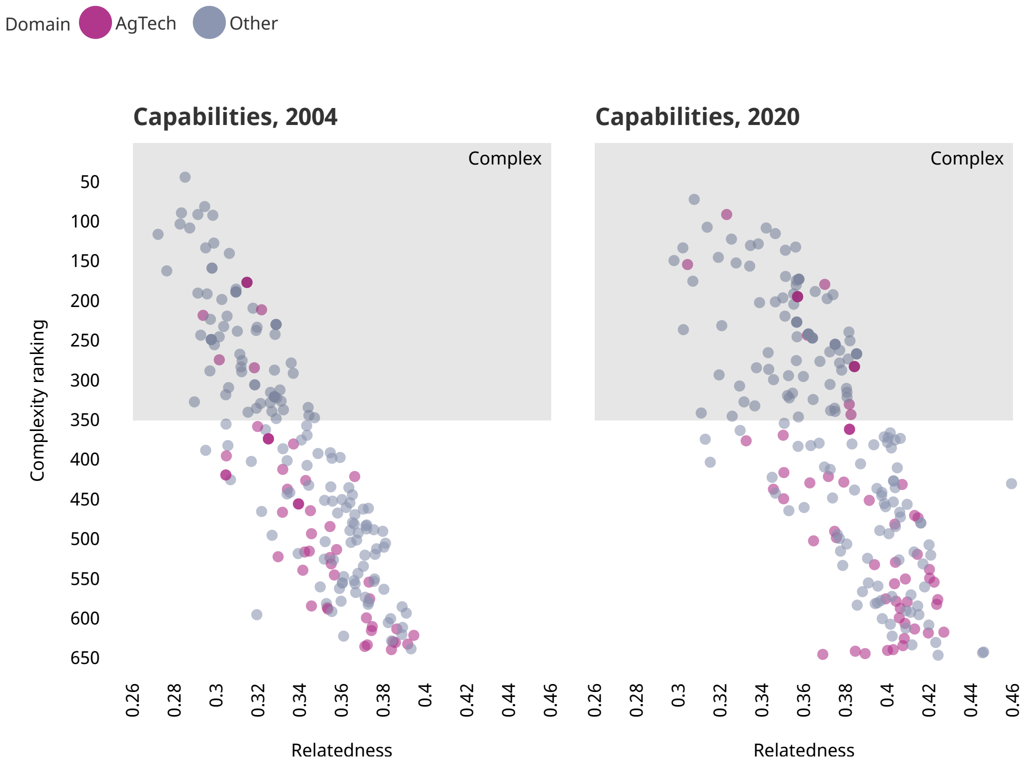
Brazil has been able to build its AgTech hub from being a net importer of agricultural commodities into a world-class ethanol producer. It did this through strong government support and the entry of the private sector into the industry when it started maturing. This evolution can be seen in Figure 3.10 showing how Brazil built its innovation capabilities from 2004 to 2020.

The Brazilian Government initially implemented the National Alcohol Program to reduce its dependency on oil as an energy source. Through various schemes designed to influence the demand and supply of ethanol, the Government managed to increase sugarcane production in Brazil. The Government even imported the technology in order to produce vehicles that run on ethanol from the American Ford company.

A sharp oil price drop made the program difficult to sustain. However, the invention of flexible-fuel vehicles in 2003 encouraged the use of ethanol for powering motor vehicles once again. Consumers could fill their tanks with either ethanol or oil, depending on which was cheaper. By 2010, flexible-fuel vehicles accounted for 86 percent of light vehicles in Brazil.[51]

Local capabilities in Brazil are progressing toward the frontier

Figure 3.10 Innovation capabilities of AgTech and other sectors in Brazil, 2004 and 2020



Note: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and export data. Strengths = specialized capabilities; opportunities = not specialized capabilities.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

Around the same time, there was renewed interest by the Government in producing ethanol. This was because the price of oil was rising and the use of renewable energy sources slowly gaining acceptance. At this point, a few local companies were producing ethanol using 1G technology.

The shift toward adopting 2G technology was prompted by interest from the European market, where less polluting ethanol commands a premium price. The 2G ethanol technology is new to Brazil. The 2G ethanol technology uses existing 1G ethanol technology and the waste it generated to produce ethanol, thereby reducing waste and helping address climate change concerns.[52]

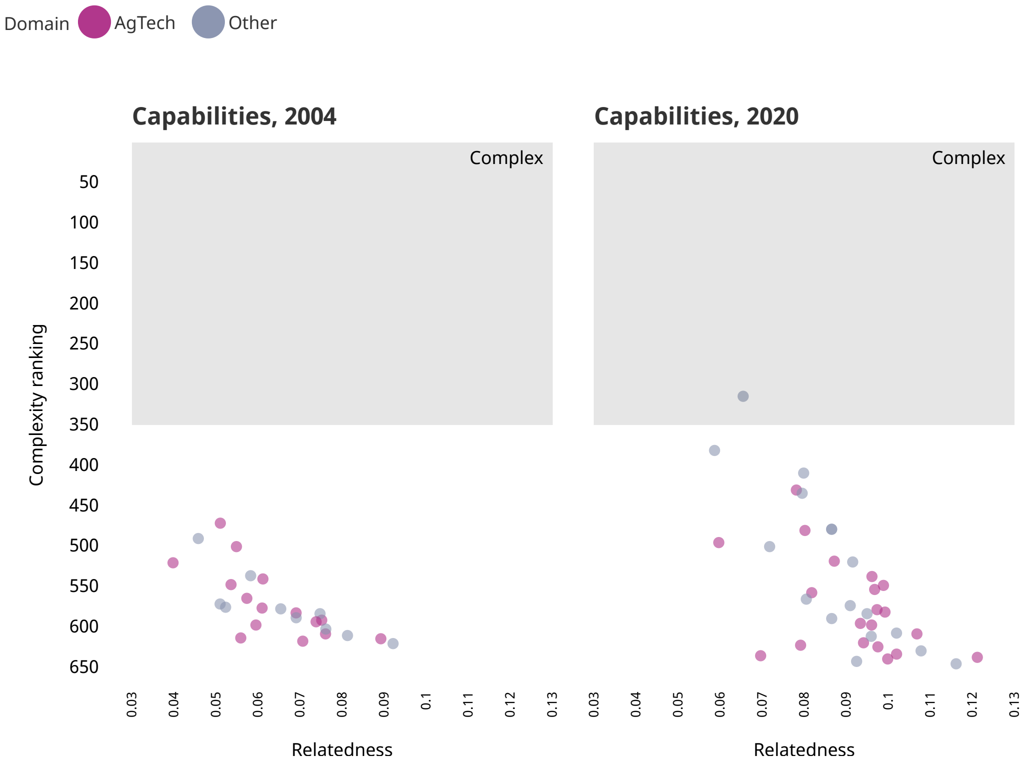
Large-scale bioethanol production using 2G ethanol technology is risky, even with government support. Only two of the six large-scale bioethanol plants established worldwide in 2000 remain in production. They are both in Brazil.[53]

Nairobi is building on its agricultural research centers and disruptive mobile banking platform

Kenya's local innovative capabilities are less diverse, related or rarer than those of the other two AgTech hubs. Figure 3.11 shows how most of Kenyan capabilities lie mostly in the simple capabilities. However, the latest data show that it has managed to shift its set of capabilities upwards and gained one complex capability, namely in immunology which could in the future be applied to maintaining the health of livestock animals for example.

Kenya is incrementally building its complex capabilities

Figure 3.11 Innovation capabilities of AgTech and other sectors in Kenya, 2004 and 2020



Note: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and export data. Strengths = specialized capabilities; opportunities = not specialized capabilities.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

A related development in the Nairobi AgTech hub is slowly benefiting the Kenyan agriculture value chain – the disruptive mobile banking platform M-PESA. Backed by the Communication Authority of Kenya, M-PESA was rapidly adopted across Kenya. It was made available to customers with little to no access to financial institutions, many of whom live in remote areas, have a low level of education and face financial security challenges. The M-PESA platform leverages mobile phone technology and enables secure electronic cash transfer through the short messaging services (SMS) available on almost all SIM-card mobile phones. Since mobile phones were already ubiquitous in Kenya, because of the relatively poor telecom infrastructure, the technology was easy for people to adopt and adapt.

M-PESA is disrupting the agricultural value chain. It provides access to finance and credit for agricultural producers and generates significant benefits.[54] It has also opened the floodgates for new start-up AgTech entrants to build on the M-PESA platform. The unique identification provided by a SIM card allows for a reliable identification system and has unleashed exchanges of products and services in the AgTech sector. For example, Hello Tractor is a new AgTech start-up that rents tractors to farmers who need them.

The next frontier: Adapting a new wave of digital technologies

One of the big challenges in the agriculture sector is how to continue to expand production while becoming much more sustainable. As climate change leads to extreme weather conditions that threaten livelihoods, there is a consensus that the world needs its food supply to be more sustainable.

Climate change poses an important and pressing issue impacting efforts to expand agricultural production globally. Paradoxically, innovation activities that have improved agricultural productivity, in respect to crops and livestock, also contribute to soil degradation, water pollution and greenhouse gas (GHG) emissions.[55] These in turn affect future opportunities for agricultural development. Moreover, external climate-related factors affecting the agricultural sector have the potential to cascade into higher global food prices and reduce food security for the poor.[56]

One of the ways to overcome waste and emissions from agricultural is to adopt precision technologies. Precision agriculture is a field of AgTech focused on using digital technologies that collect large data to optimize farming conditions and processes.

There is a large presence of startups specializing in precision technologies across the three agricultural hubs discussed. Colorado's innovation ecosystem consists of a broad range of public sector research institutions, corporations and vibrant start-up communities. Some of these new start-ups are focused on leveraging the latest wave of digital technologies and adapting them to the agricultural sector. São Paulo hosts headquarters for some of the world's largest agribusinesses and has given rise to a thriving scene of agricultural start-ups in the region. Indeed, it is known as the largest innovation and entrepreneurship center in Latin America. Moreover, it has a relatively mature financial and banking system, which provides much-needed capital to startups.[57]

Meanwhile, Nairobi is known as the "Silicon Savannah" because of its technologically-inclined ecosystem.[58] Kenyan start-ups are helping their farmers to overcome the overcoming the constraints and challenges of engaging in agriculture. These start-ups are using the innovative mobile banking M-PESA platform, to help Kenyan farmers access credit, rent tractors and even monitor real-time crop price changes.[59] This success has led to a subsequent proliferation of other fintech start-ups in the region. Related to this, Nairobi is emerging as a top region for agricultural technology start-ups in Africa, including innovators in agricultural fintech, digital supply chain management and agribusiness business-to-business (B2B) marketplaces specialized in the needs and conditions of African farming and business.[60]

These three hubs are thus well equipped to adapt digital-based agricultural technologies and once again shift their AgTech specialization trajectories.

Conclusion

Agriculture is key to addressing our pressing need for food security, nutrition and sustainability. It also plays an important role in sustainable growth and development.

Raising agricultural productivity can have a positive impact on the welfare of millions of people currently living in poverty. Several studies show how growth in agriculture can improve income levels, which leads to better health, nutrition and access to education. Among findings are estimated gains of USD 25 billion across Bangladesh, Indonesia and the Philippines from the adoption of modern rice varieties and USD 140 million to those Ethiopian farmers who adopted an improved variety of maize. Most of these gains went to individuals living below the poverty line.[61]

It is therefore not surprising that agriculture plays a pivotal role in achieving several United Nation's Sustainable Development Goals (SDGs), 15 of the 17 SDGs can be improved by growth in the agriculture sector.[62]

The evolution of the three AgTech hubs discussed, namely, Denver, Colorado (United States), São Paulo (Brazil) and Nairobi (Kenya), illustrates how they were able to build on local and related capabilities, so as to specialize in the different AgTech fields. Each hub has shown progress in building technological capabilities and know-how over time. The most advanced hub, Denver, has been able to capitalize on available related technologies to become a global leader in the agricultural sector and show several specializations across many AgTech fields.

There are three important takeaways from these hubs:

- AgTech innovation is context-specific, and dependent on the agroecological conditions of a region. The AgTech trajectories of Denver, Colorado (United States), São Paulo (Brazil) and Nairobi (Kenya) were facilitated and hampered not only by the climate of the regions concerned, but also by the infrastructure available. Technological advances in irrigation are one of the main reasons Denver has been able to become an AgTech hub. São Paulo's road infrastructure gave it an advantage over other parts of Brazil when it came to establishing itself as the country's sugar production hub. While Nairobi's central location in Africa, as well as it being home to two CGIAR research centers, has helped make it an innovation node for the entire continent.

- The public sector plays an important role in investing into agricultural innovation at the initial stage. In the United States, Brazil and Kenya, the public sector proved instrumental in helping build the initial capacities necessary to innovate in agricultural activities.
- Once a certain critical level of innovative capacity is established, and the appropriability conditions are sufficient, private enterprises can play a more prominent role in investing into agricultural innovation. This can be seen in the AgTech hubs of Denver and São Paulo. In Nairobi, the mobile banking platform M-PESA has given rise to digital start-ups applying digital technologies to agriculture. These start-ups are providing services that have the potential to overcome some of the challenges Kenyan farmers face, and help improve productivity.

One of the biggest challenges in agriculture is how to feed the nearly 10 billion people projected globally by 2050, which is nearly two billion people more than are alive today.[63] This implies a further need to increase agricultural yield, given limited and increasingly scarce natural resources. Moreover, uncertainties due to on-going conflicts, climate change and potential pandemics, will have to be taken into consideration in ensuring food security for all.[64]

Policy implications

There are three general policy implications that can help pave the way to ensuring that innovation in agriculture continues to sustain and feed the needs of the global populations:

First, investments in agricultural innovation should be continuous, consistent and for the long-term. While the pay-offs may take a while to be realized, the reward is beneficial to all.

Second, the new wave of digital technologies can help address the need for a sustainable growth in the agriculture sector. Governments may be interested in building the necessary enabling infrastructures to facilitate the adoption of these technologies and invest in infrastructure that facilitate the agriculture value chain.

Third, governments can pursue policies that promote investments from the private sector into the agricultural industry. These include having sufficient appropriability conditions that would enable the private sector to profit from investing in agricultural innovation, and a start-up friendly economy may create the conditions for them to pursue market opportunities to develop the sector.

Notes

1 This chapter is based on Hamdan-Livramento, I., G.D. Graff and A. Daly (2024). Innovation Complexity in AgTech: The Case of Brazil, Kenya and the United States. *WIPO Economics Working Paper Series No. 82*. World Intellectual Property Organization.

2 See Clancy, M., P. Heisey, Y. Ji and G. Moschini (2020). The Roots of Agricultural Innovation: Patent Evidence of Knowledge Spillovers, In P. Moser (Ed.) *Economics of Research and Innovation in Agriculture*. University of Chicago Press, 21–75. Available at: https://www.nber.org/books-and-chapters/economics-research-and-innovation-agriculture/roots-agricultural-innovation-patent-evidence-knowledge-spillovers.

3 Examples include the efforts made by organizations such as the International Service for the Acquisition of Agri-biotech Applications (ISAAA) in helping disseminate crop biotechnology technologies. Kingiri and Hall show how innovative institutions and platforms can help facilitate the commercialization of AgTech research; see Kingiri, A.N. and A. Hall (2012). The role of policy brokers: The case of biotechnology in Kenya. *Review of Policy Research*, 29(4), 492–522. DOI: https://doi.org/10.1111/j.1541-1338.2012.00573.x.

4 In contrast, farming areas greater than 50 hectares are farmed by the largest one percent of farms. See Lowder, S.K., J. Skoet and S. Singh (2014). What Do We Really Know about the Number and Distribution of Farms and Family Farms Worldwide? Background paper for The State of Food and Agriculture 2014. *ESA Working Paper No. 14-02*. Rome: Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/3/i3729e/i3729e.pdf.

5 Whitaker, M. and S. Kolavalli (2006). Floriculture in Kenya, in: Chandra, V. (Ed.), *Technology, Adaptation, and Exports: How Some Developing Countries Got It Right*. World Bank. DOI: https://doi.org/10.1596/978-0-8213-6507-6

6 Wright, B.D. (2012). Grand missions of agricultural innovation. *Research Policy*, 41(10), 1716–1728. DOI: https://doi.org/10.1016/j.respol.2012.04.021

7 OECD and FAO (2023). *OECD–FAO Agricultural Outlook 2023–2032*. Organisation for Economic Co-operation and Development. Available at: www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2023-2032_08801ab7-en.

8 Griliches, Z. (1957). Hybrid corn: An exploration in the economics of technological change. *Econometrica*, 25(4), 501–522. DOI: https://doi.org/10.2307/1905380. Alston, J.M., P.G. Pardey, D. Serfas and S. Wang (2023) . Slow magic: Agricultural versus industrial R&D lag models. *Annual Review of Resource Economics*, 15(1), 471–493. DOI: https://doi.org/10.1146/annurev-resource-111820-034312.

9 See Chapter 2 of FAO (1996) for further information on agro-ecological conditions. FAO (1996). Agro-ecological zoning guidelines, *FAO Soils Bulletin 73*. Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/3/W2962E/w2962e00.htm#P-2.

10 UPOV is an intergovernmental organization to provide and promote an effective system of plant variety protection. It currently has 78 members.

11 Graff, G.D. and I. Hamdan-Livramento (2019). Global Roots of Innovation in Plant Biotechnology. *WIPO Economics Working Paper No. 59*. World Intellectual Property Organization.

12 Data curated from the World Bank's World Development Indicator. Available at: https://databank.worldbank.org/source/world-development-indicators.

13 Patent applications filed by US innovators tend also to be filed at other national patent offices. This indicates that innovators intend to commercialize their inventions in other jurisdictions as well as the United States. See Hamdan-Livramento, I., G.D. Graff and A. Daly (2024). Innovation Complexity in AgTech: The Case of Brazil, Kenya and the United States. *WIPO Economics Working Paper Series No. 82*. World Intellectual Property Organization.

14 See Graff, G.D., A. Berklund and K. Rennels (2014). *The Emergence of an Innovation Cluster in the Agricultural Value Chain along Colorado's Front Range*. Colorado State University.

15 See Graff, G.D. and I. Hamdan-Livramento (2019). Global Roots of Innovation in Plant Biotechnology. *WIPO Economics Working Paper No. 59*. World Intellectual Property Organization; and Wright, B.D. (2012). Grand missions of agricultural innovation. *Research Policy*, 41(10), 1716–1728. DOI: https://doi.org/10.1016/j.respol.2012.04.021

16 Graff, G.D., A. Berklund and K. Rennels (2014). *The Emergence of an Innovation Cluster in the Agricultural Value Chain along Colorado's Front Range*. Colorado State University.

17 McFadden, J., D. Smith, S. Weschsler and S. Wallander (2019). Development, Adoption, and Management of Drought-Tolerant Corn in the United States *Economic Information Bulletin Number 204*. United States Department of Agriculture: Foreign Agricultural Service.

18 They include Coors Brewing (today, Molson Coors), Monfort Meats (acquired by JBS), Leprino Foods and Celestial Seasonings (today, Hain Celestial).

19 See Parikh (1979). Parikh, A. (1979). Estimation of supply functions for coffee. *Applied Economics* 11(1), 43–54. DOI: https://doi.org/10.1080/758520522

20 Manochio, C., B.R. Andrade, R.P. Rodriguez and B.S. Moraes (2017). Ethanol from biomass: A comparative overview. *Renewable and Sustainable Energy Reviews*, 80, 743–755. DOI: https://doi.org/10.1016/j.rser.2017.05.063.

21 Sugarcane produces 6,314 liters of ethanol per hectare versus corn's 2,729 liters per hectare (see Donke *et al*., 2017). Donke, A., A. Nogueira, P. Matai and L. Kulay (2017). Environmental and energy performance of ethanol production from the integration of sugarcane, corn, and grain sorghum in a multipurpose plant. *Resources* 6(1). DOI: https://doi.org/10.3390/resources6010001

22 de Castro, C.N. (2014). Agriculture in Brazil's Southeast Region: Limitations and Future Challenges to Development (Texto para Discussão, No. 1952a). Instituto de Pesquisa Econômica Aplicada (IPEA). Available at: http://hdl.handle.net/10419/121530.; Furtado, A.T., M.P. Hekkert and S.O. Negro (2020). Of actors, functions, and fuels: Exploring a second generation ethanol transition from a technological innovation systems perspective in Brazil. *Energy Research & Social Science*, 70, 101706. DOI: https://doi.org/10.1016/j.erss.2020.101706.

23 The road infrastructure in São Paulo is not, however, as bad as it is in the rest of Brazil, particularly the north; see Rada, N. (2013). Assessing Brazil's Cerrado agricultural miracle. *Food Policy*, 38, 146–155. DOI: https://doi.org/10.1016/j.foodpol.2012.11.002.

24 See the Startup Genome information on Sao Paulo at https://startupgenome.com/ecosystems/sao-paulo and the BBVA, 2022. São Paulo, the largest innovation ecosystem in Latin America - BBVA. BBVA Spark Open Innovation. Available at: https://www.bbvaspark.com/contenido/en/news/land-of-unicorns-and-fintech-empire-this-is-sao-paulo-the-largest-innovation-ecosystem-in-latin-america/ (accessed 11.13.23).

25 Whitaker, M. and S. Kolavalli (2006). Floriculture in Kenya. In Chandra, V. (ed.), *Technology, Adaptation, and Exports: How Some Developing Countries Got It Right*. World Bank. DOI: https://doi.org/10.1596/978-0-8213-6507-6.

26 Falck-Zepeda, J. B., P. Zambrano, J.I. Cohen, O. Borges, E.P. Guimaraes, D. Hautea, J. Kengue and J. Songa (2008). Plant Genetic Resources for Agriculture, Plant Breeding, and Biotechnology. *IFPRI Discussion Paper*. International Food Policy Research Institute. Available at: www.ifpri.org/publication/plant-genetic-resources-agriculture-plant-breeding-and-biotechnology.

27 Kingiri, A.N. (2022). Exploring innovation capabilities build up in the deployment of crop biotechnology innovation in Kenya. *Innovation and Development*, 12(2), 305–324. DOI: https://doi.org/10.1080/2157930X.2021.1884934.

28 See D'Alessandro, S.P., J. Caballero, J. Lichte and S. Simpkin (2015). *Kenya: Agricultural Sector Risk Assessment*. Available at: http://hdl.handle.net/10986/23350.

29 See Simtowe, F., D. Makumbi, M. Worku, H. Mawia and D.B. Rahut (2021). Scalability of Adaptation strategies to drought stress: the case of drought tolerant maize varieties in Kenya. *International Journal of Agricultural Sustainability*, 19(1), 91–105. DOI: https://doi.org/10.1080/14735903.2020.1823699

30 Ousmane, B. and T. Makombe (2015) . Agriculture, growth, and development in Africa: Theory and practice. In Monga, C. and J.Y. Lin (eds), *The Oxford Handbook of Africa and Economics: Policies and Practices – Part II, Microeconomic and Sectoral Issues*. Oxford University Press, Vol. 2, 307–324. Available at: www.ifpri.org/publication/agriculture-growth-and-development-africa-theory-and-practice.

31 Baldos, U.L.C., F.G. Viens, T.W. Hertel and K.O. Fuglie (2019). R&D spending, knowledge capital, and agricultural productivity growth: A Bayesian approach. *American Journal of Agricultural Economics*, 101(1), 291–310. DOI: https://doi.org/10.1093/ajae/aay039.

32 Beintema, N., A.N. Pratt and G.-J. Stads (2020). ASTI Global Update 2020. *Agricultural Science and Technology Indicators Program Note*. International Food Policy Research Institute.

33 Pardey, P.G., C. Chan-Kang, S.P. Dehmer and J.M. Beddow (2016). Agricultural R&D is on the move. *Nature* 537(7620), 301–303. DOI: https://doi.org/10.1038/537301a.

34 Nelson, K.P. and K. Fuglie (2022). USDA ERS – Investment in US public agricultural research and development has fallen by a third over past two decades, lags major trade competitors. Amber Waves, June 6. Economic Research Service, U.S. Department of Agriculture. Available at: www.ers.usda.gov/amber-waves/2022/june/investment-in-u-s-public-agricultural-research-and-development-has-fallen-by-a-third-over-past-two-decades-lags-major-trade-competitors.

35 See Graff, G.D. and I. Hamdan-Livramento (2019). Global Roots of Innovation in Plant Biotechnology. *WIPO Economics Working Paper No. 59*. World Intellectual Property Organization.

36 Mueller, B. and C. Mueller (2016). The political economy of the Brazilian model of agricultural development: Institutions versus sectoral policy. *The Quarterly Review of Economics and Finance*, 62, 12–20. DOI: https://doi.org/10.1016/j.qref.2016.07.012.

37 Correa, P. and C. Schmidt (2014). Public research organizations and agricultural development in Brazil: How did EMBRAPA get it right? *Economic Premise No. 145*. World Bank. Available at: http://documents.worldbank.org/curated/en/156191468236982040/Public-research-organizations-and-agricultural-development-in-Brazil-how-did-Embrapa-get-it-right.

38 See the History of RIDESA, available online at: https://www.ridesa.com.br/historia. Accessed 06.03.2024. See also da Silva Medina, G. and B. Pokorny (2022). Agro-industrial development: Lessons from Brazil. *Land Use Policy* 120, 106266. DOI: https://doi.org/10.1016/j.landusepol.2022.106266

39 Correa, P. and C. Schmidt (2014). Public research organizations and agricultural development in Brazil: How did EMBRAPA get it right? *Economic Premise No. 145*. World Bank. Available at: http://documents.worldbank.org/curated/en/156191468236982040/Public-research-organizations-and-agricultural-development-in-Brazil-how-did-Embrapa-get-it-right.

40 Gaffney, J., M. Challender, K. Califf and K. Harden (2019). Building bridges between agribusiness innovation and smallholder farmers: A review. *Global Food Security*, 20, 60–65. DOI: https://doi.org/10.1016/j.gfs.2018.12.008; Boyer, J.S., P. Byrne, K.G. Cassman, M. Cooper, D. Delmer, T. Greene, F. Gruis, J. Habben, N. Hausmann, N. Kenny, R. Lafitte, S. Paszkiewicz, D. Porter, A. Schlegel, J. Schussler, T. Setter, J. Shanahan, R.E. Sharp, T.J. Vyn, ... J. Gaffney (2013). The U.S. drought of 2012 in perspective: A call to action. *Global Food Security*, 2(3), 139–143. DOI: https://doi.org/10.1016/j.gfs.2013.08.002; Weber, V.S., A.E. Melchinger, C. Magorokosho, D. Makumbi, M. Bänziger and G.N. Atlin (2012). Efficiency of managed-stress screening of elite maize hybrids under drought and low nitrogen for yield under rainfed conditions in Southern Africa. *Crop Science*, 52(3), 1011–1020. DOI: https://doi.org/10.2135/cropsci2011.09.0486.

41 While the program has been criticized for funding larger farmers focused on export commodities in the center-south region of Brazil, it has nonetheless provided the necessary impetus to achieve its stated goal (Mueller and Mueller, 2016). Mueller, B. and C. Mueller (2016). The political economy of the Brazilian model of agricultural development: Institutions versus sectoral policy. *The Quarterly Review of Economics and Finance*, 62, 12–20. DOI: https://doi.org/10.1016/j.qref.2016.07.012; Corcioli, G., G. da S. Medina and C.A. Arrais (2022). Missing the target: Brazil's agricultural policy indirectly subsidizes foreign investments to the detriment of smallholder farmers and local agribusiness. *Frontiers in Sustainable Food Systems*, 5. Available at: www.frontiersin.org/articles/10.3389/fsufs.2021.796845; Medina, G. da S. and A.P. dos Santos (2017). Curbing enthusiasm for Brazilian agribusiness: The use of actor-specific assessments to transform sustainable development on the ground. *Applied Geography*, 85, 101–112. DOI: https://doi.org/10.1016/j.apgeog.2017.06.003.

42 Rada, N. (2013). Assessing Brazil's Cerrado agricultural miracle. *Food Policy*, 38, 146–155. DOI: https://doi.org/10.1016/j.foodpol.2012.11.002.

43 See Fuglie, K., M. Gautam, A. Goyal, and W.F. Maloney (2019). Sources of Growth in Agriculture. In: Fuglie, K., M. Gautam, A. Goyal, and W. Maloney (Eds.), *Harvesting Prosperity: Technology and Productivity Growth in Agriculture*. World Bank, 1–42. DOI: https://doi.org/10.1596/978-1-4648-1393-1_ch1.

44 This incentive mechanism was suspended in 1986 because oil prices were low.

45 Stattman, S.L., O. Hospes and A.P.J. Mol (2013). Governing biofuels in Brazil: A comparison of ethanol and biodiesel policies. *Energy Policy*, 61, 22–30. DOI: https://doi.org/10.1016/j.enpol.2013.06.005.

46 dos Santos e Silva, D.F., J.V. Bomtempo and F.C. Alves (2019). Innovation opportunities in the Brazilian sugar-energy sector. *Journal of Cleaner Production*, 218, 871–879. DOI: https://doi.org/10.1016/j.jclepro.2019.02.062.

47 EPE, 2018. *Energy Demand of Light Duty Vehicle: 2018-2030 (No. 01).* Empresa de Pesquisa Energética, Rio de Janeiro.

48 These bills and laws include the Agriculture, Livestock, Fisheries and Food Authority Bill 2012; the Livestock Bill 2012; Crops Bill 2012; the Kenya Agricultural Research Bill 2012; and the Fisheries Bill. See the USDA's Global Agricultural Information Network (GAIN) website at https://gain.fas.usda.gov/#/home

49 See Wiggins, S., G. Henley and S. Keats (2015). *Competitive or complementary? Industrial crops and food security in sub-Saharan Africa*. Overseas Development Institute (ODI). Available at: www.jstor.org/stable/resrep50756.

50 See Graff, G. D., A. Berklund, and K. Rennels (2014) . *The Emergence of an Innovation Cluster in the agricultural Agricultural Value Chain along Colorado's Front Range*. Colorado State University.

51 See de Castro, C.N. (2014). *Agriculture in Brazil's Southeast Region: Limitations and Future Challenges to Development* (Texto para Discussão, No. 1952a). Instituto de Pesquisa Econômica Aplicada (IPEA). Available at: http://hdl.handle.net/10419/121530.

52 1G ethanol is simply produced by crushing sugarcane, whereas 2G ethanol is production is based on the 1G ethanol technique plus the utilization of its "waste" called bagasse, which is the discarded stalk of sugarcane after the sugar has been squeezed out. The 2G ethanol technology is thus more environmentally friendly, as it reduces industrial waste while utilizing more of the energy embodied in the sugarcane plant to produce ethanol.

53 de C. L. e Penalva Santos, D., C. Correa, Y. Amaral Alves, C. Gomes Souza and R.A. Mancebo Boloy (2023). Brazil and the world market in the development of technologies for the production of second-generation ethanol. *Alexandria Engineering Journal*, 67, 153–170. DOI: https://doi.org/10.1016/j.aej.2022.09.004.

54 See Oostendorp, R., M. van Asseldonk, J. Gathiaka, R. Mulwa, M. Radeny, J. Recha, C. Wattel and L. van Wesenbeeck (2019). Inclusive agribusiness under climate change: a brief review of the role of finance. *Current Opinion in Environmental Sustainability*, 41, 18–22. DOI: https://doi.org/10.1016/j.cosust.2019.09.014.

55 Agriculture activities account for 20 percent of global GHG emissions. Crop and livestock activities account for 11 percent of global GHG emissions, see FAO (2020). *The Share of Agriculture in Total Greenhouse Gas Emission: Global, Regional and Country Trends 1990–2017* (FAOSTAT Analytical Brief Series No. 1). Food and Agriculture Organization. Available at: www.fao.org/documents/card/en/c/ca8389en.

56 See Porter, J.R., L. Xie, A.J. Challinor, K. Cochrane, S.M. Howden, M.M. Iqbal, D.B. Lobell and M.I. Travasso.(2014). Food security and food production systems. In IPCC. 2014. *Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 485–533. Cambridge, UK and New York, USA, Cambridge University Press

57 See the Startup Genome information on Sao Paulo at https://startupgenome.com/ecosystems/sao-paulo and the BBVA, 2022. São Paulo, the largest innovation ecosystem in Latin America - BBVA. BBVA Spark Open Innovation. Available at: https://www.bbvaspark.com/contenido/en/news/land-of-unicorns-and-fintech-empire-this-is-sao-paulo-the-largest-innovation-ecosystem-in-latin-america/ (accessed 11.13.23).

58 See the StartupGenome information on Kenya. Available at: https://startupgenome.com/ecosystems/nairobi.

59 M-PESA is a public–private partnership between the British telecom company Vodafone and its subsidiary Safaricom Kenya, a microfinance institution, Faulu Kenya, and the Commercial Bank of Africa, an established East African bank in Kenya. See Hughes, N. and S. Lonie (2007). M-PESA: Mobile money for the “unbanked” turning cellphones into 24-hour tellers in Kenya. *Innovations: Technology, Governance, Globalization*, 2(1–2), 63–81. DOI: https://doi.org/10.1162/itgg.2007.2.1-2.63; and Onsongo, E. (2019). Institutional entrepreneurship and social innovation at the base of the pyramid: The case of M-Pesa in Kenya. *Industry and Innovation*, 26(4), 369–390. DOI: https://doi.org/10.1080/13662716.2017.1409104.

60 See AgFunder (2023). *Africa AgriFood Tech Investment Report 2023*. AgFunder. Available at: https://agfunder.com/research/africa-agrifoodtech-investment-report-2023/

61 On the study on Bangladesh, Indonesia and the Philippines, see Raitzer, D.A., A.H. Sparks, Z. Huelgas, R. Maligalig, Z. Balangue, C. Launio, A. Daradjat and H.U. Ahmed (2015). Is Rice Improvement Still Making a Difference? Assessing the Economic, Poverty and Food Security Impacts of Rice Varieties Released from 1989 to 2009 in Bangladesh, Indonesia and the Philippines. Rome, Italy: CGIAR Independent Science and Partnership Council. [A report submitted to the Standing Panel on Impact Assessment (SPIA)]. Consultative Group on International Agricultural Research (CGIAR). Available at: https://research.usq.edu.au/item/q4418/is-rice-improvement-still-making-a-difference-assessing-the-economic-poverty-and-food-security-impacts-of-rice-varieties-released-from-1989-to-2009-in-bangladesh-indonesia-and-the-philippines; and on Ethiopia, see Kassie, M., P. Marenya, Y. Tessema, M. Jaleta, D. Zeng, O. Erenstein and D. Rahut (2018). Measuring farm and market level economic impacts of improved maize production technologies in Ethiopia: Evidence from panel data. *Journal of Agricultural Economics*, 69, 76–95. DOI: https://doi.org/10.1111/1477-9552.12221

62 Agriculture touches on 15 of the 17 UN SDGs, namely on standards of living, inequality and economic growth (SDGs 1, 5, 8, 9 and 16), good health (SDGs 2, 3, 6), environmental stability (SDGs 6, 7, 11, 12, 13, 14, and 15). See the 17 Goals of the UN SDGs at: https://sdgs.un.org/goals.

63 The World Bank estimates that the global population will grow to nearly 10 billion people by 2050. See the World Bank Population projection at https://databank.worldbank.org/reports.aspx?source=health-nutrition-and-population-statistics:-population-estimates-and-projections.

64 In 2022, agriculture experienced a huge shock as a consequence of the global lockdown to contain the 2020 COVID-19 pandemic. In addition, the on-going conflict in Ukraine has disrupted the global supply of grain and contributed to higher food prices worldwide. This is likely to worsen the global hunger crisis. See “Joint Statement by the Heads of the Food and Agriculture Organization, International Monetary Fund, World Bank Group, World Food Programme and World Trade Organization on the Global Food and Nutrition Security Crisis”, February 8, 2023, available online at: https://www.imf.org/en/News/Articles/2023/02/08/pr2335-joint-statement-by-the-fad-imf-wbg-wfp-and-wto-on-food-and-nutrition-security-crisis.

4 The evolution of the motorcycle industry from golden age to green revolution

The shift from combustion motorcycles to electric motorcycles has been driven by historical technological progress. The motorcycle industry draws on capabilities similar to those needed in the automobile and aviation industries, providing sources of innovation and inspiration. This chapter analyses how national technological advancements in India, Italy and Japan have shaped the direction of innovation in the motorcycle industry.

Introduction

The motorcycle industry has evolved from traditional motorbikes to a diverse array of specialized types.[1] This transformation has been driven by technological advances, the introduction of new materials,[2] shifting consumer preferences and a growing demand for sustainable transportation options. The recent shift to electrification – replacing internal combustion engines (ICEs) with electric motors and lithium-ion battery cells – has rendered certain technologies and capabilities obsolete or in need of adaptation to keep pace with state-of-the-art products and processes.[3] A retrospective analysis of the historical emergence and evolution of the industry can provide invaluable insights into its future trajectory.[4] This holds particularly true when contemplating the prospects of autonomous vehicles (AVs)[5] and electric vehicles (EVs).

Furthermore, several factors make the motorcycle industry an ideal case study for exploring concepts discussed in earlier chapters, such as relatedness, local capabilities, complexity[6] and industrial policy. First, the industry has historical ties to closely related sectors such as bicycles, automobiles and aviation, forming an interconnected web of innovation and inspiration.[7] Second, motorcycles are highly modular products, composed of various components that require diverse and specialized knowledge and capabilities for their development and assembly.[8] The modular nature of motorcycles has led to a highly disintegrated industry where manufacturers collaborate closely with suppliers and component makers, making supply chain management a central feature. Finally, the automotive industry, including motorcycles, has historically been viewed as a catalyst for economic growth, job creation and technological progress, often prompting governments to implement policies aimed at supporting domestic automotive companies and fostering innovation.

This case study aims to gain insights into the evolution of technological and production capabilities of motorcycle development by focusing on three hubs: Italy, Japan and India. These countries have significant market size, serve as leading producers and exporters of traditional motorcycles globally and represent heterogeneous segments of the market. Their diverse backgrounds offer fertile ground for discerning the core capabilities that underpin the triumphs or setbacks of firms and regions alike. The motorcycle industry is currently experiencing a seismic shift, so analyzing the historical emergence of the key industry players in these countries, the local technological capabilities they leveraged, the local policies adopted and other determinants can provide valuable insights.

This chapter yields three key takeaways. First, the genesis of the motorcycle industry is intrinsically tied to the capabilities cultivated in closely related sectors. Second, national motorcycle industries tend to chart courses shaped by their historical technological, institutional set-up and policy trajectories. These include the pursuit of high-performance and distinctive design in Italy, the emphasis on advanced technologies and product reliability in Japan and the commitment to cost efficiency and utilitarian features in India. Third, electrification, artificial intelligence and a slew of connected devices and components are revolutionizing the motorcycle industry. This trend seems to mimic the car industry.

Born from bikes: how the motorcycle industry emerged from related industries

History and research tell us that companies – and by extension, the regions they hail from – often build on what they know best when exploring new ventures.[9] In simpler terms, they use their existing capabilities and knowledge as a springboard for diversification.[10] This tendency is based on the cumulative nature of knowledge and capability honing, [11] which are reflected in the abilities and routines that individuals and firms develop.[12]

Evidence shows that firms tend to succeed more when they branch out into areas closely related to their existing expertise[13] and new firms with experience in similar industries tend to be more successful.[14] The motorcycle industry epitomizes this trend. Historically, its closest kin have been other transport industries such as bicycles, cars, engines and aviation.[15] Capabilities and technologies fostered in one of these domains often find seamless applications in another.

The precursor of the modern motorcycle can be traced back to the late 19th century when Gottlieb Daimler, now recognized as the "father of the motorcycle," crafted the first two-wheeler.[16] The early motorcycles were essentially bicycles or tricycles with small internal combustion engines mounted on them. The aftermath of the First World War marked a boom in motorcycle technology and design and allure, ushering in a "golden age" that spanned the interwar years. For instance, the 1920s and 1930s saw pivotal innovations in frames and front forks. As the engines became more powerful and larger, the need for frames designed according to the specificities of these new engines became evident.[17] Motorcycle frames departed from simple bicycle frames not only to host the powerful engines but also to be strong enough to guarantee riders' safety.

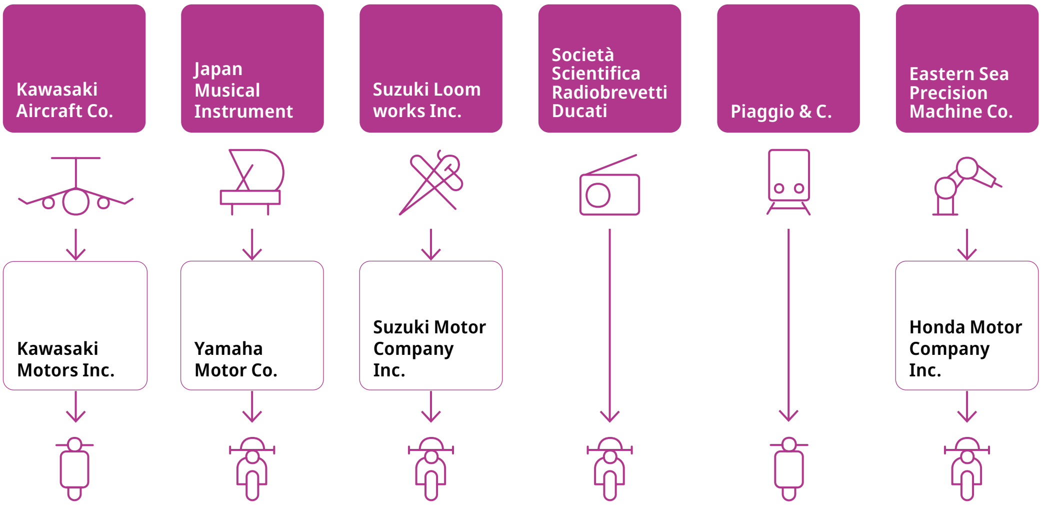
Over time, motorcycles became increasingly complex products in terms of technology and design. In the tumultuous times of both World Wars, motorcycles became vital cogs in military machinery. They were used for communication and transportation by military forces on battlefronts. In Italy, as elsewhere in Europe, many mechanical and machinery manufacturers pivoted to churning out wartime materiel, with those left catering almost exclusively to military demand, causing a lull in civilian usage of motorcycles. Unlike Italy, Japan did not have any motorcycle industry before the Second World War; it was mostly aviation firms involved in the war that repurposed their mechanical expertise, paving their way into the motorcycle industry and eventually becoming industry giants (see Figure 4.1). Wartime involvement both in Italy and Japan shaped these firms,[18] honing their skills in engineering, lightweight materials, mastering mass production and accumulating significant experience in operating large manufacturing plants – capabilities that proved to be pivotal in their post-war automotive ventures.[19]

Military, aviation and space have historically fueled both technological and design spillovers into the automotive industry, from motorcycles to cars. Many technologies, aerodynamic designs and lightweight material used in racing cars and motorcycles are borrowed from the aviation industry. After the Second World War, Italy transformed aircraft remnants into iconic scooters such as the Vespa. Even today's advances, such as global positioning systems and AVs, can trace their origins back to military tech.[20]

The flow of technological spillovers among these industries has been multidirectional. Many two-wheeler companies ventured into producing four-wheelers and vice versa. The same goes for aviation: Honda, known for its motorcycles, ventured into the aviation sector in the 1980s. The rise of EVs is also broadening horizons. Energica, an Italian electric motorcycle producer, is now exploring its e-powertrain and charging technologies in areas such as air, marine and agricultural transport.[21]Yet the one industry that has had the largest impact on motorcycles and has historically been both a competitor and a rich source of innovation remains the car industry.

Many top motorcycle companies have emerged from related industries

Figure 4.1 Origins of selected Japanese and Italian motorcycle firms, 1930–1960



Source: Alexander, 2009.

Riding in tandem: motorcycles and the automotive industry's evolution

The technological interplay between the motorcycle and automobile sectors epitomizes a dynamic exchange of capabilities and innovations. These two industries have historically exerted a profound influence on each other across several critical dimensions, including safety, materials, propulsion systems, autonomous and connected technologies, and environmental imperatives. At the same time, they often compete for consumer attention and market share. As cars became more affordable, fuel-efficient and compact, they also became more appealing to cost-sensitive consumers who would have otherwise chosen motorcycles for their affordability, efficiency and agility. This competition has encouraged both industries to innovate and offer more diverse product offerings that are not only a means of transport but also an object of leisure and passion.[22]

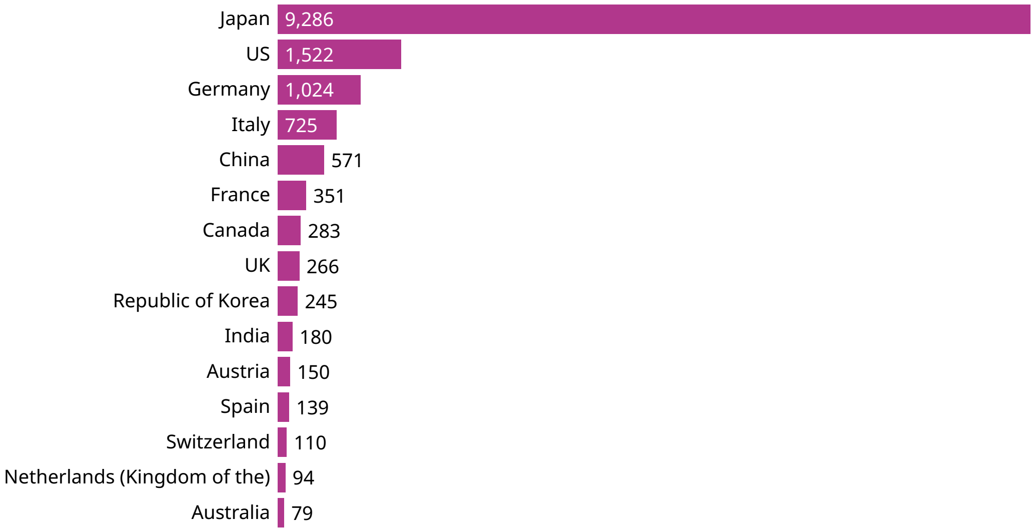
The motorcycle and car industries have several technological cross-pollinations. For instance, advancements in engine design, transmission systems and materials have been shared between the two industries. Motorcycles have influenced the development of smaller, more efficient engines for cars, while cars have contributed to innovations in motorcycle engines and transmissions. Safety is another critical concern in both industries. Advances in safety technologies, such as anti-lock braking systems, traction control and electronic stability control, have been developed in the car industry and later adapted for motorcycles. Similarly, improvements in motorcycle protective gear have influenced the development of safer car interiors and seatbelt technologies. The recent electrification push is changing the landscape of both industries.

Revving up the past: how national tech capabilities shaped the two-wheeler industry

In the realm of two-wheelers, national industries often follow paths shaped by their technological pasts, yet these trajectories are not preordained. Rather, it is the home country's inherent capabilities, institutional context and state policies that have steered both the birth and growth of the national motorcycle industry. Japan's motorcycle moguls are lauded for their innovation, reliability and quality. Italy vrooms ahead with its flair for design, speed and artisanal touches. Indian companies have focused on affordability, scale and a deft adaptation to local conditions. Currently these countries, along with other countries such as China and Germany, are leading in terms of technological and export capabilities (see Figures 4.2 and 4.3).

Technological capabilities in the motorcycle industry are concentrated in a handful of countries

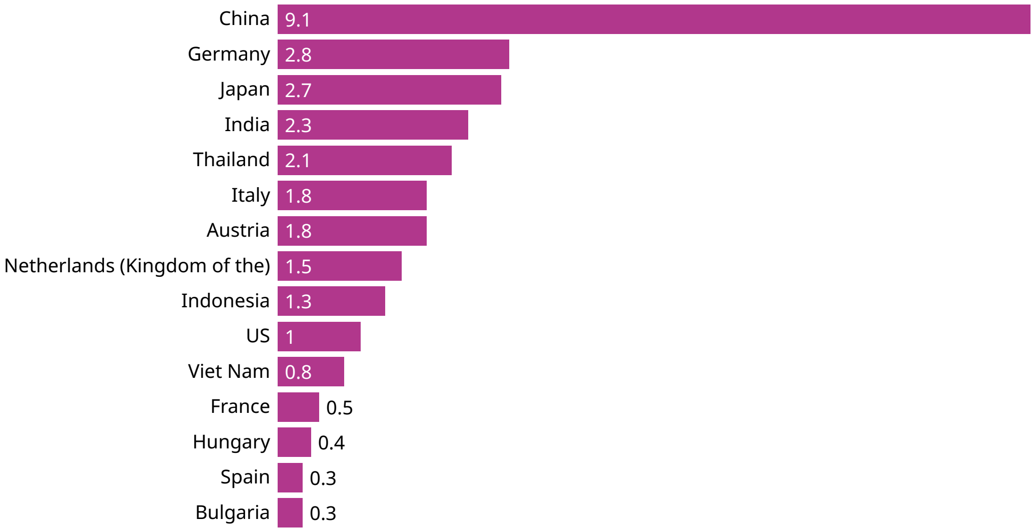
Figure 4.2 Motorcycle-related patent filings by the top 15 origins, 1970–2021



Source: EPO PATSTAT; WIPO.

Production and export capabilities in the motorcycle industry is concentrated in a handful of countries

Figure 4.3 Top 15 exporters of motorcycles by average annual value in USD billion, 2017–2022



Source: UN COMTRADE data.

Japan: riding to global dominance

Two key threads run through Japan's motorcycle story: a focus on exports and unique tight-knit supplier partnerships known as *keiretsus*. Reinforced by government policies, the remarkable Japanese motorcycle journey unfolded in the wake of its recovery after the Second World War. Wartime isolation had left Japan with a significant technological gap compared to the West.[23] However, the convergence of industrial and development policies, market demands and a drive for global competitiveness served as catalysts for the Japanese motorcycle boom.

Mirroring early Western attempts, the first Japanese motorcycles also resembled motorized bicycles. Soichiro Honda experimented with the idea of retrofitting surplus generator motors onto bicycles. This idea gave birth to the “Honda motor bicycle” in 1948 and marked the inception of Honda Motors. Initially, Japanese motorcycles were mere replicas of Western designs. However, their focus quickly shifted to innovation and quality improvement.[24] Innovation, rather than imitation, became their mantra. The emphasis was on developing advanced engineering solutions, efficient production processes and lean manufacturing practices.

Motorcycle production started with a handful of tiny workshops in the post-war years. It surged such that the number of entrants reached its peak of 127 in 1952.[25]By the mid-1950s, the period of dramatic exits started, which eventually led to the current oligopolistic structure. The survivors of this shake-out were the big four motorcycle firms: Honda, Yamaha, Suzuki and Kawasaki. Prior to the Second World War, all four of them were well-established firms in related industries and wartime experience only honed their engineering and mass production capabilities further. By the dawn of the 1960s, the big four had firmly established themselves as the world's largest motorcycle producers, annually manufacturing nearly 1.5 million motorcycles,[26] compared to just 200 units in 1948.

In their quest for global supremacy, Japanese manufacturers soon made substantial investments in research and development. Honda was at the forefront of this technological drive. It inaugurated Honda R&D in 1960, which operated in tandem with Honda Motor Co. Ltd.[27] These investments bore fruit in the form of groundbreaking advances across various facets of motorcycle design. Engines underwent transformative developments, becoming more efficient and powerful. Suspension systems evolved to enhance ride comfort and stability. Safety features were integrated, reducing risks for riders.[28]

In the 1980s, further remarkable technological innovations, including the introduction of advanced engine technologies, enhanced suspension systems and improvements in aerodynamics, transformed Japanese motorcycles. During this period, thousands of motorcycle-related patents of Japanese origin were filed, with those pertaining to engine-related technologies being the most common (see Table 4.1). In contrast, patents of Italian origin were merely a small fraction of the Japanese numbers in the same timeframe.[29] With a strong global presence, Japanese motorcycle companies offer a wide range of motorcycles, from commuter bikes to high-performance sport bikes, catering to diverse markets.

Engine-related technologies transformed the Japanese motorcycles in the 1980s

Table 4.1 The top 10 most frequent IPC classes for Japanese origin motorcycle patents, 1980-1990

IPC Class	Description	Fractional count
F02B 61/02	Engines with gearing for driving cycles	56.49
B62K 11/00	Motorcycles, engine-assisted cycles or motor scooters with one or two wheels	42.55
B62J 35/00	Fuel tanks specially adapted for motorcycles or engine-assisted cycles	29.37
B62K 25/28	Axle suspensions with pivoted chain-stay	29.37
B62K 11/04	Motorcycles frames characterised by the engine being between front and rear wheels	29.32
B62M 7/02	Motorcycles characterised with engine between front and rear wheels	24.64
B62J 17/00	Weather guards for riders	23.58
B62K 5/04	Cycles with handlebars, equipped with three or more main road wheels	22.35
B62K 19/46	Luggage carriers forming part of cycle frame	20.39
B62K 25/24	Axle suspensions for front wheel	18.07

Source: EPO PATSTAT; WIPO.

In addition to technological capabilities, another linchpin of the Japanese motorcycle industry has been its unique supply chain capabilities due to the *keiretsu* ethos[30] – a tight network of suppliers, financial entities, distribution and retail outlets (see Chapter 1). The cohesive tapestry of Japan's motorcycle manufacturers has resulted in the pooling of knowledge and resources, enhanced communication, risk reduction, punctual deliveries and overall better coordination along the supply chain. This interconnected approach doesn't just streamline operations; it fosters a collective mindset, shaping technological and design trajectories with concerted synergy.[31]

The post-war motorcycle industry in Japan owes much of its success to a series of strategic government decisions.[32] Although the policies adopted in Japan were not that different from those in other countries, they were far more effective. Japan's journey in the motorcycle industry commenced with government initiatives aimed at boosting small-vehicle production through subsidies as well as export-oriented policies administered by two key government bodies: the Japan External Trade Organization (JETRO) and the Ministry of International Trade and Industry (MITI).

JETRO and MITI were instrumental in providing Japanese firms with valuable insights into international markets.[33] In a strategic move in 1958, MITI steered the motorcycle industry towards global exports and imposed a rigorous industrial rationalization policy for four years. This policy focused on strengthening a handful of capable manufacturers to export winning products, such as motorcycles. As a result, numerous companies exited the market, leaving only the big four standing. In parallel, government shielded the Japanese motorcycle industry from undesirable competition by foreign companies in the domestic market.

Italian motorcycles: where passion meets precision

In Italy, motorcycles are more than just vehicles; they are thrilling *objets d'art*. They embody a dedication to design aesthetics, unrivaled performance and craftsmanship. Italian manufacturers have a gift for crafting high-end and limited-edition motorcycles, catering to collectors, passionate enthusiasts and racing champions. What sets Italy apart are capabilities that correspond to two opposite ends of the market: high-performance motorcycles, influenced by a rich racing heritage, and stylish scooters and mopeds catering to urban commuters.[34]

As in Japan, the genesis of Italy's modern motorcycle journey began with firms primarily engaged in related industries: bicycle,[35] aviation and those supplying mechanical components during the Second World War (see Figure 4.1). However, unlike Japan, Italy already had an established motorcycle industry since the beginning of the century. Though war damaged this established sector, its resurgence from the late 1950s to the 1990s hinged on new entrants rather than the reorganization of its incumbent firms.[36]

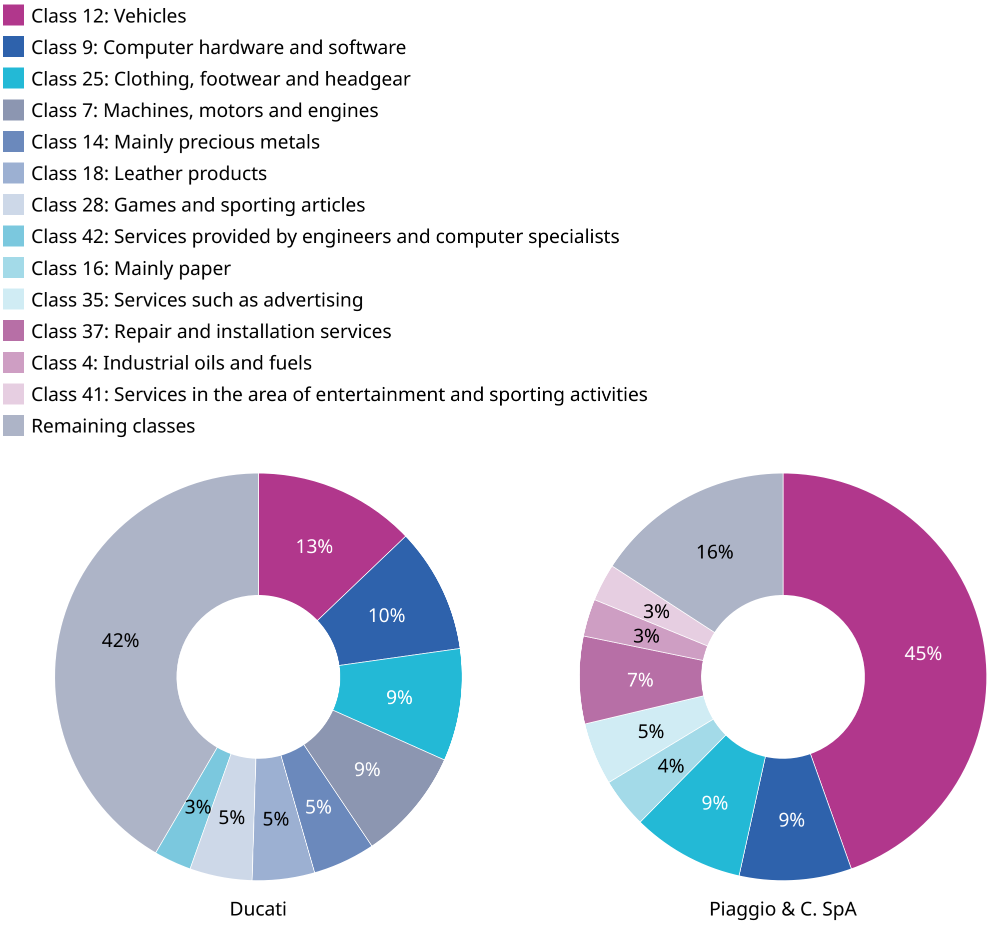
Contrary to the typical trend in mature industries, where consolidation often leads to significant firm exits, the Italian industry had a surge of new entrants after the Second World War. From the 1960s to the 1980s, when government protectionist policies partially shielded the local market, it was the capabilities of these new firms that allowed them to differentiate themselves from the fierce Japanese competitors.[37] In this period, Japanese manufacturers' advanced technology, efficient production methods and aggressive pricing posed significant challenges for most European manufacturers. Two distinct types of Italian firm emerged: high-volume producers and specialist producers.

High-volume producers focused on stylish but affordable low-capacity models such as scooters and mopeds (think Vespa and Lambretta) and emphasized mass production in northern Italy. Specialist and niche specialist producers, based mainly in Emilia Romagna in central Italy, defined use markets where motorcycles were not a mere mode of transport, but an object of passion, leisure and beauty. These specialist firms were focused on high-end models which were unprofitable for volume producers. The core capability of these firms was their "specialized flexibility." Their small size increased their ability to rapidly adapt to new customer preferences. Additionally, the local setting, characterized by cooperation between local government and the business community, along with a prevalent entrepreneurial spirit, fostered a favorable environment for motorcycle companies in the Emilia region.[38]

Proximity to other Emilian iconic brands such as Ferrari and Lamborghini allowed firms such as Ducati to infuse racing innovations into their designs. This translated into improvements in engine, equipment, performance and other technological advances. Additionally, Italian companies invest heavily in branding to cultivate a unique community spirit among enthusiasts, further supported by an extensive range of accessories and branded merchandise. The breadth of goods and services for which they hold registered trademarks reflects their diverse offerings (see Figure 4.4).[39]

Italian motorcycle-related companies invest heavily in branding in a diverse variety of goods and services

Figure 4.4 Top 10 Nice classes filed by Ducati and Piaggio & C. SpA



Note: Nice Classification is an international classification of goods and services applied to trademark applications and registrations. Applicants provide a description of the goods or services for which the mark is to be used according to one or more of the 45 Nice classes. Classes listed are abbreviated. See www.wipo.int/classifications/nice for the complete list of all classes.
Source: WIPO Global Brands database.

Italian volume producers valued capabilities related to streamlining the process and reducing friction points to reduce the time taken to develop a product and bring it to market. However, specialist producers placed greater reliance on the technical capabilities and supplier collaboration for the new product development process.

Technological partnerships prevail among Italian specialized manufacturers (e.g., Ducati and Benelli) and the high-end customized motorcycles often used in racing events (e.g., Bimota).[40] These collaborations with suppliers focus on co-developing and co-designing innovative components, especially engines. The timing and nature of supplier collaborations vary depending on the project. Typically, co-design opportunities emerge during the detailed design phase for specific sub-projects rather than the initial conceptualization.[41] This intensive knowledge-sharing along an extensive network of local suppliers ensures that components align with the evolving complexities of products.

In the Italian two-wheeler manufacturing sphere, the deep involvement of suppliers enables producers to achieve swift product development cycles, cost reductions, superior product quality and expedited problem-solving. This collaboration grants manufacturers access to suppliers' expertise and resources, boosting the innovation process. Moreover, research indicates that networks with robust knowledge transfer mechanisms between manufacturers and suppliers tend to outperform those with less developed knowledge-sharing routines.[42]

India: cost efficiency and localization

India’s motorcycle industry tells a tale of transformation, technological catch-up and emergence as a global powerhouse. Once dependent on imports, the industry evolved to meet the vast domestic demand through local production. Apart from this achievement, in 2022 it ranked among the top global exporters of two- and three-wheelers (see Figure 4.3). Two-wheelers are integral to Indian life, constituting about three-quarters of all registered vehicles. Known for its cost-effective production methods, India has become a global nexus for affordable motorcycle manufacturing, prioritizing fuel efficiency and practicality. Emphasizing localization, Indian motorcycle manufacturers often source domestically, optimizing production costs.

In the decades following India’s independence in 1947, the Indian motorcycle industry swiftly evolved from a nascent, domestically focused sector into a robust economic engine. The gradual influx of foreign automobile companies led to further transfer of technology and the ability to produce advanced two-wheeler components and vehicles at relatively favorable costs. Benefiting from resources such as globally competitive steel prices, initially low labor costs and an evolving R&D infrastructure, the industry grew significantly.

Companies transitioned from being original equipment manufacturers (OEMs) to original brand manufacturers (OBMs).[43] An OEM in the motorcycle industry typically produces parts or equipment (such as engines, frames or other components) that are integral to the assembly of motorcycles by another company – the brand that ultimately markets the finished product to consumers. An OBM, however, is responsible for the entire product lifecycle: designing, manufacturing and selling the products under its own brand. Within the motorcycle sector, OBMs manage every phase of a motorcycle’s creation – from its conception to its manufacturing – and proceed to sell directly to consumers or through a network of dealers. For example, Bajaj (a current industry giant) started by trading Vespa scooters in 1948 and began manufacturing them under a Piaggio license from 1959 to 1971. It then produced a range of two- and three-wheelers under its own brand, illustrating a shift from OEM to OBM.[44]

The 1960s marked the rise of two pivotal two-wheeler hubs: Chennai and Pune. Renowned for their manufacturing capabilities, these regions became magnets for prominent global and local companies. Chennai hosts major players such as TVS Motor Company, Bajaj Auto and Royal Enfield, along with automotive giants such as Hyundai and BMW, and tire manufacturers such as Michelin and MRF. Meanwhile, Pune’s two-wheeler scene hosts KTM, Kawasaki and Piaggio, complemented by car brands such as BMW and auto component leader Bosch. Supported by a skilled workforce, favorable policies and investment, these hubs have also seen a surge in their information technology (IT) and electronics capabilities in recent years.

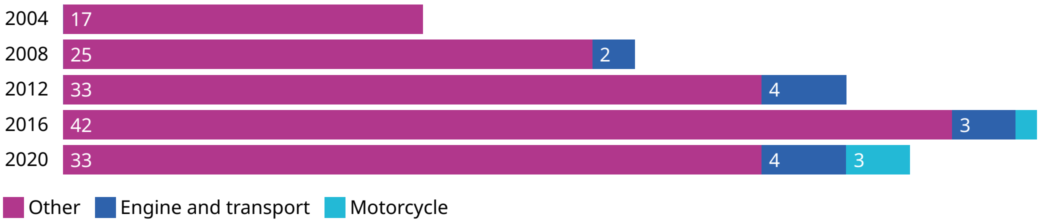
However, the period between the 1960s and 1980s was characterized by sluggish growth and limited innovation, primarily due to regulatory restrictions. The 1980s brought a resurgence with Indo-Japanese ventures, notably Hero Honda, introducing fuel-efficient motorcycles. The capability to produce environmentally compliant, fuel-efficient engines emerged from collaborations between Indian and Japanese producers.

Following the 1991 economic liberalization, the industry underwent a paradigm shift, thanks to trade liberalization, deregulation and promotion of foreign direct investment. Nonetheless, significant innovation only came at the dawn of the 21st century, driven by increased product and process innovation and evolving local consumer preferences. Evidence from patent data reveals that early 2000s India showed no engine and transport capability but, during the next two decades, the country managed to develop complex capabilities in combustion engines, aviation and space (see Figure 4.5).

Government-led infrastructure enhancements, coupled with research and development (R&D) funding, have fostered collaborations and innovation. This trend was amplified by private entities ramping up their R&D investments and global partnerships. The emerging EV sector offers fresh avenues, introducing new brands and dynamics. Electric two- and three-wheelers, given their affordability and suitability for short commutes, are predicted to spearhead India’s EV transition. While these electric variants will need enhancements to match combustion engine prices, their inherent simplicity resonates with budget-conscious consumers and eco-aware regulators.

Complex engine and transport technologies developed rapidly in India in just two decades

Figure 4.5 Comparison of India's technological capabilities between 2004 and 2020



Note: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and export data.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

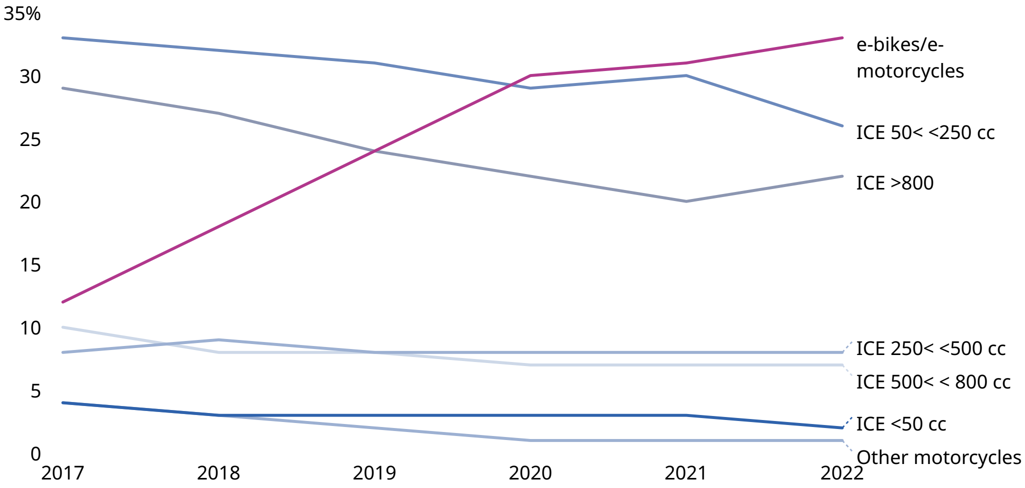
Greener twists and turns: electrification on two and three wheels

The global shift towards sustainability, driven by the mix of environmental concerns, policy initiatives and evolving consumer preferences, has ushered in an era of transformation within the transport industry. Electrification has become the name of the game, not only for cars but also for motorcycles, electric bicycles (e-bicycles) and micro-mobility solutions such as unicycles and push scooters. Over five years, from 2017 to 2022, e-cycles increased their share of the total motorcycle trade from only 12 percent to 33 percent (see Figure 4.6) with China, Germany and the Netherlands being the top exporters.[45]

The e-cycle trade in Japan has seen a notable increase, tripling from two percent in 2017 to six percent in 2022. Similarly, it doubled in Italy, rising from seven percent to 15 percent, and in India went from zero to two percent within the same timeframe. However, it is in China where the surge has been most significant, with e-cycles jumping from 27 percent of the total motorcycle trade in 2017 to 41 percent in 2022.[46] This shift towards EVs is making significant waves in automotive manufacturing, driven by environmental consciousness, policy incentives and evolving consumer preferences. Evidence from patent data also indicates the surge of patenting in fields related to e-motorcycles since 2008 (see Figure 4.7).

E-cycle trade increased dramatically from 2017 to 2022

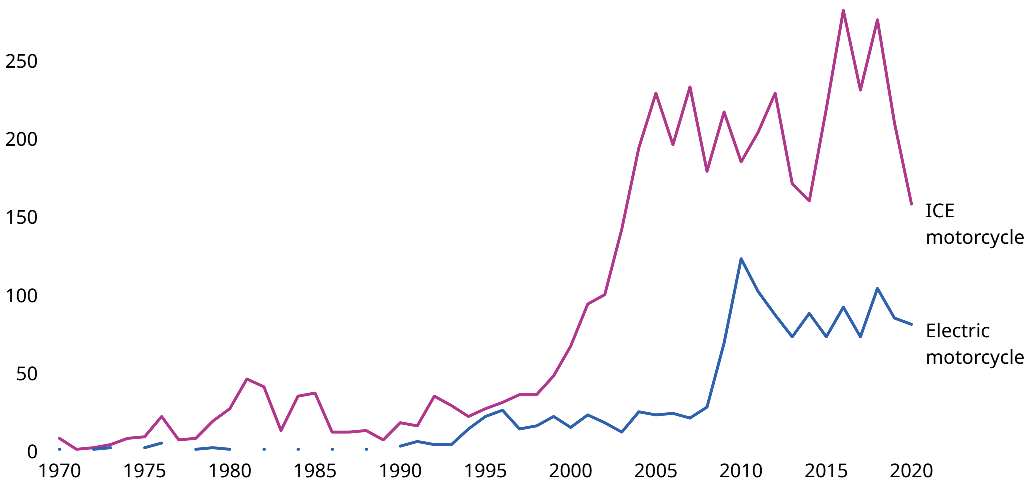
Figure 4.6 Share of e-cycle trade in global motorcycle trade, 2017–2022



Source: UN COMTRADE data.

E-motorcycle patenting has taken off since 2008

Figure 4.7 Counts of international patent families for electric and ICE motorcycles, 1970–2020



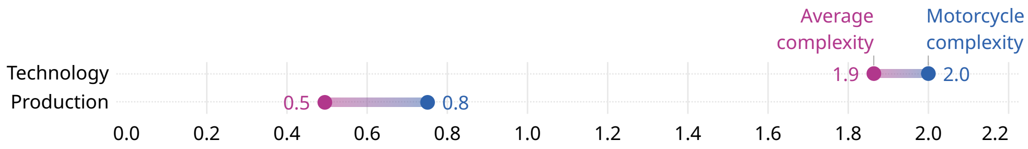
Source: EPO PATSTAT; WIPO.

From gears to gigawatts: how electrification is shifting motorcycle complexity

Motorcycle assembly and production capabilities typically lean towards the lower end of the complexity spectrum compared to technological capabilities, as illustrated in Figure 4.8. Less straightforward is the comparison between the complexity of traditional motorcycles and e-motorcycles. While there are overarching similarities, manufacturing electric motorcycles (e-motorcycles) and traditional motorcycles involves several fundamental distinctions stemming from differences in powertrains, components and assembly procedures. E-motorcycles are generally regarded as mechanically simpler when compared to traditional motorcycles, primarily owing to their streamlined powertrains and reduced mechanical components. Compared to traditional motorcycles equipped with internal combustion engines, e-motorcycles feature powertrains with fewer moving parts. Traditional motorcycles have intricate engines with an array of components, including pistons, cylinders and shafts, requiring precise machining and assembly processes.

Production capabilities in the motorcycle industry fell at the lower end of the complexity spectrum compared to technological capabilities

Figure 4.8 Complexity scale for production and technological capabilities in the motorcycle industry, 2000–2020



Note: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and export data.
Sources: EPO PATSTAT; UN COMTRADE; WIPO; WoS SCIE.

Many e-motorcycles either utilize a single-speed transmission or, in some cases, forgo the transmission altogether. In contrast, traditional motorcycles typically incorporate multi-speed transmissions, adding complexity through additional components and maintenance requirements. Furthermore, the absence of fuel and exhaust systems in e-motorcycles contributes to their overall mechanical simplicity. Despite the mechanical simplicity, it is essential to recognize that they have their own set of complexities tied to battery technology, electric motor design and electronics. Additionally, integral components such as the battery pack, battery management system and charging infrastructure are intrinsic to e-motorcycles and necessitate their own manufacturing and scale production capabilities. This suggests that, while electrification has shifted the industry's complexity from mechanical to battery-related aspects, determining whether it has increased or decreased the overall industry complexity is a more nuanced matter.

Battery technology is at the core of e-motorcycles, requiring development and procurement of high-performance lithium-ion battery capabilities that can deliver sufficient range and durability. Equally crucial capabilities are design of efficient and powerful electric motors as well as expertise in power electronics for optimizing motor performance, efficiency and range. Integrating sophisticated software for motor control, battery management and rider assistance features is essential and demands expertise in software development and integration. Features such as smartphone connectivity, touchscreen displays and rider-assist technology are increasingly important to enhance the overall rider experience.

Conclusion: the changing landscape of the industry

Since the 2010s, major producers around the world have geared up for the electrification transition. For instance, in Italy, in 2016 the first electric versions across all categories – including motorcycles, scooters, mopeds and bicycles – were introduced. E-motorcycles and e-scooters experienced robust growth in the years following their launch, although 2020 saw a temporary drop, likely attributable to the impact of COVID-19. However, production swiftly rebounded to pre-COVID levels in 2021. Traditional bicycles also saw a resurgence after the pandemic, while e-bikes have consistently gained popularity since their introduction, even in the face of COVID-related challenges. The integrative capabilities of Italian producers allowed them to achieve appealing design despite the addition of batteries for electric engines. These vehicles became viable solutions for urban mobility and sport across various age segments, rebalancing at least in part the loss of market share in other two-wheeler categories. The Italian market's openness to adopting electric motorcycles is growing, but it is still lagging compared to electric cars.

Moreover, in addition to Western countries such as Germany, the United States of America and the Netherlands, which together account for 50 percent of global electric motorcycle imports,[47] there has been significant growth in the market in Asian countries, especially China and India. Chinese companies such as NIU Technologies and Evoke Motorcycles have become prominent players in the e-motorcycle industry. This growth is facilitated by a robust manufacturing base, battery production capabilities and government incentives aimed at promoting electric mobility.

India, with its vast two-wheeler market and growing enthusiasm for EVs, presents a promising market. In India, the trend toward electrification is driven by shared and smaller vehicles, particularly two- and three-wheelers.[48] Sales of Indian two- and three-wheelers are projected to increase by 50 percent and 70 percent respectively by 2030.[49] Although fewer than two percent of cars sold are EVs, 55 percent of three-wheelers sold are electric.[50] Companies such as Hero Electric, Ather Energy, Okinawa, Pure EV and Ampere Vehicles are developing electric motorcycle offerings. Ola, India's top EV company by revenue, is concentrating on smaller mobility and aims to double its electric two-wheeler manufacturing capacity to two million by the end of 2023, and to reach an annual production capacity of 10 million between 2025 and 2028. The company also seeks to build lithium-ion battery manufacturing facilities,[51] reflecting the evolving landscape of the industry.[52]Further opportunities are being created with the emergence of subscription services for battery-swapping or battery-leasing services such as those planned by Sun Mobility.[53] The key is to create an ecosystem with a battery-swapping infrastructure and charging services.

Determining which country is best suited for the motorcycle industry's electrification involves nuanced elements such as EV infrastructure, government policies, market demand and technological capabilities. China, with its vast market for two-wheelers and rapid expansion of EV infrastructure, leads the race, bolstered by proactive government support and a leading position in battery technology. Japanese consumers have so far proven less willing to adopt EVs, despite initiatives by leading manufacturers and governmental carbon reduction initiatives. Germany and Italy, known for engineering and design excellence and supported by strong European Union environmental policies, are also making strides. India, with one of the largest two-wheeler markets, faces challenges in EV infrastructure. While China currently seems the most prepared, other countries such as Japan, Germany, Italy and India are significant contenders in the evolving e-motorcycle landscape.

Economic and policy implications

The electrification of the motorcycle industry, much like the broader transition to EVs in the automotive sector, comes with advantages and risks. Significant advantages will be mainly in terms of environmental benefits and reduced operating costs. However, due to the automotive sector's multiple linkages with various sectors, electrification can be a double-edged sword for the economy, having ripple effects beyond the motorcycle industry.

The shift from ICE to electric could lead to erosion of capabilities tied to manufacturing and servicing in traditional ICE motorcycles and consequently job losses in those areas. However, it can generate new job opportunities that require new or repurposed capabilities.[54] These include capabilities in battery production, electric motor manufacturing and the development and maintenance of charging infrastructure. Moreover, there will be a growing demand for capabilities related to software development, as EVs often incorporate more advanced digital and connected technologies. All these factors can attract talent, funding and entry of new players, fostering economic growth in regions that position themselves as leaders in electric mobility.

Another important aspect of this transition is the shift in the supply chain dynamics. Once centered on petroleum-based fuels, metal components for engines and the machinery involved in producing ICEs, the industry now demands a different set of raw materials such as lithium, cobalt and nickel for batteries. These minerals are rare and found only in certain countries. This can shift economic strength to regions or countries that have abundant reserves of these minerals. Without advances in battery technology that use more widespread minerals, such as sodium, any disruption in the supply of these rare resources could spark price volatility.[55] Moreover, switching and managing a whole new network of suppliers and component makers would be neither fast nor straightforward for traditional manufacturers.

The agility of traditional manufacturers in enhancing their existing capabilities and generating brand new ones is crucial for their survival. To face this, industry giants are pooling resources, moving toward battery standardization, and making alliances with battery makers and beyond. For instance, in April 2019, Swappable Battery Consortium for Electric Motorcycles was established in Japan to propel the industry to join forces to ensure that batteries can be exchanged among different brands and types. The consortium currently consists of 39 members including the Japanese big four, KTM, Piaggio and some big names in electric scooters and even powersports companies.[56]

Role of government policies

A coordinated approach between governments and the private sector can significantly influence the rate and success of transitioning to electrification. Through a mix of incentives, regulations and direct interventions, governments have the tools to shape the future of electric mobility.

Funding or subsidizing research and development in electric mobility, battery technology and related infrastructure can accelerate technological advancements and reduce costs in the long run. Financial incentives through fiscal measures such as subsidies and tax credits to both manufacturers and consumers can help reduce the initial cost barrier associated with purchasing EVs. For instance, in April 2022, Italy issued a decree to incentivize EV purchases. For motorcycles and scooters, the decree will subsidize up to 40 percent of the purchase cost, while for push scooters, e-bicycles and bicycles it offers up to EUR 750 in tax redemptions.

In India, the two iterations of the Faster Adoption and Manufacturing of Electric Vehicles (FAME I and FAME II) plan, in 2015 and 2019, have been directed at stimulating the supply and demand for electric two-wheelers and charging infrastructure by proving incentives to all stakeholders. FAME has resulted in the expansion of product portfolios and capabilities of the traditional two-wheeler and three-wheeler manufacturers, such as Hero and Bajaj, expansion of brands from other sectors that entered the electric two-wheeler manufacturing sector, such as Ola Electric, and the introduction of new brands that are solely focused on producing electric two-wheelers, such as Ather Energy.

Governments can adjust import and export tariffs to favor the import of e-motorcycles, their components or raw materials needed for battery production. Imposing differential pricing of petrol and electricity can also make electric two-wheelers more appealing.[57] Governments can support training programs to equip the workforce with the necessary skills and capabilities for the e-motorcycle industry.

Correctly implemented government policies, coupled with the private sector's adaptability during moments of industrial transition, can create significant opportunities for technological catch-up and leapfrogging in developing countries.[58] However, advanced economies such as Japan and Italy, which have long led in traditional ICE motorcycle technology and production, face potential risks. Despite continuous improvements, the demand for traditional motorcycles has steadily declined since 2010s in both countries.

The failure of the Italian and Japanese private and public sectors to adapt swiftly and the possibility of becoming entrenched in outdated technologies could threaten their dominance. Notably, even if they pioneered e-bikes and e-motorcycles and hybrid technologies decades ahead of the current electrification trend,[59] history offers cautionary tales. The stories of Polaroid and Kodak remind us that possessing a design or patent years in advance does not guarantee the ability to manage the transition and adapt business models to prevent obsolescence.[60] Current incumbents' failure to pivot their technological and production capabilities toward emerging trends might not just weaken their standing in the automotive sector but could also have broader economic repercussions.[61]

Notes

1 A scooter is a small-engined, two-wheeled motor vehicle with certain design characteristics such as a step-through frame, small wheels and automatic transmission. See Lipparini, A., G. Lorenzoni and S. Ferriani (2014). From core to periphery and back: A study on the deliberate shaping of knowledge flows in interfirm dyads and networks. *Strategic Management Journal*, 35(4), 578–595.

2 Plastics, titanium, carbon fibers, light alloys etc. are used and/or replaced in the production of frames and components.

3 See Lipparini, A., G. Lorenzoni and S. Ferriani (2014). From core to periphery and back: A study on the deliberate shaping of knowledge flows in interfirm dyads and networks. *Strategic Management Journal*, 35(4), 578–595; and Gavetti, G. (2001). Ducati. *Harvard Business School: Case, 701132*

4 This case study draws on Aversa, P. (2024). The Evolution of the Two-Wheeler Industry: A Comparative Study of Italy, Japan, and India. *WIPO Economic Research Working Paper Series No. 83*. World Intellectual Property Organization.

5 For a detailed discussion of the emergence of AVs, their sub-technologies and how two types of players – traditional automakers such as Volkswagen and tech companies such as Waymo – leverage different capabilities, refer to WIPO (2019). *World Intellectual Property Report 2019 –The Geography of Innovation: Local Hotspots, Global Networks.*Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4467.

6 See Hausmann, R., C.A. Hidalgo, S. Bustos, M. Coscia and A. Simoes (2014). *The Atlas of Economic Complexity: Mapping Paths to Prosperity*. MIT Press.

7 See Morrison, A. and R. Boschma (2019). The spatial evolution of the Italian motorcycle industry (1893–1993): Klepper's heritage theory revisited. *Industrial and Corporate Change*, 28(3), 613–634.

8 See Lipparini, A., G. Lorenzoni and S. Ferriani (2014). From core to periphery and back: A study on the deliberate shaping of knowledge flows in interfirm dyads and networks. *Strategic Management Journal*, 35(4), 578–595; Cenzatti (1990); and Wezel, F.C. and A. Lomi (2009). 'Built to last 'or 'new and improved'? Trajectories of industrial evolution in the European motorcycle industry, 1885–1993. *European Management Review*, 6(2), 107–119.

9 See Boschma, R., K. Frenken, H. Bathelt, M. Feldman and D. Kogler (2012). Technological relatedness and regional branching. *Beyond territory: Dynamic geographies of knowledge creation, diffusion and innovation*, 29, 64–68.

10 See Morrison, A. and R. Boschma (2019). The spatial evolution of the Italian motorcycle industry (1893–1993): Klepper's heritage theory revisited. *Industrial and Corporate Change*, 28(3), 613–634.

11 See Dosi, G. (1988). Sources, procedures, and microeconomic effects of innovation. *Journal of Economic Literature*, 1120–1171.

12 See Nelson, R.R. and S.G. Winter (1982). The Schumpeterian tradeoff revisited. *The American Economic Review*, 72(1), 114–132; Dosi, G., C. Freeman, R. Nelson, G. Silverberg and L. Soete (eds) (1988). *Technical Change and Economic Theory*(Vol. 988). London: Pinter; and Boschma, R., K. Frenken, H. Bathelt, M. Feldman and D. Kogler (2012). Technological relatedness and regional branching. *Beyond territory: Dynamic geographies of knowledge creation, diffusion and innovation*, 29, 64–68.

13 See Klepper, S. (2007). Disagreements, spinoffs, and the evolution of Detroit as the capital of the US automobile industry. *Management Science*, 53(4), 616–631; Neffke, F., M. Henning and R. Boschma (2011). How do regions diversify over time? Industry relatedness and the development of new growth paths in regions. *Economic Geography*, 87(3), 237–265; Boschma, R., A. Minondo and M. Navarro (2013). The emergence of new industries at the regional level in Spain: A proximity approach based on product relatedness. *Economic Geography*, 89(1), 29–51; and Aversa, P. (2024). The Evolution of the Two-Wheeler Industry: A Comparative Study of Italy, Japan, and India. *WIPO Economic Research Working Paper Series No. 83*. World Intellectual Property Organization.

14 See Carroll, G.R., L.S. Bigelow, M.-D.L. Seidel and L.B. Tsai (1996). The fates of de novo and de alio producers in the American automobile industry 1885–1981. *Strategic Management Journal*, 17(S1), 117–137.

15 See Morrison, A. and R. Boschma (2019). The spatial evolution of the Italian motorcycle industry (1893–1993): Klepper's heritage theory revisited. *Industrial and Corporate Change*, 28(3), 613–634.

16 See Bishop, G. and S. Barrington (1995). *Encyclopedia of Motorcycling.*London: Bison Group.

17 See Cenzatti, M. (1990). Restructuring in the motorcycle industry in Great Britain and Italy until 1980. *Environment and Planning D: Society and Space*, 8(3), 339–355.

18 For the impact of the Second World War on other industries and firms, see WIPO (2022a). *World Intellectual Property Report 2022: The Direction of Innovation*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4594.

19 See Alexander (2009); and Brondoni, S. (2021). Global competition & state intervention – The genesis of Japan's motorcycle global leaders: Honda, Suzuki, Kawasaki & Yamaha. *Symphonya: Emerging Issues in Management*, 1, 7–22.

20 For the origin of AVs and the Defense Advanced Research Projects Agency in the United States, see WIPO (2019). *World Intellectual Property Report 2019 – The Geography of Innovation: Local Hotspots, Global Networks*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4467.

21 See Energica Inside (2022). Energica inside: About us. Energica Motor Company [online]. Available at: www.energicamotor.com/us/energica-inside-about-us. and Energica News (2023a). Energica Inside applications on ultralight airplanes sector. Energica Motor Company [online]. Available at

22 See Wezel, F.C. and A. Lomi (2009). 'Built to last 'or 'new and improved'? Trajectories of industrial evolution in the European motorcycle industry, 1885–1993. *European Management Review*, 6(2), 107–119.

23 See Oshima, K. (1984). Technological innovation and industrial research in Japa*Research Policy*, 13(5), 285–301.

24 See Yamamura, E., T. Sonobe and K. Otsuka (2005). Time path in innovation, imitation, and growth: The case of the motorcycle industry in postwar Japan.*Journal of Evolutionary Economics*, 15, 169–186; and Herbig, P. and L. Jacobs (1997). A historical perspective of Japanese innovation.*Management Decision*, 35(10), 760–778.

25 See Yamamura, E., T. Sonobe and K. Otsuka (2005). Time path in innovation, imitation, and growth: The case of the motorcycle industry in postwar Japan. *Journal of Evolutionary Economics*, 15, 169–186.

26 See Yamamura, E., T. Sonobe and K. Otsuka (2005). Time path in innovation, imitation, and growth: The case of the motorcycle industry in postwar Japan. *Journal of Evolutionary Economics*, 15, 169–186. Yamamura, Sonobe and Otsuka (2005).

27 See History, Honda Official. Available at: https://www.honda.co.uk/cars/world-of-honda/past/history.html

28 See Swim, W.B. (1967). The History of Japanese Motorcycles. *Cycle World*, November 1, 1967. Available at: https://magazine.cycleworld.com/article/1967/11/01/the-history-of-japanese-motorcycles.

29 Based on calculations for Italy similar to those of Table 4.1.

30 For a definition and discussion of the impact of *keiretsus* on the Japanese big four, see Gerlach, M.L. (1992). *Alliance Capitalism: The Social Organization of Japanese Business*. University of California Press; and Aversa, P. (2024). The Evolution of the Two-Wheeler Industry: A Comparative Study of Italy, Japan, and India. *WIPO Economic Research*

Working Paper Series No. 83. World Intellectual Property Organization.

31 See Martin, X., W. Mitchell and A. Swaminathan (1995). Recreating and extending Japanese automobile buyer–supplier links in North America. *Strategic Management Journal*, 16(8), 589–619; and Clark, K.B., W.B. Chew, T. Fujimoto, J. Meyer and F.M. Scherer (1987). Product development in the world auto industry. *Brookings Papers on Economic Activity*, 1987(3), 729–781.

32 See Ohno, K. (2006). *The Economic Development of Japan: The Path Traveled by Japan as a Developing Country*. GRIPS Development Forum; and Brondoni, S. (2021). Global competition & state intervention – The genesis of Japan's motorcycle global leaders: Honda, Suzuki, Kawasaki & Yamaha. *Symphonya: Emerging Issues in Management*, 1, 7–22.

33 See Johnson, C. (1982). *MITI and the Japanese Miracle: The Growth of Industrial Policy, 1925–1975*. Stanford University Press; and Brondoni, S. (2021). Global competition & state intervention – The genesis of Japan's motorcycle global leaders: Honda, Suzuki, Kawasaki & Yamaha. *Symphonya: Emerging Issues in Management*, 1, 7–22.

34 See Tragatsch, E. (2000). *The New Illustrated Encyclopedia of Motorcycles*. Edison, NJ: Quantum Publishing, p. 48; and Wezel, F.C. and A. Lomi (2009). 'Built to last 'or 'new and improved'? Trajectories of industrial evolution in the European motorcycle industry, 1885–1993. *European Management Review*, 6(2), 107–119.

35 Companies such as Bianchi and Frera, see Cenzatti, M. (1990). Restructuring in the motorcycle industry in Great Britain and Italy until 1980. *Environment and Planning D: Society and Space*, 8(3), 339–355. Bianchi eventually stopped producing motorcycles and focused only on bicycles.

36 See Cenzatti, M. (1990). Restructuring in the motorcycle industry in Great Britain and Italy until 1980. *Environment and Planning D: Society and Space*, 8(3), 339–355.

37 See Wezel, F.C. and A. Lomi (2009). 'Built to last 'or 'new and improved'? Trajectories of industrial evolution in the European motorcycle industry, 1885–1993. *European Management Review*, 6(2), 107–119.

38 See Amin, A. 1999. The Emilian model: Institutional challenges.*European Planning Studies*, 7(4), 389–405; and Brusco, S. (1982). The Emilian model: Productive decentralisation and social integration. *Cambridge Journal of Economics*, 6(2), 167–184.

39 Based on WIPO's motorcycle-related trademark data.

40 See Muffatto, M. and R. Panizzolo (1996). Innovation and product development strategies in the Italian motorcycle industry. *Journal of Product Innovation Management*, 13(4), 348–361.

41 See Muffatto, M. and R. Panizzolo (1996). Innovation and product development strategies in the Italian motorcycle industry. *Journal of Product Innovation Management*, 13(4), 348–361.

42 See Lipparini, A., G. Lorenzoni and S. Ferriani (2014). From core to periphery and back: A study on the deliberate shaping of knowledge flows in interfirm dyads and networks. *Strategic Management Journal*, 35(4), 578–595.

43 See Innomantra (2011). *Patent Portfolio of Major Indian Automobile Companies*. Bangalore: Innomantra. Available at: https://innomantra.com/images/pdf/Innomantra%20-%20Patent%20Portfolio%20of%20Major%20Indian%20Automobile%20Companies.pdf.

44 See Iyer, N.V. and M.G. Badami (2007). Two-wheeled motor vehicle technology in India: Evolution, prospects and issues. *Energy <Policy*, 35(8), 4319–4331.

45 The three together make up 70 percent of the global exports of e-cycles.

46 Calculation based on UN COMTRADE data.

47 Calculation based on UN COMTRADE data.

48 See The Economist (2023). Forget Teslas, India's EV revolution is happening on two wheels. *The Economist*, April 20. Available at: www.economist.com/asia/2023/04/20/forget-teslas-indias-ev-revolution-is-happening-on-two-wheels.

49 See McKinsey (2022). *The Future of Mobility: Transforming to Be Ahead of the Opportunity*. McKinsey & Company. Available at: www.mckinsey.com/~/media/mckinsey/industries/automotive%20and%20assembly/our%20insights/the%20future%20of%20mobility%20transforming%20to%20be%20ahead%20of%20the%20opportunity/the-future-of-mobility-transforming-to-be-ahead-of-the-opportunity.pdf.

50 See IEA (2023). *Global EV Outlook 2023*. International Energy Agency. Available at: www.iea.org/reports/global-ev-outlook-2023.

51 See IEA (2023). *Global EV Outlook 2023*. International Energy Agency. Available at: www.iea.org/reports/global-ev-outlook-2023.

52 See IEA (2023). *Global EV Outlook 2023*. International Energy Agency. Available at: www.iea.org/reports/global-ev-outlook-2023.

53 See Economic Times (2021). EV Day Special In-depth: India's 2W industry approaches a crossroad; will electrification take over? *Economic Times*[online]. Available at: https://auto.economictimes.indiatimes.com/news/two-wheelers/scooters-mopeds/ev-day-special-in-depth-indias-2w-industry-approaches-a-crossroad-will-electrification-take-over/86025614.

54 See Henderson, R. (1993). Underinvestment and incompetence as responses to radical innovation: Evidence from the photolithographic alignment equipment industry. *The RAND Journal of Economics*, 248–270; Henderson, R.M. and K.B. Clark (1990). Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. *Administrative Science Quarterly*, 9–30; Tushman, M.L. and P. Anderson (2018). Technological discontinuities and organizational environments. In *Organizational Innovation*. Routledge, 345–372; and Tushman, M.L. (1992). Organizational determinants of technological change: Toward a sociology of technological evolution. *Research in Organizational Behavior*, 14, 311–347.

55 See The Economist (2023). Firms are exploring sodium batteries as an alternative to lithium. *The Economist*, October 28. Available at: www.economist.com/science-and-technology/2023/10/25/firms-are-exploring-sodium-batteries-as-an-alternative-to-lithium.

56 See www.sb-mc.net.

57 See Chakraborty, R. and S. Chakravarty (2023). Factors affecting acceptance of electric two-wheelers in India: A discrete choice survey. *Transport Policy*, 132, 27–41.

58 For a discussion on the role of government in the rise of the IT industry in east Asia, see WIPO (2022a). *World Intellectual Property Report 2022: The Direction of Innovation*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4594.

59 Yamaha Motor Co. introduced the world's first electrically powered bicycle models in 1993. See Yamaha Global (2023). The 30th Anniversary of the Yamaha e-Bike. Available at: The 30th anniversary of the Yamaha e-Bike - e-Bike Systems | Yamaha Motor Co., Ltd. (yamaha-motor.com)

60 See Lucas Jr, H.C. and J.M. Goh (2009). Disruptive technology: How Kodak missed the digital photography revolution. *The Journal of Strategic Information Systems*, 18(1), 46–55; and Tripsas and Gavetti (2000). Capabilities, cognition, and inertia: Evidence from digital imaging. *Strategic Management Journal*, 21(12), 1147-1162.

61 See The Economist (2023c), How Japan is losing the global electric-vehicle race. *The Economist*, April 16. Available at: www.economist.com/asia/2023/04/16/how-japan-is-losing-the-global-electric-vehicle-race.

5 Leveraging local know-how to develop video game hubs

The video game industry is a thriving creative sector, generating USD 184 billion in 2023. It is intertwined with other industrial sectors such as computing and entertainment, sharing similar capabilities. However, video game hubs have clustered in certain parts of the world. This chapter looks at how Finland, Japan, Poland and the US, four video game innovation hubs, have leveraged their local capabilities to develop video game industries.

Introduction

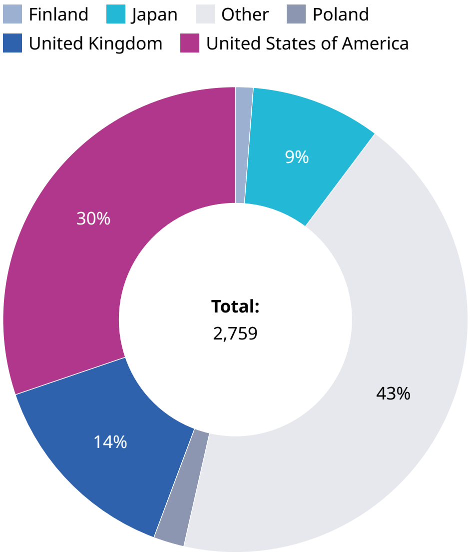
The video game industry contributes significantly to economic activity in the hubs where it is located and to the leisure and relaxation activities of many people. Globally, the industry generated an estimated revenue of USD 184 billion in 2023.[1] Revenue is distributed between mobile (49 percent), console (30 percent), personal computer (PC) (20 percent) and browser (one percent) games.[2] In comparison, the second largest entertainment industry, the movie industry, generated revenue of USD 99.7 billion dollars in 2021.[3]

Big-budget video games now have budgets that rival big-budget movies. For example, in 2023, the video game Cyberpunk 2077 cost USD 441.9 million compared to Fast X, the most expensive film released that year and which cost USD 340 million. Apart from its overall contribution to economic activity, the video game industry also creates high-skilled, high paying jobs. Between 2018 and 2022, video game industry workers earned one to three times the average wage in Finland, Japan, Poland and the United States of America (US).[4]

Video games are being consumed by more and more people. It is estimated that over three billion people play video games every year. Players are also diverse. In Poland, 47 percent of video game consumers are women, while in the United States women account for 48 percent of gamers.[5] Most games are casual mobile games such as the hits Angry Birds and Candy Crush Saga, although PC and console games continue to be very popular. Despite the benefits of video game development hubs, they are still relatively rare, and many countries have little to no such economic activity. What explains why video game development and publishing hubs have appeared and clustered in certain regions?

This chapter uses four case studies to illustrate how economies accumulate, diversify and apply knowledge. The case studies are the video game industries of Japan, the United States, Finland and Poland. As shown in Figure 5.1, these four economies account for almost 43 percent of all game development studios, with the United States and Japan having the highest and third highest number of studios, respectively, the second highest being the United Kingdom (UK). These cases have been selected to represent a diversity of success stories in the leveraging of local capabilities to develop video game industries. This chapter describes the nature of the video game industry and presents the four case studies mentioned. It briefly discusses the industrial policy in video game hubs and concludes with recommendations for policymakers. Key takeaways include the need to leverage technological and cultural strengths, the value of adaptability, and the importance of fostering entrepreneurship and mobility.

The largest game industry is in the United States.
Figure 5.1 Share of game developers around the world



Sources: Mobygames; WIPO.

Not just a game: the nature of the video game industry

The video game industry encompasses all economic activity related to developing, marketing and monetizing video games, and its stakeholders include developers, publishers, distributors, retailers, hardware manufacturers and consumers. The industry today spans consoles, PCs, mobile devices, and browser and cloud services. Key components of the industry include game development; publishing (both physical and digital); hardware (including consoles, headsets and other accessories); electronic sports (esports) and competitive gaming; and community and support services.

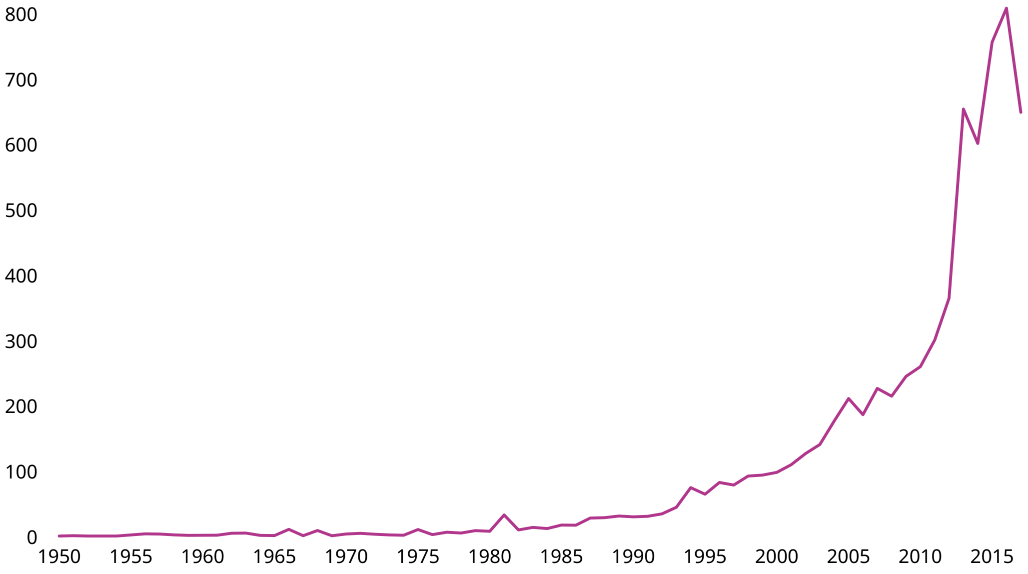
Within the video game industry two main players are key to bringing a game to market: the publisher and the developer. Publishers finance and promote the game, while developers, who can be either independent individuals or large companies, are tasked with the actual game creation. With games becoming more complex, the process of game development has also become more intricate and challenging.

Producing a video game involves significant risk, primarily due to the unpredictability of a game's popularity. This uncertainty is heightened by the increasing costs associated with game development, which have escalated in recent years. This change is evident in the growth of development teams. For example, in 1995 an average development team comprised about 26 people (see Figure 5.2). By 2015, this figure had risen to approximately 94 people, illustrating a substantial increase in staffing and, consequently, development costs.

In this intricate landscape, the role of publishers has evolved. Many have taken on development roles, integrating vertically to better control production, distribution and marketing. This vertical integration that started in the 2000s reflects a strategic response to the economic realities of the industry, aiming to streamline operations and leverage synergies between development and distribution. Major publishers such as Activision and Electronic Arts have acquired several smaller development studios, a strategic move to create efficiencies and manage escalating costs. These consolidations reflect the increasing economic complexity of the global video game industry.

Video game development teams have grown in size

Figure 5.2 Team size per game, 1950–2017



Sources: Mobygames; WIPO.

Multi-players: economic complexity and relatedness in the video game industry

The video game industry is a dynamic and multifaceted sector, with deep ties to and dependencies on other industrial sectors such as computing and entertainment. The industry not only mirrors these other sectors in terms of product diversity and expertise but also shares a complex network of skills, technological advancements and market strategies. Central to this interconnectedness are transferable skills such as graphic design, software development and storytelling. These skills are pivotal in driving innovation across various gaming segments, allowing for a seamless blend of elements from different genres and media forms. This fusion has given birth to a diverse entertainment ecosystem, enriching the gaming experience and expanding its audience reach.

Technological advancements, particularly in computing areas such as virtual reality (VR) and mobile technology, have had a profound impact on the video game industry. These innovations have not only enhanced gameplay but also broadened the industry's reach, making games more accessible and engaging. The trend toward cross-platform playability is a testament to this, both improving user experience and opening new markets.

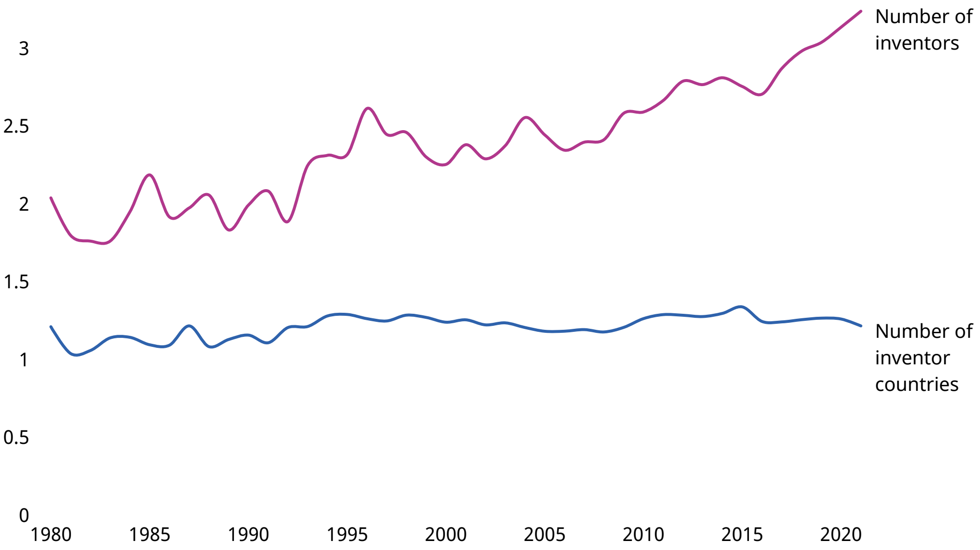
The industry's market and audience overlap is significant, with gamers frequently engaging in various game types across multiple platforms. This overlap is a driving force within the industry’s ecosystem, where the success of one segment, such as video game development, can spur growth in related areas, such as hardware sales. This interdependence is complicated by the industry's extensive global supply chains, which encompass development, production and distribution across many countries. This global interconnectedness is a cornerstone of the industry's capacity for innovation and market expansion and a testament to its complexity. Evidence from patent filings in Figure 5.3 suggests that international collaboration in video game innovation is quite common but may have declined over recent years.[6]

Moreover, the economic complexity of the video game industry is evident in its product diversity, ranging from large-scale AAA titles to indie games developed by smaller teams.[7] It is also evident in the diversity of roles the industry encompasses. From game designers, programmers and artists to marketing, business development and user experience experts, each role brings specialized skills and contributes uniquely to the development and success of video games. The industry benefits from interdisciplinary collaboration whereby these varied roles work together to create a cohesive gaming experience. The diversity of roles and skill sets within this industry has grown over time as shown in Figure 5.4. This growth has largely been to accommodate consumer expectations for more sophisticated games that can be played on more platforms, as well as technological advances in related fields such as artificial intelligence (AI) and VR.

In summary, the video game industry's evolution is a tale of increasing economic complexity, spurred by technological advances in related industries, product diversification and strategic corporate responses. As the industry continues to grow and diversify, understanding these facets of economic complexity becomes increasingly important for policymakers and other stakeholders aiming to navigate the myriad challenges and opportunities that define this vibrant sector.

International collaboration on video game innovation has stagnated

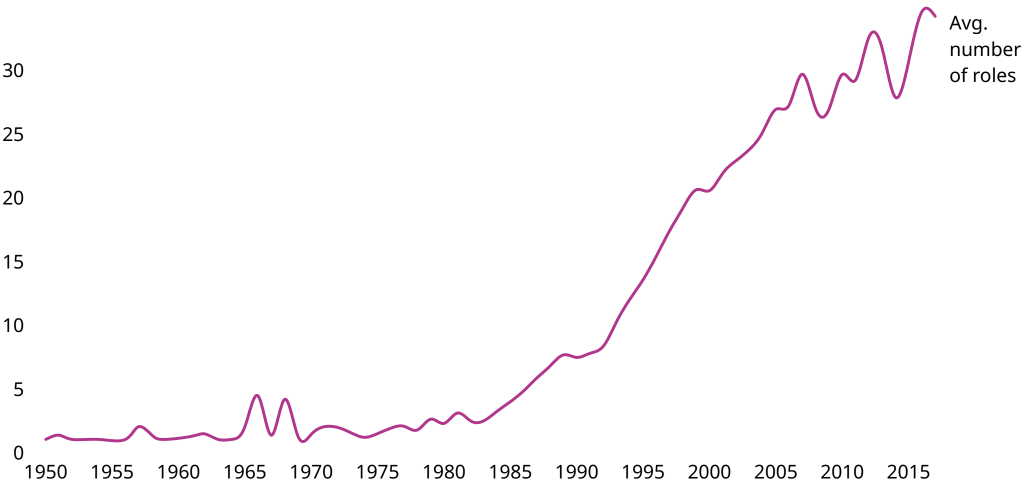
Figure 5.3 **All video game patents, 1980–2021**



Sources: EPO PATSTAT; WIPO.

Video game production has grown more complex and requires more specialized know-how

Figure 5.4 **Unique jobs roles per game, 1950–2017**



Source: Mobygames.

Global Gamedev: four case studies

The video game industry is multidisciplinary, building on a wide range of capabilities. The following sections discuss the crucial early know-how and development trajectories of the video game hubs in Japan, the United States, Finland and Poland.[8]

The aim of these case studies is to provide a historical perspective on the path-dependent development of industry know-how in each nation's key hub. These four countries were chosen based on two dimensions. On the one hand, it was important to consider and compare countries that established a video game industry earlier rather than later. On the other hand, it was important to consider countries that represent different trajectories of capability development, as well as the eventual positioning of their industry, for example, local specialization in mobile versus PC and console games.

Notably, Japan and the United States were both early movers into the video game industry building primarily on world-leading know-how related to electro-mechanical devices and computing, respectively. Naturally, they also represented a very high share of the global gaming industry and continue to do so today. In 2000, the top three clusters were Tokyo (~200 developer or publisher firms), Los Angeles (~100 firms) and San Francisco (~70 firms), and among the top 10 clusters only London, Paris and Vancouver were neither Japanese nor American.[9] Although Japan and the United States remain hubs for the global gaming industry, many other countries have also grown significantly, with the Chinese market already ranking second after the US market in terms of revenue, having overtaken the Japanese market.

Finland and Poland are newer entrants into this industry, building primarily on computer art and programming hobbyist culture and translation/video game localization know-how, respectively. Poland developed its local video game industry mostly by focusing on PC and console games, and already has many AAA successes, which is rare for a newer hub. Finland has a long history of mobile games and is still a leading hub in this segment. In addition, these two countries followed a separate developmental trajectory, showcasing different yet eventually successful paths for video game hub development.

Japan: pioneering video game development

According to gamedevmap, a catalogue of game development organizations, there were 242 video companies in Japan in 2023, including developers and/or publishers.[10] Almost 70 percent of these companies were in the Tokyo region, with roughly 15 percent in the Kyoto and Osaka regions, respectively. The big five companies alone (Sony, Nintendo, Square Enix, Sega and Capsicum) employ around 30,000 people.[11] The share of women employees within the gaming industry in Japan was 25.85 percent in 2017.[12]

The current structure of the industry has been greatly affected by mergers and acquisitions, with Bandai Namco, Sega Sammy and Square and all being the product of mergers in 2003–2005. Japanese developers/publishers have been acquiring overseas firms over the last two decades, with a large recent example being the 2023 acquisition of Rovio Entertainment by Sega Sammy Holdings for EUR 706 million.

Japanese developers were pioneers within the global video game industry. The start of the industry can be traced back to Nakamura Seisakusho, a leading manufacturer of coin-operated amusement rides. In the 1960s, Nakamura Seisakusho, later known as Namco, partnered with Walt Disney Productions, thereby obtaining the resources it needed to start manufacturing electromechanical games such as the hit Periscope. The two important early video game successes within the industry were Space Invaders by Taito (1978) and Pac-Man by Namco (1980), which together ushered in the Golden Age of the Arcades and a boom for many Japanese arcade game developers in the years that followed.

That was until the video game crash of 1983 (known as "Atari Crash" in Japan), which happened due to the market becoming oversaturated with dubious quality games and a lack of quality control. In the same year, Nintendo released its Family Computer (Famicom) in Japan, later redesigned and released in the United States (in 1985) and Europe (in 1986) under the name of Nintendo Entertainment System (NES). NES became a big success, partly due to Nintendo's use of security chip access to control which games could be released and played on its platform.[13] As the NES succeeded greatly worldwide, it proved to be a boon for many Japanese developers that released games for the NES. Tokyo and the wider Kanto region was and remains the main hub of the industry by far. That said, Kyoto and Osaka host key companies such as Nintendo (Kyoto) and Capcom (Osaka).

Sony's release of PlayStation in 1994 in Japan had a big impact on the console market by bringing both 3D gaming and CD-ROMs to mainstream gaming, with the CD-ROM technology building largely on Sony's own R&D and proprietary knowledge. This period saw Sony become the global market leader ahead of Nintendo, Sega and others, despite being a later entrant, solidifying the dominance of Japanese consoles globally.

The period shortly after Sony's entry represents Japan's peak market power within the industry, with Japan dominant in the global console hardware and software market. However, this dominance did not extend to the PC market where the Japanese video game industry was already mature and not showing much growth.[14]

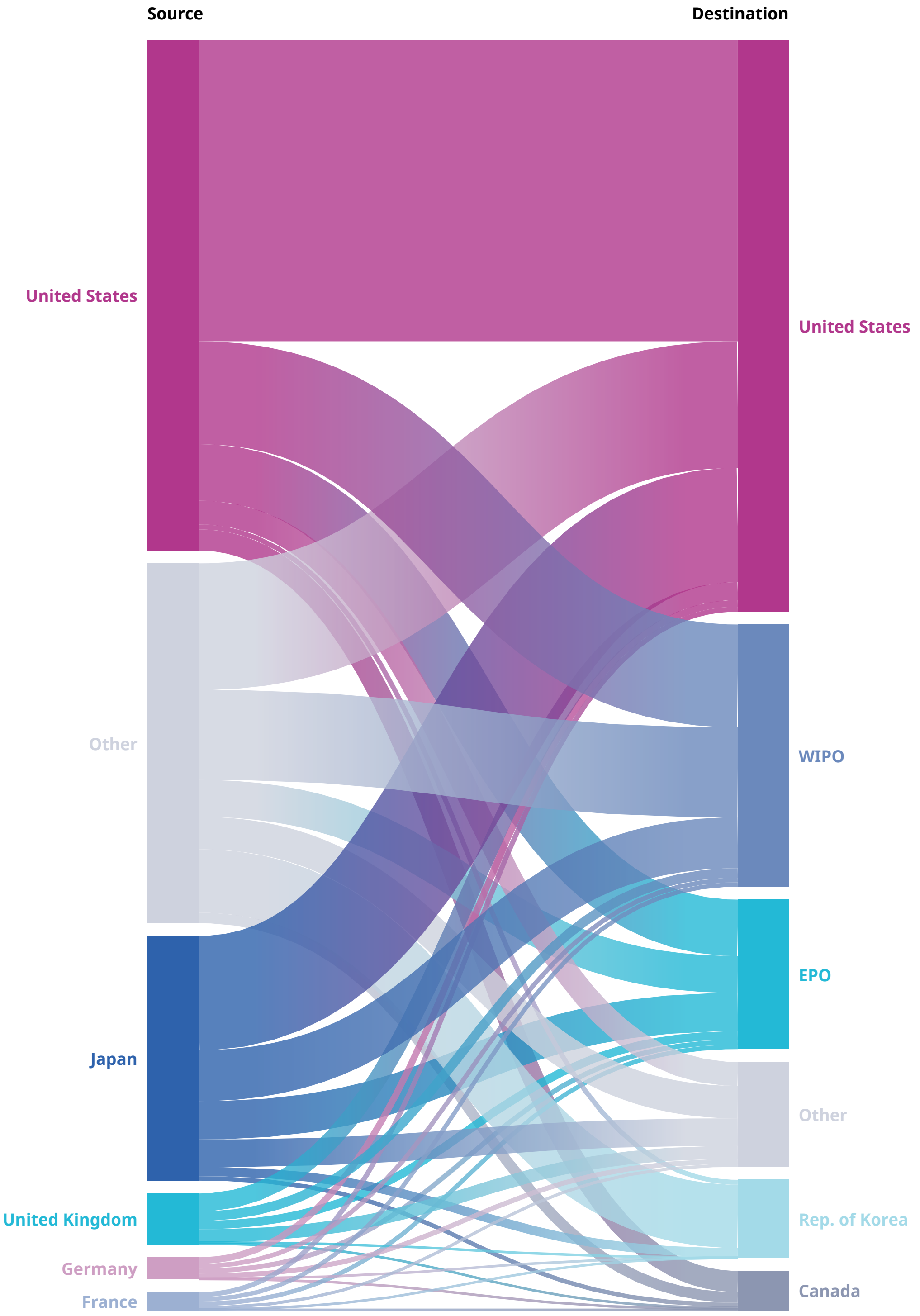
Following the release of PlayStation 3, console architecture had become so complex that many developers were finding it difficult and expensive to develop games for that platform. It was during this period that handheld games consoles had their second major boom (the first was 1996–1998 with the release of Pokémon for Gameboy) in Japan, with Nintendo DS and PlayStation Portable (PSP) having a high number of game releases. This is because handhelds were cheaper and easier to develop.

The latter half of the 2010s saw a comeback for Japanese video game developers. This was for several reasons. First, by leveraging those niches in which Japanese developers were successful, they created new global hits, culminating in the global multiple award-winning hit game Elden Ring. Second, Nintendo Switch, the innovative hybrid stationary and mobile gaming console released in 2017, became a success, creating opportunities for many local developers and working equally well with small or big-budget titles. Third, both new and established Japanese developers embraced mobile games, which occupied a rapidly growing segment. Finally, Japanese developers had begun to adopt outsourced technology. In particular they increased the use of licensed game engines, something that Japanese developers were hesitant to do compared to their counterparts in the United States and Europe.

Nowadays, the Japanese gaming industry is vibrant, both in leading advances in technologies such as AR/XR/VR and having significant market shares across all video game segments. In addition, the largest hub, Tokyo, is benefiting from a booming start-up scene, with new gaming firms betting on new technologies such as Web 3.0. Finally, the convergence of the console market with the PC market has helped Japanese developers that have traditionally focused on consoles, since PC is an important segment for selling games to global audiences. As such, sales of major Japanese developers have again become competitive worldwide, with many games becoming global hits.

The United States is the top origin and destination for video game patents.

Figure 5.5 Top patent filing countries of origin and destination



Notes: Origin is based on the patent applicant's country of residence; destination is based on the IP office where the patent is filed.
Sources: EPO PATSTAT; WIPO.

United States of America: two hubs dominate

The video game industry in the United States emerged simultaneously on two fronts. The arcade segment represented the more commercial effort, which got a boost when newly founded Atari released Pong in 1972. Arcades reached the zenith of their technological development and cultural influence during the 1980s and 1990s, a period today known as the Golden Age of Arcades. However, the earliest computer games were developed for mainframes and minicomputers, with the very first one being Spacewar! developed at MIT in 1962.

Since mainframes were only available in universities and large corporations, and minicomputers (despite being relatively smaller and cheaper) were still more suited to organizations than individual consumer adoption, video games for computers were a small niche focusing largely on microcomputer users. This tradition of making video games for general-purpose computers is a major difference between the US video game industry and that of Japan.

While Japanese video game producers are known to have found success by building highly successful consoles, the only major recent US console success is the Xbox manufactured by Microsoft, a major PC company. Unlike other major consoles, its architecture makes many of its games PC-compatible. Nonetheless, the US and Japanese video game industries were linked early on, most notably with the acquisition of the Japanese division of US game developer Atari by Japanese company Namco in 1974.

Early on, two hubs stood out in the United States: California – with Silicon Valley and to some degree Hollywood – and the Seattle metropolitan area, which includes Seattle, Redmond and Bellevue. At the start of the video game industry, Silicon Valley and Hollywood were already renowned as hotbeds of technology and entertainment industry talent. The Seattle metro area, however, rose to prominence as companies such as Nintendo of America and Microsoft made it the location of their respective headquarters and DigiPen Institute of Technology, the first university to offer training specifically for careers within the video game industry, started operating in the region during the 1980s. This inevitably created a concentration of capabilities and talent in key fields relevant for video game production. Following the Video Game Crash of 1983, many developers moved from console to PC development. Some developers founded during this period such as Electronic Arts (EA) went on to become among the most influential and important within the industry.

The launch of Windows 95 in 1995 and Microsoft's presence in Bellevue, Washington, encouraged the founding of new game developer firms in that state. Valve is one particularly important developer, founded by ex-Microsoft employees in 1996 in Kirkland, Washington. It became famous for its debut title, Half-Life, considered a major milestone in the first-person shooter genre. But it was the launch of Steam, the digital distribution platform of Valve, that changed the industry fundamentally.

Around the mid-2000s, PC gaming was declining relative to the console market, and unlicensed consumption was contributing to this decline. It was increasingly difficult to justify quickly rising PC games' budgets when consoles were similarly capable and had less unlicensed consumption. Digital distribution through Steam helped reduce unlicensed consumption, though it also reduced the power of retailers and opened a new avenue for indie developers. Together with the availability of free or cheaply licensed game engines and crowdfunding, thousands of smaller developers could now distribute games at a lower upfront cost. Console manufacturers have since created their own digital distribution platforms with an eye on growing their own base of indie developers. These console manufacturers have actively supported indie developers with programs such as Xbox Live Arcade, which introduced many indie games to console gamers.

The late 2000s also saw an expansion of the industry thanks to the dual growth of social and mobile gaming. Social gaming grew virally with Zynga's games on Facebook such as Farmville launched on Facebook in 2009. Nowadays, social gaming is in decline, whereas mobile gaming has continued to grow. In combination, these segments have created a new demand for games and opportunities for many new and existing game developers.

In recent years, the industry has been consolidating. On the one hand, many of the social and mobile gaming companies have been acquired by large incumbents. For example, Zynga was acquired by Take-Two software in 2022 (for USD 12.7 billion), King (Candy Crush) was acquired in 2016 by Activision Blizzard (for USD 5.9 billion), and Activision Blizzard itself was acquired by Microsoft in 2023 for USD 68.7 billion. In parallel, cloud gaming, cross-play and other innovations have accelerated convergence across different hardware, with industry actors such as Microsoft, Google and Epic Games pushing the industry forward on this front. In addition, established developers and venture capital-backed start-ups are already exploring the use of generative AI-based game development tools.[15] The US video game industry is home to the most important digital game distribution platforms such as Steam, App Store and Play Store.

Along with Japan, it is a leading source of innovation in video game technologies as already shown in Figure 5.5.

According to the Entertainment Software Association’s 2020 Economic Impact Report, the US video game hub supports over 143,000 direct jobs. Although there is no authoritative data on the share of women within this industry, numbers from a few major gaming firms suggest it was around 24 percent, in 2020.[16]

In terms of esports revenues according to Statista, the United States comes second after China.[17]The United States has a very lively and developed esports scene, with well-developed leagues, esports organizers and organizations. Many of the esports teams in the United States are essentially companies, some of which, such as FaZe Holdings, are publicly listed.

Finland: impact of the demoscene

The Finnish video game industry is today considered to be a mobile games pioneer. But it did not start out that way. The early adoption of video game-oriented PCs from developers such as Amiga and Atari ST gave rise to many teenage hobbyists in the late 1980s and early 1990s. These teenagers then started spending the cold, dark winters tinkering with their PCs ultimately laying the foundation of “demoscene” subculture.[18] This is a subculture in which programmers and artists come together and try to do impressive computer audiovisual demos with limited hardware.

Although the Finnish video game industry did not bloom immediately, the local pool of capable programmers and artists that flourished in the demoscene, together with the largest demoscene event, “Assembly,” eventually came to play crucial roles in the development and evolution of the Finnish mobile games industry. The history of Finland’s video game industry exemplifies how video game technologies are related and how skills developed for one platform can often be transferred to another. Figure 5.6 visualizes how video game contributors may take know-how developed on one platform to projects on another. Video game development skills are transferrable across platforms; however, for contributors that switch platforms, PC and mobile are the most common destinations.

By the early 1980s, individual programmers were publishing games for Commodore 64 through Amersoft. But these were mostly one-off, individually authored games. The first professional video game development firms were not established until 1993. They included Bloodhouse and Terramarque, which went on to merge in 1995 to become Housemarque. The Greater Helsinki Region was and is the main hub for video game development in the country.

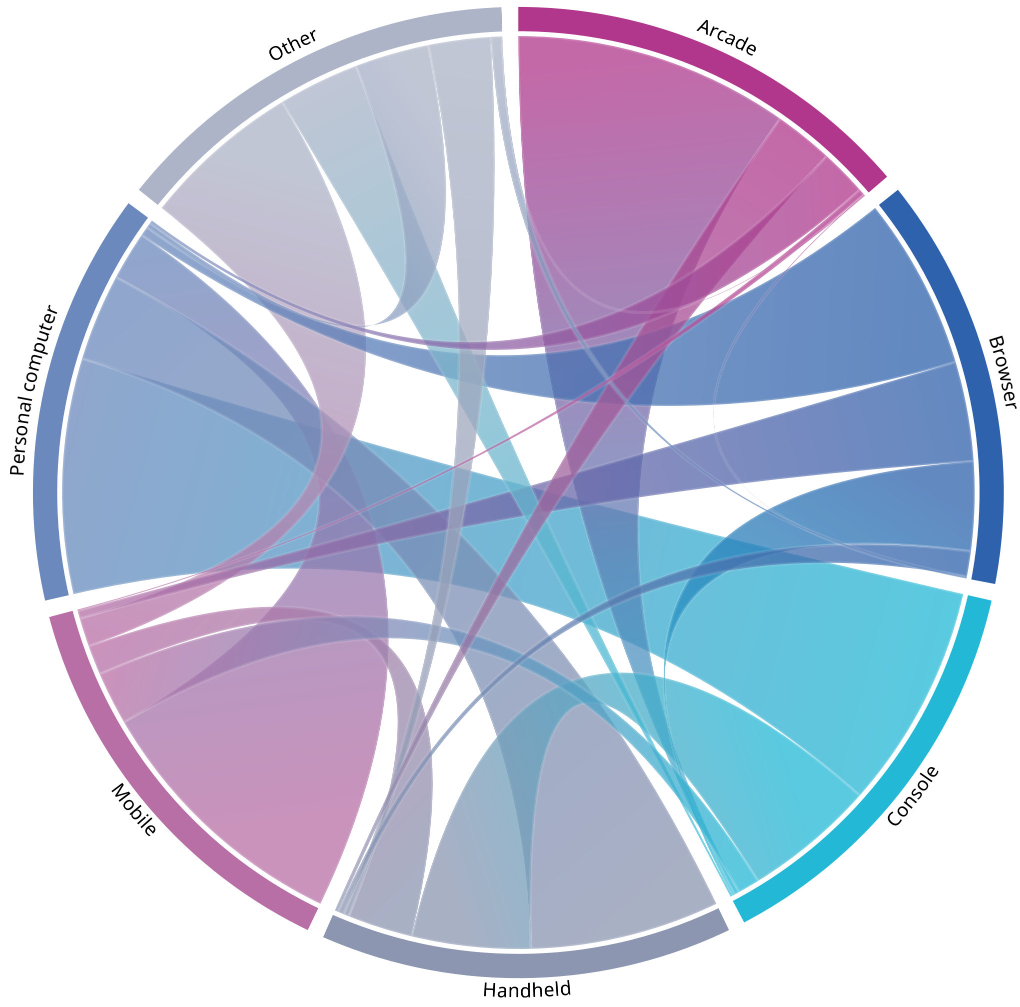
In 2001, Remedy Entertainment, founded in 1995 by members of various demoscene groups, scored the first big international success by a Finnish game developer, Max Payne, which inspired the foundation of other game development firms in Finland. Around the same period, Nokia, the Finnish global leader in mobile phones, was increasingly interested in mobile games. In 2003, Nokia launched the N-Gage, a hybrid of a handheld game console and a mobile phone, something that was unique at the time. Around the launch of N-Gage, many mobile developers got funding from Nokia to start their own mobile game development firms, with many of the founders coming from the demoscene. Since mobile phones at that time – including N-Gage – had limited hardware compared to PCs and consoles, the expertise that demoscene programmers and artists had gained from working with limited hardware was a perfect fit. For example, Rovio Entertainment (known for Angry Birds) was founded in 2003 as Relude, after the three founders competed in and won an award at the Assembly mobile game jam sponsored by Nokia and Hewlett-Packard. That victory gave them the necessary resources and visibility (which eventually resulted in them having a publisher to work with) to found the company.

Nokia ended up scrapping N-Gage in early 2006, as it failed to meet sales targets. However, Nokia’s push for mobile games had been key in the formation and support of the mobile gaming developer ecosystem, which became even more successful with the advent of modern iOS and Android smartphones. The launch of the widely adopted iPhone 3GS in 2009 was an important turning point, as, in addition to popular adoption, iPhone’s hardware, together with the App Store, proved to be well suited for gaming. It was also in 2009 that Rovio released Angry Birds, which became a big hit worldwide.[19] Despite the collapse of Nokia's mobile technology division in the early 2010s, the company continued to play a major role in the development of the video game industry by offering funding and training that enabled laid-off employees to start hugely successful video game development companies. According to Finnish industry association Neogames, there were 232 active studios in Finland in 2022, 48 percent of them located in the Helsinki metropolitan area. They employed 4,100 people, 20 percent of them women, with a total turnover of EUR 3.2 billion, which is ten times the turnover in 2012.[20] To put the size and growth of the industry into context, there were 70 active studios in 2010, and 180 studios just two years later in 2012. Finland now also has a developed esports scene, which has received a boost from institutional developments, including the official recognition of esports players as athletes in 2017. This gives tax benefits to players at the end of their playing careers, which is often in their 30s. These tax benefits incentivize more esports talent to take up esports as a career. In addition, in 2019, the Finnish Esports Federation (SEUL) became a full member of the Finland Olympic Committee. Esports growth in Finland has also led to an increase in esports betting.

Lately, Finnish development companies have attracted international acquirers, as global industry consolidation has increased. Major deals include the acquisition of 80 percent of Supercell by Chinese video game giant Tencent in 2016, and Housemarque being acquired by Sony Interactive Entertainment in 2021. In total, there were seven acquisitions between 2021 and 2022.

Video game development skills are transferrable across platforms

Figure 5.6 Flows of video game contributors switching platforms, 1950–2018



Sources: Mobygames; WIPO.Notes: The starting value is 100 percent for each platform indicating all contributors who switched from a platform. Flows represent the share of video game contributors that switch from working on one video game platform to another.

Poland: development through localization

The first notable video game developers based in Poland's capital Warsaw appeared in the early 1990s around the time the country was transitioning to a market economy. Developers such as Mirage Media (founded as Studio Komputerowe AS in 1988) and Metropolis Software (founded in 1992) quickly achieved national and sometimes European success. Mirage Media was set up to create hardware such as tape-recording systems and custom disk drives for 8-bit computers. Eventually, Mirage Media started developing its own video games and distributing third-party games for 8- and 16-bit computers in Poland.[21]

In 1994, CD Projekt was established to import CD-ROM games for Polish consumers. In response to a widespread consumption of unlicensed video games, CD Projekt started offering Polish translations of game manuals, as an incentive for consumers to buy genuine versions of video games. In those years, game manuals of over a hundred pages in length were not uncommon. The scope of CD Projekt's localization efforts grew, moving beyond translating only the game manual. CD Projekt's first big success came from its fully localized release of Baldur's Gate, a text-heavy role-playing game released by BioWare in the United States in 1999. Baldur's Gate was a global hit, for which CD Projekt translated not only hundreds of pages of in-game text and dialogue, but also hired famous Polish actors to voiceover the in-game speeches made by the game's cast of characters. The game became the biggest success for the firm at that time, providing enough funds and vital connections for it to start developing the first game in the Witcher series, which transformed the Polish gaming industry into one of the main global players and made it a key financial and cultural export for the country.[22]

The initial success of the Witcher release in 2007 kickstarted the growth of the video game industry in Poland, as many employees of CD Projekt began to spin-off their own development studios in the Warsaw area and in Poland more broadly over the years that followed. However, it was the global hit Witcher 3, released in 2015, that proved to be a turning point for the industry both in terms of institutional support and the size of the industry, making it one of Poland's key export industries.

Polish game developers continue to be highly active in the traditional AAA industry segment with PC and console games, competing with counterparts in more established hubs in the United States, Japan and other countries. According to the European Games Developer Federation's report in 2021, among the games under development by Polish developers, 71.8 percent of games targeted PCs, whereas only 11.8 percent targeted mobile devices, the lowest among the countries surveyed.[23]

According to the Polish Agency for Enterprise Development's 2023 report, there were 494 development studios (including publishers) in Poland at that time, employing 15,290 employees, 24 percent of whom were women. The industry had an estimated total revenue of EUR 1.2 billion, 2.5 times the revenue in 2018.[24] There were three hubs: the Warsaw region, accounting for 30 percent of firms in Poland, with the regions around the two southern cities of Krakow and Katowice representing 19 and 14 percent of firms, respectively. This likely means that Poland's video game industry is less spatially concentrated than hubs in Japan, the United States and Finland, which may have implications for collaboration and the overall trajectory of the industry.

Reaching the next level: video game industry development strategies

The evolution of the video game industry across various regions shows a dynamic interplay between local capabilities and global influences. While each region charts a distinctive path in developing its video game industry, there are underlying commonalities that thread these diverse experiences together.

In regions such as the United States and Japan, the genesis of the video game industry was driven by established world-leading sectors. The United States, with its robust computing industry, saw the birth of video games on mainframes and minicomputers. This industry later flourished alongside the PC revolution, exemplified by brands such as Atari and Apple. A significant boost came from an influx of creative talents from interactive art and animation, originally cultivated for Hollywood, who enriched the video game industry with high-quality content and storytelling.

Japan's journey was similar. The country's strong electromechanical amusement device manufacturing base initially focused on arcade games for public entertainment. With time and an influx of consumer electronics industry talent, this focus shifted toward home console gaming; a transition that broadened the industry's reach. Additionally, the infusion of artistic talent from the anime and manga industries significantly enhanced the artistic depth and appeal of Japanese video games.

Conversely, some economies have taken a more grassroots approach to building their video game sectors. Finland, for example, witnessed the rise of its video game industry alongside demoscene culture, marked by a strong emphasis on hobbyist computer programming and art. The Assembly demoparty, a demoscene and gaming event, played a pivotal role in this development. The growth of Nokia and the subsequent demand for mobile games on its platform catalyzed the Finnish video game industry. This environment fostered a skills transfer from Nokia to the gaming sector, with many former Nokia employees founding game development companies.

In a case such as Poland's, the video game industry's development was more unconventional. CD Projekt, a leading Polish video game producer, initially began by translating game manuals. This humble beginning gradually evolved into localizing video games and, ultimately, developing original titles. This progression underlines the potential for growth and innovation, even with limited initial technical expertise.

Across these varied narratives certain common threads emerge. The video game industry's growth often relies on leveraging existing local capabilities and industries, be they computing, electronics or entertainment. In general, entrepreneurship, labor mobility, collaboration and acquisitions have played a significant role in the development of the video game industry by enabling the transfer and adaptation of skills from related industries.

Entrepreneurship: The video game industry has greatly benefited from the entrepreneurial spirit. Start-ups and independent developers have often been the source of innovative game concepts and technological advancements. Video game entrepreneurs driven by passion and creativity have continually pushed the boundaries of what is possible in gaming, introducing new genres, gameplay mechanics and business models.

Labor mobility: Labor mobility within the industry has facilitated the transfer of knowledge and skills across companies and regions. It is not uncommon for video game contributors to move to other companies at the end of a project. This movement of talent helps disseminate best practices and innovative ideas. It also allows professionals to advance their careers by joining different projects and teams, fostering a dynamic and competitive workforce.

Collaboration: Collaboration, both within and between companies, has been crucial within the video game industry. Developers often collaborate with artists, musicians, writers and technology providers to create complex and engaging games. Cross-company and cross-industry collaborations, such as those between gaming companies and hardware manufacturers, have also been pivotal in advancing the industry.

Acquisitions: These have been a significant factor in the growth and consolidation of the video game industry. Larger companies acquire smaller studios in order to expand their intellectual property (IP) portfolio, enter new markets or gain access to new technology and talent. Acquisitions can provide the resources and stability needed for smaller studios to develop their ideas, while contributing to the strategic growth of the acquiring company.

In summary, these four elements have collectively contributed to the vibrancy and continued evolution of the video game industry, driving innovation, expanding market reach and enhancing the overall gaming experience. Whether by spinning off from other established sectors or through grassroots approaches, the development trajectories of the video game industry in different regions reflects a blend of local innovation, global trends and cross-sectoral collaboration. Understanding these diverse yet interconnected paths provides valuable insights into the global dynamics of the video game industry and its future potential.

Box 5.1 IP is important in video games

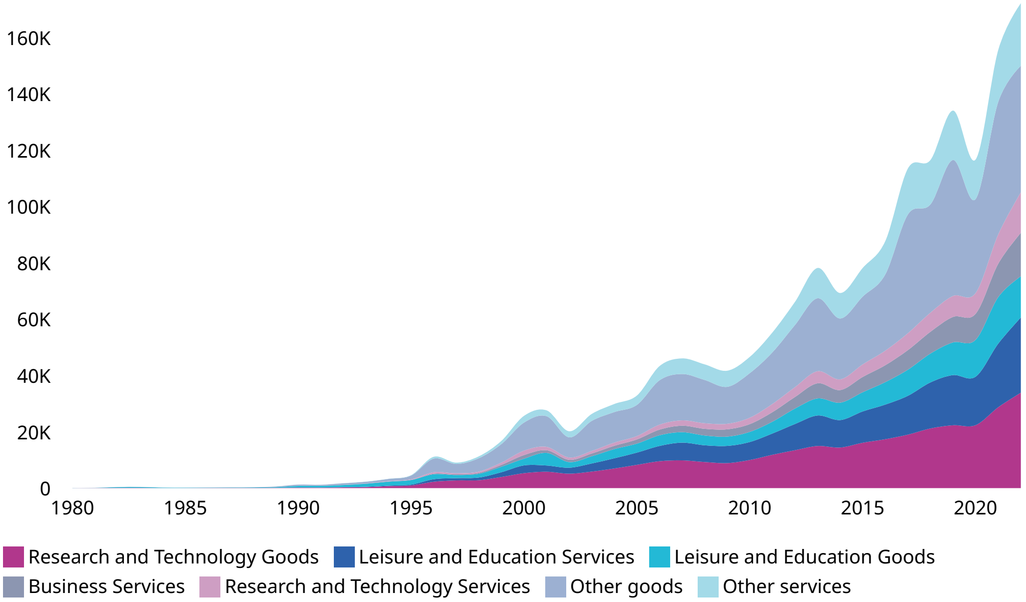
Intellectual property rights (IPR) enforcement is critical to the success of a video game hub. This is largely because video game development is a high-risk venture which requires high up-front development costs. However, once a video game is produced, the cost of every new unit – such as a CD or download – is low. In this sense, it is like other creative industries, such as the film industry. In such a context, strong IPR protection and enforcement raises infringement costs for an infringer, which gives a video game developer a better chance of profiting from their work and investment.

Trademarks, copyright, patents and industrial designs are the most common types of IPR within the video game industry. Trademarks protect the brand names associated with a game. Copyright protects the artistic and creative elements of a video game – such as graphics, music, storylines, characters and dialogue, as well as the game's software code. Patents protect technical in-game mechanisms, game development technologies and software, as well as aspects of gaming hardware such as consoles. Industrial designs protect the visual design, the aesthetic and ergonomic aspects of video game user interfaces and hardware.

At the same time, the ability to exploit video game IP in diverse ways mitigates the risk associated with video game development by providing multiple revenue streams for developers. Movies based on video game IP had a record year at the North American cinema box office in 2022, thanks to the success of films such as Paramount's Sonic the Hedgehog 2 and Sony's Uncharted. In 2023, The Super Mario Bros. Movie became the first film based on gaming IP to gross over USD 1 billion (about USD 3 per person in the United States) worldwide and ranked among the 20 highest grossing films of all time. Meanwhile, Netflix has at least five movies based on video game IP in either the planning or production stages, while HBO Max's series The Last of Us, based on the eponymous video game, has further cemented the power of games as assets. [25] Notably, the highly successful Mario Bros. and Pokémon games have spawned numerous spinoff games and non-game merchandise. Overall, this trend indicates that gaming IP is increasingly valuable for rights holders. Figure 5.7 shows how global video game-related filings have grown, while Figure 5.8 shows how such filings are becoming increasingly diverse, as the top five filing categories come to represent a smaller share of total filings.

Global trademark filings related to video games have grown

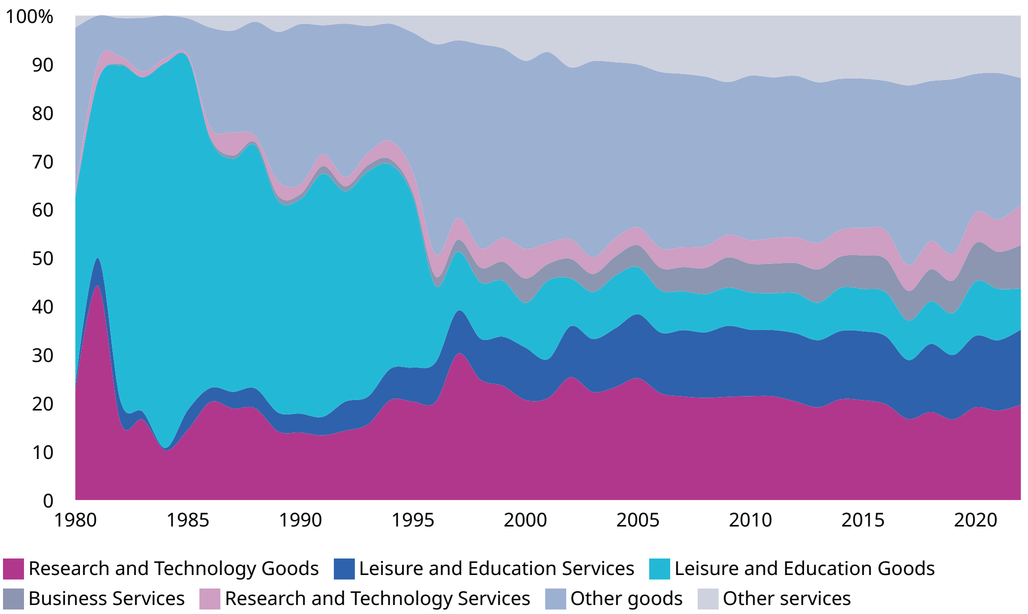
Figure 5.7 Top 5 Nice classes of video game-related trademarks, 1980–2022



Source: WIPO Global Brands Database.

Video game-related trademarks are increasingly filed for more diverse use cases

Figure 5.8 Share of the top 5 Nice classes for video game-related trademarks, 1980–2022



Source: WIPO Global Brands Database.

Finally, for many game developers and publishers, the ability to build on existing IP in new products is crucial. While it is difficult to predict the extent of any game's success in the market, games built on existing IP are lower risk ventures, as they can draw upon an established fan base more willing to spend money to acquire the new game. IP is important because, although most consumers expect novelty in a game, they also want some familiarity to be present, meaning there is a need to balance the two.[26] Overall, 11.6 to 14.6 percent of new video games – excluding sequels – are based on prior IP, including movies, novels, comic books and other sources.[27]

Owing to customer expectations and rising development costs, publishers have increasingly focused on sequels, spin-offs of existing IP and more mainstream genres as a means of managing risk.[28] Often this clashes with the main priorities of development firms, which tend to want to focus on the artistic value of developing novel games with completely new IP. Moreover, when overdone, sequels and spinoffs based on existing IP can create franchise fatigue in gamers.

Controllers and creators: industrial policy in video game hubs

Seeing the evident benefits of video game industries to local economies, policymakers have made strategic moves in support of their development. They have done so by providing subsidies to the industry, as well as non-financial support for video game companies, particularly start-ups, and by investing in education that prepares people for careers within the video game industry.

Subsidies for R&D and cultural industries

Video game developers in Finland and Poland benefit from the European Union's (EU) Horizon Europe program, which subsidizes research and development (R&D), and its Creative Europe MEDIA program, which has a sub-program dedicated to supporting video game developers in the EU. In addition, developers in these two countries may also benefit from national and local subsidy programs.

In Finland, Business Finland (formerly Tekes and Finpro), a government agency that funds R&D and game development, played a crucial role the initial years of many game developers, such as the highly successful Supercell, since the early 2000s. There is also limited support for video game companies through a cultural fund known as the DigiDemo grant.

Similarly, as Poland's video game hub has grown and become a strategic priority for the country, there has been strong governmental support at multiple levels. Video games are seen as important cultural exports that are highly valued in Poland. Cultural state aid in the form of grants for video game developer firms is provided by the Ministry of Culture & National Heritage's Development of Creative Industries program. R&D subsidies for video game developers also exist in Poland, most notably GAMEINN, a program implemented by the National Center for Research and Development.[29]

By contrast, the video game hub in Japan did not receive many subsidies during its formative years. However, the Creative Industries Promotion Office, founded in 2010, acting in partnership with the Visual Industry Promotion Organization, now offers the Localization and Promotion Support grant (J-LOD), through which, for example, a Japan Games Pavilion is funded at key international video game industry trade fairs. Furthermore, in 2013, the Creative Industries Promotion Office established the Cool Japan Fund for which video game companies are eligible.

In the United States, there were no tax benefits or subsidies directed specifically toward the video game industry in the older California and Seattle hubs, spurring some newer hubs such as Texas into attempting to use such benefits to lure away video game developers. Nonetheless, video game developers have always been eligible to benefit from R&D tax credits just like any other company.

Non-financial business support

Helsinki City provides a wide range of support to the Helsinki hub, ranging from support for foreign workers to start-up incubators and cultural events to promote the industry. For example, the City's youth services organize video game industry-related events, including game development camps, for young people. Overall, Helsinki City not only formally recognizes and supports the industry, but it also actively works with the main industry associations and organizations to promote it.

In Poland, the Polish Agency for Enterprise Development's Creative Industries Development Center (founded in 2022) and the Polish Investment & Trade Agency all support video game developers in different aspects of business development, aiming to help developers successfully grow their market globally. In Krakow, the Krakow Technology Park supports the industry through the Digital Dragons hub that serves as a start-up accelerator and incubator, housing many developers, as well as the Digital Dragons Conference, which is one of the two major conferences for developers in Poland. In addition, Krakow Technology Park offers workshops and undertakes research regarding the video game industry in Poland. The city of Katowice hosts and supports the international esports competition Intel Extreme Masters and other esports events, as well as the Esports Association, while the city of Poznan hosts and supports the Poznan Game Arena Expo and the Game Industry Conference.

Education for video game industry careers

To ensure the continued development of their local video game industry, policymakers are investing in education for video game-related careers. In Finland, for example, higher education attainment related to the video game industry is one of the highest per capita in the world. This has provided the industry with a steady talent stream, as it has grown over time. Thirty-seven higher education institutions offer formal education directly targeted at careers within the video game industry. That is about 6.7 institutions per million citizens – far above the European average.[30]

In Poland, there were an estimated 65 degree courses in 52 universities targeted at careers within the video game industry in 2022. Most of these courses were for developing programming (26 courses) and art skills (23 courses). The number of universities offering programs targeted at careers within the video game industry ranks among the top four in Europe. Poland has 1.4 institutions offering video game-related degrees per million inhabitants, which is more than Germany (1.2 institutions) but less than France (2.2 institutions). In addition, the video game industry is also embraced culturally within the overall education system, with the This War of Mine (a unique game that helps players imagine civilians' lives during wartime) being added to the official reading list for children in schools, in 2020.

In the United States, specialized educational programs for game design and video game industry careers in general started to appear in 1998, with the opening of the DigiPen Institute of Technology's Redmond campus. Traditional universities soon after started to also offer programs that are now considered to be the premier programs to study for a career within the industry. These programs include the University of Southern California's programs on game design, interactive design, animation, and an interdisciplinary program on computer science and games. In total, there are 57 college programs in California and eight more in Washington (which includes the Seattle metropolitan area).

Conclusion: how industry hubs can foster growth and competitiveness

The development of the global video game industry has seen regional hubs navigating unique challenges and capitalizing on local strengths. The four video game industry hubs discussed exemplify the concept of relatedness, demonstrating how local expertise, cultural capital and interconnected industries collectively have influenced the industry's evolution and offer strategic insights for policymakers.

Japan, the United States, Finland and Poland showcase distinct but effective strategies in bolstering their respective presences within the global video game industry. Japan's industry, known for iconic console brands such as PlayStation and Nintendo Switch, has demonstrated adaptability and innovation by integrating consumer electronics, mobile technology and anime, ensuring sustained competitiveness in a dynamic market. In the United States, the industry's growth has been driven by a robust technological infrastructure, a skilled workforce, and an environment conducive to research and entrepreneurship, particularly in regions such as Silicon Valley and Seattle. Finland's rise in mobile gaming, led by companies such as Rovio and Supercell, capitalized on its strong telecommunications infrastructure and Nokia's legacy, illustrating the power of leveraging related industries and hobbyist cultures. Poland, with CD Projekt's success, highlights the importance of cultural relatedness and localization, utilizing its cultural heritage to develop globally recognized games such as the Witcher series. In summary, while each of these four hubs has its challenges, together they provide insight into how economic complexity and relatedness may be leveraged to foster growth, innovation and competitiveness within an evolving video game industry.

Implications for policymakers

For policymakers aiming to bolster the growth and sustainability of video game hubs, a strategic approach should consider the following six key actions.

Encourage cross-sectoral synergies: Promote collaborations between local video game hubs and established sectors in technology and culture. This strategy fosters innovation, IP reuse and specialization.

Support localization and cultural adaptation: Assist in the localization and cultural adaptation of foreign games for local markets. Such an approach helps local companies learn to develop content with both local and global appeal and to develop the capabilities necessary for global expansion.

Invest in human capital: Focus on education and gender diversity initiatives to cultivate local talent. Additionally, support the integration of foreign talent into local hubs to address skills gaps.

Foster entrepreneurship and encourage labor mobility: Encourage and support entrepreneurial ventures within the video game sector. Provide resources, mentorship and funding opportunities for start-ups and independent game developers to stimulate innovation and diversity within the industry. Implement policies that facilitate the movement of talent within the industry thereby enhancing knowledge transfer and fostering innovation.

Support R&D: Promote investment in R&D to ensure global competitiveness within this economically complex industry.

Be open to industry consolidation: Antitrust issues notwithstanding, recognize and support the role of industry consolidation in achieving scalability, resource optimization and market expansion. Ensure that consolidation efforts are balanced by fair competition practices. Policymakers should focus on facilitating the type of consolidation that is healthy for consumers, so as to enhance global competitiveness.

By embracing these six strategies policymakers can significantly influence the development of robust video game hubs, address the unique challenges and capitalize on the opportunities within what is a dynamic and rapidly evolving industry.

Notes

1 According to Newzoo (2023). *Free Edition: Global Games Market Report, 2023*. Available at: https://newzoo.com/resources/trend-reports/newzoo-global-games-market-report-2023-free-version.

2 Tencent, Sony and Apple generate the most revenue from video games according to Newzoo (2023). *Free Edition: Global Games Market Report, 2023*. Available at: https://newzoo.com/resources/trend-reports/newzoo-global-games-market-report-2023-free-version.

3 This represents 24 percent growth from 2020 and surpasses the pre-pandemic 2019 total. See Motion Picture Association (2021). *Theme Report 2021*. Available at: www.motionpictures.org/research-docs/2021-theme-report.

4 See Shrider, E.A., M. Kollar, F. Chen and J. Semega (2021). *Income and Poverty in the United States: 2020*. United States Census Bureau. Available at: www.census.gov/library/publications/2021/demo/p60-273.html; OECD (2023). OECD Data: Average wages. Organisation for Economic Co-operation and Development. Available at: https://data.oecd.org/earnwage/average-wages.htm; Glassdoor. (2023). *How Much Does a Game Developer Make in Poland?* Game Developer Salaries. Available at: https://www.glassdoor.com/Salaries/poland-game-developer-salary-SRCH_IL.0,6_IN193_KO7,21.htm; Game Makers of Finland. (2022). *Finnish Game Industry Salary Survey 2022*: Results and Conclusions. Available at: https://peliala.fi/wp-content/uploads/2023/03/Game_Makers_of_Finland_Salary_Survey_Results_2023.pdf; and, Salary Explorer. (2023). Game Developer Average Salary in Japan 2023. Salary Explorer. Available at: https://www.salaryexplorer.com/average-salary-wage-comparison-japan-game-developer-c107j10578#:~:text=Average%20Monthly%20Salary%0A%0A471%2C000%20JPY%0A%0A,735%2C000%20%20%20%0AJPY

5 ESA (2022). *Essential Facts about the Video Game Industry*. Entertainment Software Association. Available at: www.theesa.com/resource/2022-essential-facts-about-the-video-game-industry.

6 Balland and colleagues anticipated and proposed two explanations for this trend towards decreasing international collaboration. First, given the project-based and flexible nature of work within the industry, tasks and objectives are often more ad hoc and thus less easily communicated and appreciated remotely. Second, the increasing complexity of videogame development tends to favor having teams located in geographical proximity so that they can quickly experiment, tinker, and troubleshoot together. The decline in international collaboration on videogame patenting is further evidence of the growing economic complexity of this industry. See Balland, P.-A., De Vaan, M., & Boschma, R. (2013). The dynamics of interfirm networks along the industry life cycle: The case of the global video game industry, 1987–2007. *Journal of Economic Geography*, 13(5), 741–765. Available at: https://doi.org/10.1093/jeg/lbs023. More recently, Oguguo tracks innovation and complexity in the video game industry, highlighting the link between technological innovation and changing business models in the video game industry. See Oguguo, P. (2024). Innovation and Intellectual Property Use in the Global Video Game Industry. *WIPO Economic Research Working Paper No. 85*. World Intellectual Property Organization.

7 In the video game industry, AAA (pronounced 'Triple-A') titles refer to videogames that are of a high quality, have a high budget, and are produced and distributed by major publishers.

8 For more details about the history and nature of the video game hubs in these countries, see Özalp, H. (2024). Heterogeneous development paths to growth and innovation: The evolution of the video game industry across four hubs. *WIPO Economic Research Working Paper No. 84*. World Intellectual Property Organization.

9 For an examination of clustering within the global video game industry between 1972 and 2007, see De Vaan, M., Boschma, R., & Frenken, K. (2013). Clustering and firm performance in project-based industries: the case of the global video game industry, 1972–2007. *Journal of Economic Geography*, 13(6), 965–991. Available at: https://doi.org/10.1093/jeg/lbs038

10 Based on data from gamedevmap.

11 Based on filings from Sony, Nintendo, Square Enix, Sega and Capsicum.

12 Based on analysis of Mobygames data using WIPO's World Gender Name Dictionary.

13 This also allowed Nintendo to have very tough business terms, for which it was later fined USD 25 million by the US Federal Trade Commission.

14 For a detailed history of the Japanese video game industry, see Koyama, Y. (2023). *History of the Japanese Video Game Industry*. Springer Nature, 2023; and, Özalp, H. (2024). Heterogeneous development paths to growth and innovation: The evolution of the video game industry across four hubs. *WIPO Economic Research Working Paper No. 84*. World Intellectual Property Organization.

15 San Francisco-based tech company Scenario raised USD 6 million ahead of the early access launch of its generative AI engine according to, Dealessandri, M. (2023). Scenario raises $6m ahead of AI-powered art engine early access. Games Industry.biz. Available at: www.gamesindustry.biz/scenario-raises-6m-ahead-of-ai-powered-art-engine-early-access.

16 The percentage of women globally at Activision Blizzard, Unity and Electronic Arts was around 24 percent, in 2020 and 2021, according to Burton and Carson. Most Big Tech companies, including Facebook and Google, are above 30 percent. See Burton, A. and B. Carson. (2022). The gaming industry is only just beginning to address its diversity problem. Protocol. Available at: www.protocol.com/workplace/gaming-industry-diversity-reports.

17 Esports has grown into a global industry, with players, sponsors and spectators contributing to its popularity and economic significance. Esports competitions often attract both online and offline audiences. For more information on market sizes, see Statista (2023). *Revenue of the esports market in selected countries worldwide in 2023*. Statista. Available at: www.statista.com/forecasts/1130696/esports-revenue-share-country.

18 As of April 2020, Finland added the demoscene to its national UNESCO list of intangible cultural heritage of humanity.

19 Angry Birds was Rovio's 52nd game release.

20 For more information about the current state of the Finnish video game industry, see Neogames (2023). *The Game Industry of Finland: Report 2022*. Available at: https://neogames.fi/wp-content/uploads/2023/05/FGIR2022report.pdf.

21 Mobygames gives a brief history of Mirage Media, see Mobygames (n.d.). Mirage Media S. C. Available at: www.mobygames.com/company/1109/mirage-media-s-c. Accessed March 12, 2024.

22 The game sold 18,000 units on its first day of release in Poland, compared to sales of 1,000 to 2,000 for past releases of CD Projekt according to, Pitts, R. (2014). How the team behind The Witcher conquered Poland. Polygon. Available at: www.polygon.com/features/2014/7/16/5884227/cd-projekt-the-witcher-3. Witcher's development had troubles, and BioWare – the developer of the Baldur's Gate series – ultimately had to provide CD Projekt with a license to BioWare's Aurora 3D game engine. BioWare also provided CD Projekt with a space at the E3 convention in the United States, which helped CD Projekt to secure a global publisher for Witcher.

23 EGDF (2021). *2021 European Video Games Industry Insight Report*. European Game Developers Federation. Available at: 2021 report:https://www.egdf.eu/video-game-industry-report2021.

24 For more details, see Marszałkowski, J., S. Biedermann and E. Rutkowski (2023). *The Game Industry of Poland – Report 2023*. Polish Agency for Enterprise Development. Available at: https://en.parp.gov.pl/storage/publications/pdf/The_Game_Industry_Poland_2023_12_07.pdf.

25 According to, PwC (2023). *Perspectives from the Global Entertainment and Media Outlook 2023–2027*. Available at: www.pwc.com/gx/en/industries/tmt/media/outlook/insights-and-perspectives.html.

26 Lampel and colleagues examine how managers within creative industries are typically faced with the problem of reconciling artistic values, on one hand, which are the basis for value creation within these industries, with economic considerations, on the other. See Lampel, J., T. Lant and J. Shamsie (2000). Balancing act: Learning from organizing practices in cultural industries. *Organization Science*, 11(3), 263–269. DOI: https://doi.org/10.1287/orsc.11.3.263.12503.

27 Based on WIPO analysis of Mobygames data spanning 1950 - 2018.

28 In the video game industry (and the movie industry), the term 'IP' is often used as shorthand for a franchise rather than the broader set of intellectual property (although still referring to intellectual property). This usage can probably be attributed to the fact that a franchise (generally represented by a trademark) is the key type of intellectual property within this industry. According to Tschang, developers prefer to create completely new products not only for artistic reasons, but also because by creating original IP they can increase their bargaining power with publishers. See Tschang, F.T. (2007). Balancing the tensions between rationalization and creativity in the video games industry. *Organization Science*, 18(6), 989–1005. DOI: https://doi.org/10.1287/orsc.1070.0299.

29 According to Gałuszka, D., M. Bobrowski, A. Krampus-Siepielak, P. Rodzińska-Szary and M. Śliwiński (2020). *The State of Polish Video Games Industry 2020 Report*. Kraków Technology Park with Polish Gamers Observatory and Partners.

30 For more details, see Marszałkowski, J., S. Biedermann and E. Rutkowski (2023). *The Game Industry of Poland – Report 2023*. Polish Agency for Enterprise Development. Available at: https://en.parp.gov.pl/storage/publications/pdf/The_Game_Industry_Poland_2023_12_07.pdf.

Technical notes

Country income groups

This report uses the World Bank income classification to refer to particular country groups. The classification is based on gross national income per capita in 2018 and establishes the following four groups: low-income economies (USD 1,135 or less); lower middle-income economies (USD 1,136 to USD 4,465); upper middle-income economies (USD 4,466 to USD 13,845); and high-income economies (USD 13,846 or more).

More information on this classification is available at http://data.worldbank.org/about/country-classifications.

Scientific publication data

The scientific publication data used in this report comes from scientific articles published from 2001 to 2022 in the Science Citation Index Expanded (SCIE) of the Web of Science (WOS), the citation database operated by the Clarivate Analytics company. The analysis focuses on observations referring only to scientific articles, conference proceedings, scientific abstracts and data papers. Scientific articles constitute the bulk of the resulting dataset.

Trademark data

The trademark data used in this report comes from WIPO's Global Brands Database (sourced in November 2023). The main unit of analysis is a trademark filing filed in a country by an applicant.

Patent data

The patent data used in this report are from the European Patent Office's (EPO) Worldwide Patent Statistical Database (PATSTAT, October 2023), the United States Patent and Trademark Office (USPTO) and WIPO's Patent Cooperation Treaty (PCT) collections.

The main unit of analysis is the first filing for a set of patent applications filed in one or more countries and claiming the same invention. Each set containing one first and, potentially, several subsequent filings is defined as a patent family.

The analysis also distinguishes foreign-oriented patent families – also referred to as international patent families – from domestic-only ones. Foreign-oriented patent families concern those inventions for which the applicant has sought for patent protection beyond its home patent office. This definition includes also patent applications by applicants filing only abroad, filing only through the PCT system or any international system (such as ARIPO, EPO, OAPI, etc.). Reciprocally, domestic-only patent families refer to those patent applications filed only at the applicant's home office – regardless of how many filings in the home office there are within the same family – without any subsequent foreign filing through the Paris or PCT routes.

Likewise, patent applications with applicants of more than one origin are foreign-oriented patent families.

Video game publishing data

Some video game data used in this report comes from the online wiki database www.mobygames.com accessed between 2016 and 2023. The data provide details on games, contributors, publishers and developers spanning games published from 1950 to 2018.

International trade data

The export data used in this report comes from the United Nations Commodity Trade Statistics Database (UN COMTRADE) extracted from the API in June, 2023. Export data on goods refers to statistics at SITC v.3 at the 3-digit level from 2001 to 2020. Export data on services refers to the Extended Balance of Payments Services Classification 2010 (EBOPS 2010) using the SDMX standard format.

Mapping strategies

The mapping strategy for each of the case studies – agricultural technologies, motorcycles and videogames – is based on prior studies and expert suggestions. Each strategy was compared to existing alternative sources whenever possible.

The scientific publication mapping strategies are based on a combination of journals' main scientific subjects and keywords searched for in abstracts. The patent mapping strategies are based on a combination of patent classifications – namely, the International Patent Classification (IPC) and the Cooperative Patent Classification (CPC) – and keywords searched for in PATSTAT data. The production mapping strategies are based on the categories from the Standard International Trade Classification (SITC) version 3.

A brief description of the three strategies follows.

Agricultural technologies

The agricultural technologies utility model and patent mapping is based on the combination of CPC and IPC symbol of "A01".

The statistics in the chapter for country-levels are based on the above-mentioned definition of patent families, including both international patent families and domestic-only ones.

UPOV data used in the chapter is based on data disclosed to UPOV by its Member States.

Motorcycles

The motorcycle patent mapping is based on the following combination of CPC and IPC symbols and keywords, sought in titles and abstracts. The statistics in the chapter are based on international patent families. These patents are classified in seven sub-categories of motorcycle-related technologies as follows:

Pure motorcycle: B62K11/00; B62M7/00; B60Y2200/12

Motorized scooter: B62K2202/00

Motorcycle parts: F02B61/02; B62J35/00; B62J37/00; B62J43/16; B60C2200/10

Other cycle parts that can be common in both motorcycle and bicycle: B62J1/00; B62J3/00; B62J6/00; B62J7/00; B62J7/02; B62J9/00; B62J11/00; B62J13/00; B62J15/00; B62J17/00; B62J19/00; B62J21/00; B62J23/00; B62J25/00; B62J29/00; B62J31/00; B62J33/00; B62J40/00;

B62J41/00; B62J43/00; B62J45/00;B62J50/00; B62J99/00Including keywords: motorcycle*; motorbike*; moped*; motor scooter*; scooter*; two wheeler*; two-wheeler*; three wheeler*; three-wheeler*

Broad vehicle: B62; B60; G06Q; G06F; G08G; H04W; B01D; F02D; F02M; F01N; F16D; F02B; Y02TIncluding keywords: motorcycle*; motorbike*; moped*; motor scooter*; scooter*; two wheeler*; two-wheeler*; three wheeler*; three-wheeler*

Electric motorcycle: B60L2200/12; B62K2204/00

Three wheeled cycles: B62K5/027

The motorcycle trade data refers to HS codes 871110, 871120, 871130, 871140, 871150, 871160, and 871190, in UN COMTRADE, from 2017 to 2022.

Video games

The video game industry patent mapping strategy is based on a combination of keywords CPC and IPC codes

Electronic versions of card games, board games, roulette or casino games: A63F 13*; A63F13*; A63F 9/24*; A63F 9/24*

Features of electronic games: A63F2300*

Software and processing technologies: G06*

Technologies for voice commands in gaming and interactive technologies: G10L*

Simulators and games for training: G09B*

interactive sports or physical games that have an electronic or digital component. A63B 69*; A63B69*

The search also includes the following keywords: video, consol, PC, comput, game, gaming, play, esport, e sport, e sports, electronic sport, e virtual realit, virtual-realit, virtual world, virtual-world, virtual-realit, mixed realit, augmented realit, augmented-realit

The trademark mapping strategy for this chapter involved searching trademark filling descriptions for combinations of the following keywords: video, computer, PC, console, game, gaming, e sport, esport, e-sport, video-game, and video-gaming.

Acronyms

1G	First-generation ethanol
2G	Second-generation ethanol
3D	Three dimensions/dimensional
AATF	African Agricultural Technology Foundation
AGRA	Alliance for a Green Revolution in Africa
AgTech	Agricultural technologies
AI	Artificial intelligence
AR	Augmented reality
ASTI	Agricultural Science and Technology Indicator
AV	Autonomous vehicles
B2B	Business-to-business
CD	Compact disc
CD-ROM	Compact disc – read-only memory
CGIAR	Consultative Group on International Agricultural Research
CIFOR-ICRAF	Center for International Forestry Research and World Agroforestry
CIMMYT	International Maize and Wheat Improvement Center
COVID-19	Coronavirus disease 2019
CRF	Coffee Research Foundation
EA	Electronic arts
e-bicycle	electric bicycle
ECI	Economic complexity indicator
EMBRAPA	Empresa Brasiliera de Pesquisa Agropecuária (Brazilian Agricultural Research Corporation)
EPO	European Patent Office
EU	European Union
EUR	Euro
EV	Electric vehicles
FAME	Faster Adoption and Manufacturing of Electric Vehicles schemes in India
FAO	United Nation’s Food and Agriculture Organization
FAPESP	Fundação de Amparo à Pesquisa do Estado de São Paulo (São Paulo Research Foundation)
FDI	Foreign direct investment
Gamedev	Game development
GDP	Gross Domestic Product
GE	Genetically-engineered
GHG	Greenhouse gas
HHI	Herfindahl–Hirschman index
IAC	Instituto Agronômico de Campinas (University of Agronomy in Campinas)
ICE	Internal combustion engine
ICT	Information and communication technology
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
IP	Intellectual property
IPC	International patent classification
IPR	Intellectual property right
ISAAA	International Service for the Acquisition of Agri-biotech Applications

IT	Information technology
JETRO	Japan External Trade Organization
J-LOD	Japan Content Localization and Distribution
KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Institute
KESREF	Kenya Sugar Research Foundation
MIT	Massachusetts Institute of Technology
MITI	MITI Japan’s Ministry of International Trade and Industry
MLN	Maize lethal necrosis
NES	Nintendo Entertainment System
NGO	Non-governmental organization
NOAA	National Oceanic and Atmospheric Administration
OBM	OBM Original brand manufacturers
OECD	Organisation for Economic Co-operation and Development
OEM	Original equipment manufacturers
PATSTAT EPO	Worldwide Patent Statistical Database
PC	Personal Computer
PLANALSUCAR	Programa Nacional de Melhoramento da Cana-de-Açúcar (National Sugarcane Improvement Program)
PPP	Purchasing power parity
PSP	PlayStation Portable
R&D	Research and development
RCA	Relative comparative advantage
RIDESA	Rede Interuniversitária para o Desenvolvimento do Setor Sucroenergético (Interuniversity Network for the Development of the Sugar-Energy Sector)
SDG	Sustainable Development Goal
SEUL	Finnish E-Sports Federation
SMS	Short messaging services
STI	Science, technology and innovation
TRFK	Tea Research Foundation of Kenya
UK	United Kingdom
UN	United Nations
UN COMTRADE	United Nations Commodity Trade Statistics Database
UNESCO	United Nations Educational, Scientific and Cultural Organization
UPOV	International Union for the Protection of New Varieties of Plantsce Citation Index Expanded
US	United States of America
USD	USD United States’ Dollar
USDA	United States’ Department of Agriculture
VR	Virtual reality
WDI	World Bank World Development Indicators
WIPO	World Intellectual Property Organization
WoS SCIE	Web of Science, Science Citation Index Expanded

Bibliography

AgFunder, 2023. *Africa AgriFood Tech Investment Report 2023*. AgFunder.

Aghion, P. and P. Howitt (1992). A model of growth through creative destruction. *Econometrica,* 60(2), 323–351. DOI: https://doi.org/10.2307/2951599.

Alexander, J.W. (2009). *Japan's Motorcycle Wars: An Industry History.* UBC Press.

Alston, J.M., P.G. Pardey, D. Serfas and S. Wang (2023). Slow magic: Agricultural versus industrial R&D lag models. *Annual Review of Resource Economics*, 15(1), 471–493. DOI: https://doi.org/10.1146/annurev-resource-111820-034312.

Amin, A. 1999. The Emilian model: Institutional challenges. *European Planning Studies*, 7(4), 389–405.

Arrow, K.J. (1962). The economic implications of learning by doing. *The Review of Economic Studies*, 29(3), 155–173. DOI: https://doi.org/10.2307/2295952.

Aversa, P. (2024). The Evolution of the Two-Wheeler Industry: A Comparative Study of Italy, Japan, and India. *WIPO Economic Research Working Paper Series*, (83). World Intellectual Property Organization.

Aversa, P., S. Furnari and M. Jenkins (2022). The primordial soup: Exploring the emotional microfoundations of cluster genesis. *Organization Science*, 33(4), 1340–1371.

Badiane, O., Makombe, T., 2015. Agriculture, Growth, and Development in Africa: Theory and Practice. In Monga, C., Lin, J.Y. (eds), *The Oxford Handbook of Africa and Economics: Policies and Practices. Part II: Microeconomic and Sectoral Issues*. Oxford University Press, New York, pp. 307–324. Available online: https://www.ifpri.org/publication/agriculture-growth-and-development-africa-theory-and-practice

Bahar, D. and H. Rapoport (2018). Migration, knowledge diffusion and the comparative advantage of nations. *The Economic Journal*, 128(612), F273–F305. DOI: https://doi.org/10.1111/ecoj.12450.

Baldos, U.L.C., F.G. Viens, T.W. Hertel and K.O. Fuglie (2019). R&D spending, knowledge capital, and agricultural productivity growth: A Bayesian approach. *American Journal of Agricultural Economics*, 101(1), 291–310. DOI: https://doi.org/10.1093/ajae/aay039.

Balland, P.A. and D. Rigby (2017). The geography of complex knowledge. *Economic Geography,* 93(1), 1–23.

Balland, P.-A. and R. Boschma (2022). Do scientific capabilities in specific domains matter for technological diversification in European regions? *Research Policy*, 51(10), 104594. DOI: https://doi.org/10.1016/j.respol.2022.104594.

Balland, P.-A., De Vaan, M., & Boschma, R. (2013). The dynamics of interfirm networks along the industry life cycle: The case of the global video game industry, 1987–2007. *Journal of Economic Geography*, 13(5), 741–765. Available at: https://doi.org/10.1093/jeg/lbs023

Balland, P.-A., R. Boschma, J. Crespo and D.L. Rigby (2019). Smart specialization policy in the European Union: Relatedness, knowledge complexity and regional diversification. *Regional Studies*, 53(9), 1252–1268. DOI: https://doi.org/10.1080/00343404.2018.1437900.

Balland, P.-A., T. Broekel, D. Diodato, E. Giuliani, R. Hausmann, N. O'Clery and D. Rigby (2022). The new paradigm of economic complexity. *Research Policy*, 51(3), 104450. DOI: https://doi.org/10.1016/j.respol.2021.104450.

BBVA, 2022. São Paulo, the largest innovation ecosystem in Latin America - BBVA. BBVA Spark Open Innovation. URL https://www.bbvaspark.com/contenido/en/news/land-of-unicorns-and-fintech-empire-this-is-sao-paulo-the-largest-innovation-ecosystem-in-latin-america/ (accessed 11.13.23).

Beintema, N., Pratt, A.N., Stads, G.-J., 2020. ASTI Global Update 2020 (Washington, D.C.), Agricultural Science and Technology Indicators Program Note. International Food Policy Research Institute.

Bishop, G. and S. Barrington (1995). *Encyclopedia of Motorcycling*. London: Bison Group.

Bolt, J. and J.L. Van Zanden (2020). Maddison style estimates of the evolution of the world economy: A new 2020 update. *Maddison-Project Working Paper No. WP-15*. University of Groningen.

Boschma, R. (2017). Relatedness as driver of regional diversification: A research agenda. *Regional Studies*, 51(3), 351–364. DOI: https://doi.org/10.1080/00343404.2016.1254767.

Boschma, R. (2022). Designing Smart Specialization Policy: Relatedness, unrelatedness, or what? In Anderson, M., C. Karlsson and S. Wixe (eds), *Handbook of Spatial Diversity and Business Economics*. Oxford: Oxford University Press, forthcoming.

Boschma, R., A. Minondo and M. Navarro (2013). The emergence of new industries at the regional level in Spain: A proximity approach based on product relatedness. *Economic Geography*, 89(1), 29–51.

Boschma, R., K. Frenken, H. Bathelt, M. Feldman and D. Kogler (2012). Technological relatedness and regional branching. Beyond territory: *Dynamic Geographies of Knowledge Creation, Diffusion and Innovation*, 29, 64–68.

Boyer, J.S., P. Byrne, K.G. Cassman, M. Cooper, D. Delmer, T. Greene, F. Gruis, J. Habben, N. Hausmann, N. Kenny, R. Lafitte, S. Paszkiewicz, D. Porter, A. Schlegel, J. Schussler, T. Setter, J. Shanahan, R.E. Sharp, T.J. Vyn, … J. Gaffney (2013). The U.S. drought of 2012 in perspective: A call to action. *Global Food Security*, 2(3), 139–143. DOI: https://doi.org/10.1016/j.gfs.2013.08.002.

Brondoni, S. (2021). Global competition & state intervention – The genesis of Japan's motorcycle global leaders: Honda, Suzuki, Kawasaki & Yamaha. Symphonya: *Emerging Issues in Management*, 1, 7–22.

Brusco, S. (1982). The Emilian model: Productive decentralisation and social integration. *Cambridge Journal of Economics*, 6(2), 167–184.

Bruton, H.J. (1998). A reconsideration of import substitution. *Journal of Economic Literature*, 36(2), 903–936.

Burton, A. and B. Carson. (2022). The gaming industry is only just beginning to address its diversity problem. Protocol. Available at: www.protocol.com/workplace/gaming-industry-diversity-reports.

Carroll, G.R., L.S. Bigelow, M.-D.L. Seidel and L.B. Tsai (1996). The fates of de novo and de alio producers in the American automobile industry 1885–1981. *Strategic Management Journal*, 17(S1), 117–137.

Cenzatti, M. (1990). Restructuring in the motorcycle industry in Great Britain and Italy until 1980. *Environment and Planning D: Society and Space*, 8(3), 339–355.

Chakraborty, R. and S. Chakravarty (2023). Factors affecting acceptance of electric two-wheelers in India: A discrete choice survey. *Transport policy,* 132, 27–41.

Clancy, M., P. Heisey, Y. Ji and G. Moschini (2020). The Roots of Agricultural Innovation: Patent Evidence of Knowledge Spillovers. In P. Moser (ed.) *Economics of Research and Innovation in Agriculture.* University of Chicago Press, 21–75. Available at: https://www.nber.org/books-and-chapters/economics-research-and-innovation-agriculture/roots-agricultural-innovation-patent-evidence-knowledge-spillovers.

Clark, K.B., W.B. Chew, T. Fujimoto, J. Meyer and F.M. Scherer (1987). Product development in the world auto industry. *Brookings Papers on Economic Activity*, 1987(3), 729–781.

Cohen, W.M. and D.A. Levinthal (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, 128–152. DOI: https//doi.org/10.2307/2393553.

Corcioli, G., G. da S. Medina and C.A. Arrais (2022). Missing the target: Brazil's agricultural policy indirectly subsidizes foreign investments to the detriment of smallholder farmers and local agribusiness. *Frontiers in Sustainable Food Systems*, 5. Available at: www.frontiersin.org/articles/10.3389/fsufs.2021.796845.

Correa, P. and C. Schmidt (2014). Public research organizations and agricultural development in Brazil: How did EMBRAPA get it right? *Economic Premise* No. 145. World Bank. Available at: http://documents.worldbank.org/curated/en/156191468236982040/Public-research-organizations-and-agricultural-development-in-Brazil-how-did-Embrapa-get-it-right.

Coscia, M., F.M. Neffke and R. Hausmann (2020). Knowledge diffusion in the network of international business travel. *Nature Human Behaviour*, 4(10), 1011–1020. DOI: https://doi.org/10.1038/s41562-020-0922-x.

Crescenzi, R., A. Dyèvre and F. Neffke (2022). Innovation catalysts: how multinationals reshape the global geography of innovation. *Economic Geography*, 98(3), 199–227. DOI: https://doi.org/10.1080/00130095.2022.2026766.

Crescenzi, R., S. Iammarino, C. Ioramashvili, A. Rodríguez-Pose and M. Storper (2019). The Geography of Innovation: Local Hotspots and Global Innovation Networks. *WIPO Economic Research Working Paper No. 57*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4471.

Cristelli M, A. Tacchella and L. Pietronero (2015). The heterogeneous dynamics of economic complexity. *PLoS ONE*, 10(2), e0117174. Available at: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0117174.

D'Alessandro, S.P., J. Caballero, J. Lichte and S. Simpkin (2015). *Kenya: Agricultural Sector Risk Assessment*. Available at: http://hdl.handle.net/10986/23350.

da Silva Medina, G. and B. Pokorny (2022). Agro-industrial development: Lessons from Brazil. *Land Use Policy* 120, 106266. DOI: https://doi.org/10.1016/j.landusepol.2022.106266.

Daly, A., D. Humphreys, J. Raffo and G. Valacchi (eds). (2022). *Global Challenges for Innovation in Mining Industries*. Cambridge University Press. DOI: https://doi.org/10.1017/9781108904209.

de C. L. e Penalva Santos, D., C. Correa, Y. Amaral Alves, C. Gomes Souza and R.A. Mancebo Boloy (2023). Brazil and the world market in the development of technologies for the production of second-generation ethanol. *Alexandria Engineering Journal*, 67, 153–170. DOI: https://doi.org/10.1016/j.aej.2022.09.004.

de Castro, C.N. (2014). Agriculture in Brazil's Southeast Region: *Limitations and Future Challenges to Development* (Texto para Discussão, No. 1952a). Instituto de Pesquisa Econômica Aplicada (IPEA). Available at: http://hdl.handle.net/10419/121530.

De Vaan, M., Boschma, R., & Frenken, K. (2013). Clustering and firm performance in project-based industries: the case of the global video game industry, 1972–2007. *Journal of Economic Geography*, 13(6), 965–991. Available at: https://doi.org/10.1093/jeg/lbs038.

Dealessandri, M. (2023). Scenario raises $6m ahead of AI-powered art engine early access. Games Industry.biz. Available at: www.gamesindustry.biz/scenario-raises-6m-ahead-of-ai-powered-art-engine-early-access.

Deegan, J., T. Broekel and R.D. Fitjar (2021). Searching through the haystack: The relatedness and complexity of priorities in smart specialization strategies. *Economic Geography*, 97(5), 497–520.

Donke, A., A. Nogueira, P. Matai and L. Kulay (2017). Environmental and energy performance of ethanol production from the integration of sugarcane, corn, and grain sorghum in a multipurpose plant. *Resources*, 6(1), 1. DOI: https://doi.org/https://doi.org/10.3390/resources6010001.

dos Santos e Silva, D.F., J.V. Bomtempo and F.C. Alves (2019). Innovation opportunities in the Brazilian sugar-energy sector. *Journal of Cleaner Production*, 218, 871–879. DOI: https://doi.org/10.1016/j.jclepro.2019.02.062.

Dosi, G. (1988). Sources, procedures, and microeconomic effects of innovation. *Journal of Economic Literature*, 1120–1171.

Dosi, G., C. Freeman, R. Nelson, G. Silverberg and L. Soete (eds) (1988). *Technical Change and Economic Theory* (Vol. 988). London: Pinter.

Economic Times (2021). EV Day Special In-depth: India's 2W industry approaches a crossroad; will electrification take over?

Economic Times [online]. Available at: https://auto.economictimes.indiatimes.com/news/two-wheelers/scooters-mopeds/ev-day-special-in-depth-indias-2w-industry-approaches-a-crossroad-will-electrification-take-over/86025614.

EGDF (2021). *2021 European Video Games Industry Insight Report*. European Game Developers Federation. Available at: 2021 report: https://www.egdf.eu/video-game-industry-report2021.

Elekes, Z., R. Boschma and B. Lengyel (2019). Foreign-owned firms as agents of structural change in regions. *Regional Studies*, 53(11), 1603–1613. DOI: https://doi.org/10.1080/00343404.2019.1596254.

Energica Inside (2022). Energica inside: About us. Energica Motor Company [online]. Available at: www.energicamotor.com/us/energica-inside-about-us.

Energica News (2023a). Energica Inside applications on ultralight airplanes sector. Energica Motor Company [online]. Available at: www.energicamotor.com/us/news/energica-inside-applications-on-ultralight-airplanes-sector.

Energica News (2023b). Plenitude and Energica together to provide new innovative solutions for electric mobility. Energica Motor Company [online]. Available at: www.energicamotor.com/us/news/plenitude-and-energica-together-to-provide-new-innovative-solutions-for-electric-mobility.

EPE (2018). Energy Demand of Light Duty Vehicle: 2018-2030 (No. 01). Empresa de Pesquisa Energética, Rio de Janeiro

ESA (2022). *Essential Facts about the Video Game Industry*. Entertainment Software Association. Available at: www.theesa.com/resource/2022-essential-facts-about-the-video-game-industry.

Evenett, S., A. Jakubik, F. Martín and M. Ruta. (2024). The return of industrial policy in data. *IMF Working Paper No. 2024/001*. International Monetary Fund. Available at: www.imf.org/en/Publications/WP/Issues/2023/12/23/The-Return-of-Industrial-Policy-in-Data-542828.

Falck-Zepeda, J. B., P. Zambrano, J.I. Cohen, O. Borges, E.P. Guimaraes, D. Hautea, J. Kengue and J. Songa (2008). Plant Genetic Resources for Agriculture, plant breeding, and biotechnology. *IFPRI Discussion Paper*. International Food Policy Research Institute. Available at: www.ifpri.org/publication/plant-genetic-resources-agriculture-plant-breeding-and-biotechnology.

FAO (1996). *Agro-Ecological Zoning Guidelines* (FAO Soils Bulletin 73). Food and Agriculture Organization. Available at: https://www.fao.org/3/W2962E/w2962e00.htm#P-2.

FAO (2020). *The Share of Agriculture in Total Greenhouse Gas Emission*: Global, Regional and Country Trends 1990–2017 (FAOSTAT Analytical Brief Series No. 1). Food and Agriculture Organization. Available at: www.fao.org/documents/card/en/c/ca8389en.

Fink, C. (2022). Calculating private and social returns to COVID-19 vaccine innovation. *WIPO Economic Research Working Paper No. 68*. World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4595&plang=EN.

Fink, C. and J. Raffo (2019). What role for intellectual property in industrial development? In Correa, C. and X. Seuba (eds), *Intellectual Property and Development: Understanding the Interfaces*. Springer Singapore, 119–136. DOI: https://doi.org/10.1007/978-981-13-2856-5.

Foray, D. (2014). *Smart Specialisation: Opportunities and Challenges for Regional Innovation Policy*. London: Routledge.

Foray, D. (2019). In response to ‘Six critical questions about smart specialization’. *European Planning Studies*, 27:10, 2066–2078. DOI: https://doi.org/10.1080/09654313.2019.1664037.

Foray, D., P.A. David and B. Hall (2009). Smart specialisation: The concept. In *Knowledge for Growth: Prospects for Science, Technology and Innovation*, EUR 24047 EN. European Commission. Available at: https://ec.europa.eu/invest-in-research/pdf/download_en/selected_papers_en.pdf.

Fuglie, K., M. Gautam, A. Goyal, and W.F. Maloney (2019). Sources of Growth in Agriculture. In Fuglie, K., M. Gautam, A. Goyal, and W. Maloney (eds), *Harvesting Prosperity: Technology and Productivity Growth in Agriculture*. World Bank, 1–42. DOI: https://doi.org/10.1596/978-1-4648-1393-1_ch1.

Furman, J. L., M. E. Porter, and S. Stern (2002). The determinants of national innovative capacity. *Research Policy*, 31(6), 899–933. DOI: https://doi.org/10.1016/S0048-7333(01)00152-4.

Furtado, A.T., M.P. Hekkert and S.O. Negro (2020). Of actors, functions, and fuels: Exploring a second generation ethanol transition from a technological innovation systems perspective in Brazil. *Energy Research & Social Science*, 70, 101706. DOI: https://doi.org/10.1016/j.erss.2020.101706.

Gaffney, J., M. Challender, K. Califf and K. Harden (2019). Building bridges between agribusiness innovation and smallholder farmers: A review. *Global Food Security*, 20, 60–65. DOI: https://doi.org/10.1016/j.gfs.2018.12.008.

Gałuszka, D., M. Bobrowski, A. Krampus-Siepielak, P. Rodzińska-Szary and M. Śliwiński (2020). *The State of Polish Video Games Industry 2020 Report*. Kraków Technology Park with Polish Gamers Observatory and Partners.

Game Makers of Finland. (2022). *Finnish Game Industry Salary Survey 2022: Results and Conclusions*. Available at: https://peliala.fi/wp-content/uploads/2023/03/Game_Makers_of_Finland_Salary_Survey_Results_2023.pdf

Gavetti, G. (2001). Ducati. *Harvard Business School: Case, 701132*.

Gerlach, M.L. (1992). *Alliance Capitalism: The Social Organization of Japanese Business*. University of California Press.

Giuri, P., M. Mariani, S. Brusoni, G. Crespi, D. Francoz, A. Gambardella, W. Garcia-Fontes, A. Geuna, R. Gonzales, D. Harhoff, K. Hoisl, C. Le Bas, A. Luzzi, L. Magazzini, L. Nesta, Ö. Nomaler, N. Palomeras, P. Patel, M. Romanelli and B. Verspagen (2007). Inventors and invention processes in Europe: Results from the PatVal–EU survey. *Research Policy*, 36(8), 1107–1127. DOI: https://doi.org/10.1016/j.respol.2007.07.008.

Glassdoor. (2023). *How much does a Game Developer make in Poland?* Game Developer Salaries. Available at: https://www.glassdoor.com/Salaries/poland-game-developer-salary-SRCH_IL.0,6_IN193_KO7,21.htm

Graff, G.D. and I. Hamdan-Livramento (2019). Global Roots of Innovation in Plant Biotechnology. *WIPO Economics Working Paper No. 59*. World Intellectual Property Organization.

Graff, G.D., A. Berklund and K. Rennels (2014). *The Emergence of an Innovation Cluster in the Agricultural Value Chain along Colorado’s Front Range*. Colorado State University.

Griliches, Z. (1957). Hybrid corn: An exploration in the economics of technological change. *Econometrica*, 25(4), 501–522. DOI: https://doi.org/10.2307/1905380.

Grizzi, O. and M. Clarke (2014). La moto italiana: *le grandi marche dalle origini a oggi*. Giunti.

Hamdan-Livramento, I., G.D. Graff and A. Daly (2024). Innovation Complexity in AgTech: The Case of Brazil, Kenya and the United States. *WIPO Economics Working Paper Series no. 81*. World Intellectual Property Organization.

Hanushek, E. and L. Woessman. (2015). *The Knowledge Capital of Nations: Education and the Economics of Growth*. MIT Press.

Hausmann, R. and F.M. Neffke (2019). The workforce of pioneer plants: The role of worker mobility in the diffusion of industries. *Research Policy*, 48(3), 628–648. DOI: https//doi.org/10.1016/j.respol.2018.10.017.

Hausmann, R. and L. Nedelkoska (2018). Welcome home in a crisis: Effects of return migration on the non-migrants' wages and employment. *European Economic Review*, 101, 101–132. DOI: https://doi.org/10.1016/j.euroecorev.2017.10.003.

Hausmann, R., C.A. Hidalgo, S. Bustos, M. Coscia and A. Simoes (2014). The Atlas of Economic Complexity: *Mapping Paths to Prosperity*. MIT Press.

Hausmann, R., D. Stock and M.A. Yildirim (2022). Implied comparative advantage. *Research Policy*, 51(8), 104143. DOI: https//doi.org/10.1016/j.respol.2020.104143.

Hausmann, R., M.A. Yildirim, C. Chacua, S. Gadgin Matha and M. Hartog (2024). Global Trends in Innovation Patterns: A Complexity Approach. *WIPO Economic Research Working Paper No. 80*. World Intellectual Property Organization.

Haussmann, R., C.A. Hidalgo, S. Bustos, M. Coscia, A. Simoes and M.A. Yildirim (2014). *The Atlas of Economic Complexity*: Mapping Paths to Prosperity. The MIT Press.

Haussmann, R., M.A. Yildirim, C. Chacua, M. Hartog and S. Gadgin Matha (2024). Innovation policies under economic complexity. *WIPO Economic Research Working Paper No. 79*. World Intellectual Property Organization.

Havard Growth Lab (2023). The Atlas of Economic Complexity. Available at: https//atlas.cid.harvard.edu [accessed September 26, 2023].

Henderson, R. (1993). Underinvestment and incompetence as responses to radical innovation: Evidence from the photolithographic alignment equipment industry. *The RAND Journal of Economics*, 248–270.

Henderson, R.M. and K.B. Clark (1990). Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. *Administrative science quarterly*, 9–30.

Herbig, P. and L. Jacobs (1997). A historical perspective of Japanese innovation. *Management Decision*, 35(10), 760–778.

Hidalgo, C.A. (2021). Economic complexity theory and applications. *Nature Reviews Physics*, 3(2), 92–113.

Hidalgo, C.A. (2022). The policy implications of economic complexity. *arXiv preprint arXiv:2205.02164*. Available at: https://arxiv.org/ftp/arxiv/papers/2205/2205.02164.pdf.

Hidalgo, C.A. and R. Hausmann (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences*, 106(26), 10570–10575.

Hidalgo, C.A. and R. Hausmann (2009). The building blocks of economic complexity. *Proceedings of the national academy of sciences*, 106(26), 10570–10575.

Hidalgo, C.A., B. Klinger, A.-L. Barabási and R. Hausmann (2007). The product space conditions the development of nations. *Science*, 317(5837), 482–487. DOI: https//doi.org/10.1126/science.1144581.

Hidalgo, C.A., P.-A. Balland, R. Boschma, M. Delgado, M. Feldman, K. Frenken, E. Glaeser, C. He, D.F. Kogler, A. Morrison, F. Neffke, D. Rigby, S. Stern, S. Zheng and S. Zhu (2018). The principle of relatedness. In Morales, A., C. Gershenson, D. Braha, A. Minai and Y. Bar-Yam (eds), *Unifying Themes in Complex Systems IX: Proceedings of the Ninth International Conference on Complex Systems.* Cham: Springer, 451–457. DOI: https://doi.org/10.1007/978-3-319-96661-8_46.

Hufbauer, G.C. and E. Jung (2021). Scoring 50 years of US industrial policy, 1970–2020. Peterson Institute for International Economics. Available at: www.piie.com/publications/piie-briefings/scoring-50-years-us-industrial-policy-1970-2020.

Hughes, N. and S. Lonie (2007). M-PESA: Mobile money for the "unbanked" turning cellphones into 24-hour tellers in Kenya. *Innovations: Technology, Governance, Globalization*, 2(1–2), 63–81. DOI: https://doi.org/10.1162/itgg.2007.2.1-2.63.

IEA (2023). *Global EV Outlook 2023*. International Energy Agency. Available at: www.iea.org/reports/global-ev-outlook-2023.

Innomantra (2011). *Patent Portfolio of Major Indian Automobile Companies*. Bangalore: Innomantra. Available at: https://innomantra.com/images/pdf/Innomantra%20-%20Patent%20Portfolio%20of%20Major%20Indian%20Automobile%20Companies.pdf.

Irwin, D.A. (2021). The rise and fall of import substitution. *World Development*, 139, 105306. DOI: https://doi.org/10.1016/j.worlddev.2020.105306.

Iyer, N.V. and M.G. Badami (2007). Two-wheeled motor vehicle technology in India: Evolution, prospects and issues. *Energy Policy*, 35(8), 4319–4331.

Johnson, C. (1982). *MITI and the Japanese Miracle: The Growth of Industrial Policy,* 1925–1975. Stanford University Press.

Jones, B.F. (2014a). The human capital stock: A generalized approach. *American Economic Review*, 104(11), 3752–3777. DOI: https://doi.org/10.1257/aer.104.11.3752.

Jones, B.F. (2014b). The knowledge trap: Human capital and development reconsidered. *Northwestern University Working Paper*. Available at: www.kellogg.northwestern.edu/faculty/jones-ben/htm/Knowledge%20Trap.pdf.

Jones, B.F. and L.H. Summers (2020). A calculation of the social returns to innovation. *National Bureau of Economic Research Working Paper No. 27863*. DOI: https://doi.org/10.3386/W27863.

Juhász, R., N.J. Lane and D. Rodrik (2023). The new economics of industrial policy. *National Bureau of Economic Research Working Paper No. 3153*. Available at: www.nber.org/papers/w31538.

Kassie, M., Marenya, P., Tessema, Y., Jaleta, M., Zeng, D., Erenstein, O., Rahut, D., 2018. Measuring Farm and Market Level Economic Impacts of Improved Maize Production Technologies in Ethiopia: Evidence from Panel Data. *Journal of Agricultural Economics* 69, 76–95. DOI: https://doi.org/10.1111/1477-9552.12221.

Kim, S.R. (1998). The Korean system of innovation and the semiconductor industry: A governance perspective. *Industrial and Corporate Change*, 7(2), 275–309. DOI: https://doi.org/10.1093/icc/7.2.275.

Kingiri, A.N. (2022). Exploring innovation capabilities build up in the deployment of crop biotechnology innovation in

Kenya. *Innovation and Development*, 12(2), 305–324. DOI: https://doi.org/10.1080/2157930X.2021.1884934.

Kingiri, A.N. and A. Hall (2012). The role of policy brokers: The case of biotechnology in Kenya. *Review of Policy Research*, 29(4), 492–522. DOI: https://doi.org/10.1111/j.1541-1338.2012.00573.x.

Klepper, S. (2007). Disagreements, spinoffs, and the evolution of Detroit as the capital of the US automobile industry. *Management Science*, 53(4), 616–631.

Kogler, D.F., E. Evenhuis, E. Giuliani, R. Martin, E. Uyarra and R. Boschma (2023). Re-imagining evolutionary economic geography. *Cambridge Journal of Regions, Economy and Society*, 16(3), 373–390.

Koyama, Y. (2023). *History of the Japanese Video Game Industry*. Springer Nature.

Lampel, J., T. Lant and J. Shamsie (2000). Balancing act: Learning from organizing practices in cultural industries. *Organization Science*, 11(3), 263–269. DOI: https://doi.org/10.1287/orsc.11.3.263.12503.

Lerner, J. (2009). Boulevard of Broken Dreams: *Why Public Efforts to Boost Entrepreneurship and Venture Capital Have Failed – And What to Do About It*. Princeton University Press.

Li, Y. and F. Neffke (2023). Evaluating the principle of relatedness: Estimation, drivers and implications for policy. *CID Research Fellows and Graduate Student Working Paper Series No. 146*. Cambridge, MA: Center for International Development at Harvard University.

Lipparini, A., G. Lorenzoni and S. Ferriani (2014). From core to periphery and back: A study on the deliberate shaping of knowledge flows in interfirm dyads and networks. *Strategic Management Journal*, 35(4), 578–595.

Lowder, S.K., Skoet, J., Singh, S., n.d. What do we really know about the number and distribution of farms and family farms worldwide? Background paper for *The State of Food and Agriculture 2014*.

Lucas Jr, H.C. and J.M. Goh (2009). Disruptive technology: How Kodak missed the digital photography revolution. *The Journal of Strategic Information Systems*, 18(1), 46–55.

Manochio, C., B.R. Andrade, R.P. Rodriguez and B.S. Moraes (2017). Ethanol from biomass: A comparative overview. *Renewable and Sustainable Energy Reviews*, 80, 743–755. DOI: https://doi.org/10.1016/j.rser.2017.05.063.

Marrocu, E., R. Paci, D. Rigby and S. Usai (2023). Evaluating the implementation of Smart Specialisation policy. *Regional Studies*, 57(1), 112–128. https://doi.org/10.1080/00343404.2022.2047915.

Marszałkowski, J., S. Biedermann and E. Rutkowski (2023). *The Game Industry of Poland – Report 2023*. Polish Agency for Enterprise Development. Available at: https://en.parp.gov.pl/storage/publications/pdf/The_Game_Industry_Poland_2023_12_07.pdf.

Martin, X., W. Mitchell and A. Swaminathan (1995). Recreating and extending Japanese automobile buyer–supplier links in North America. *Strategic Management Journal*, 16(8), 589–619.

Maskell, P. and A. Malmberg (1999). The competitiveness of firms and regions: 'Ubiquitification' and the importance of localized learning. *European urban and regional studies*, 6(1), 9–25. DOI: https://doi.org/10.1177/096977649900600102.

Mazumdar, M. (2013). An overview of the Indian pharmaceutical sector. In *Performance of Pharmaceutical Companies in India*. Berlin: Springer, 17–44.

Mazzucato, M. (2015). *The Entrepreneurial State: Debunking Public vs. Private Sector Myths* (Revised edition). New York, NY: PublicAffairs.

McFadden, J., D. Smith, S. Weschsler and S. Wallander (2019). Development, Adoption, and Management of Drought-Tolerant Corn in the United States. *Economic Information Bulletin Number 204*. United States Department of Agriculture: Foreign Agricultural Service.

McKinsey (2022). *The Future of Mobility: Transforming to be Ahead of the Opportunity*. McKinsey & Company. Available at: www.mckinsey.com/~/media/mckinsey/industries/automotive%20and%20assembly/our%20insights/the%20future%20of%20mobility%20transforming%20to%20be%20ahead%20of%20the%20opportunity/the-future-of-mobility-transforming-to-be-ahead-of-the-opportunity.pdf.

Medina, G. da S. and A.P. dos Santos (2017). Curbing enthusiasm for Brazilian agribusiness: The use of actor-specific assessments to transform sustainable development on the ground. *Applied Geography*, 85, 101–112. DOI: https://doi.org/10.1016/j.apgeog.2017.06.003.

Mewes, L. and T. Broekel (2022). Technological complexity and economic growth of regions. *Research Policy,* 51(8), 104156. DOI: https://doi.org/10.1016/j.respol.2020.104156.

Miguelez, E. and A. Morrison (2022). Migrant inventors as agents of technological change. *The Journal of Technology Transfer,* 48, 669–692. DOI: https://dx.doi.org/10.2139/ssrn.4256518.

Mobygames (n.d.). Mirage Media S. C. Available at: www.mobygames.com/company/1109/mirage-media-s-c.

Morrison, A. and R. Boschma (2019). The spatial evolution of the Italian motorcycle industry (1893–1993): Klepper's heritage theory revisited. *Industrial and Corporate Change*, 28(3), 613–634.

Moscatelli, F., C. Chacua, S. Gadgin Matha, M. Hartog, E. Hernandez Rodriguez, J.D. Raffo and M.A. Yildirim (2024). Can we map innovation capabilities? *WIPO Economic Research Working Paper No. 81*. World Intellectual Property Organization.

Motion Picture Association (2022). *Theme Report 2021*. Available at: www.motionpictures.org/research-docs/2021-theme-report.

Mueller, B. and C. Mueller (2016). The political economy of the Brazilian model of agricultural development: Institutions versus sectoral policy. *The Quarterly Review of Economics and Finance,* 62, 12–20. DOI: https://doi.org/10.1016/j.qref.2016.07.012.

Muffatto, M. and R. Panizzolo (1996). Innovation and product development strategies in the Italian motorcycle industry. *Journal of Product Innovation Management,* 13(4), 348–361.

Neffke, F. and M. Henning (2013). Skill relatedness and firm diversification. *Strategic Management Journal*, 34, 297–316. DOI: https://doi.org/10.1002/smj.2014.

Neffke, F., M. Hartog, R. Boschma and M. Henning (2018). Agents of structure change: The role of firms and entrepreneurs in regional diversification. *Economic Geography*, 94(1), 23–48. DOI: https://doi.org/10.1080/00130095.2017.1391691.

Neffke, F., M. Henning and R. Boschma. (2011). How do regions diversify over time? Industry relatedness and the development of new growth paths in regions. *Economic Geography*, 87(3), 237–265. DOI: https://doi.

org/10.1111/j.1944-8287.2011.01121.x.

Nelson, K.P. and K. Fuglie (2022). USDA ERS – Investment in US public agricultural research and development has fallen by a third over past two decades, lags major trade competitors. *Amber Waves*, June 6. Economic Research Service, US Department of Agriculture. Available at: www.ers.usda.gov/amber-waves/2022/june/investment-in-u-s-public-agricultural-research-and-development-has-fallen-by-a-third-over-past-two-decades-lags-major-trade-competitors.

Nelson, R.R. and S.G. Winter (1982). The Schumpeterian tradeoff revisited. *The American Economic Review*, 72(1), 114–132.

Neogames (2023). *The Game Industry of Finland: Report 2022*. Available at: https://neogames.fi/wp-content/uploads/2023/05/FGIR2022report.pdf.

Newzoo (2023). Free Edition: *Global Games Market Report, 2023*. Available at: https://newzoo.com/resources/trend-reports/newzoo-global-games-market-report-2023-free-version.

OECD (2013). *Innovation-driven Growth in Regions: The Role of Smart Specialisation*. Organisation for Economic Co-operation and Development. Available at: www.oecd.org/sti/inno/smartspecialisation.htm.

OECD (2023). OECD Data: Average wages. Organisation for Economic Co-operation and Development. Available at: https://data.oecd.org/earnwage/average-wages.htm.

OECD (2023). OECD–FAO *Agricultural Outlook 2023–2032*. Organisation for Economic Co-operation and Development. Available at: www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2023-2032_08801ab7-en.

Oguguo, P. (2024). Innovation and Intellectual Property Use in the Global Video Game Industry. *WIPO Economic Research Working Paper No. 85*. World Intellectual Property Organization.

Ohno, K. (2006). *The Economic Development of Japan: The Path Traveled by Japan as a Developing Country.* GRIPS Development Forum.

Onsongo, E. (2019). Institutional entrepreneurship and social innovation at the base of the pyramid: The case of M-Pesa in Kenya. *Industry and Innovation*, 26(4), 369–390. DOI: https://doi.org/10.1080/13662716.2017.1409104.

Oostendorp, R., M. van Asseldonk, J. Gathiaka, R. Mulwa, M. Radeny, J. Recha, C. Wattel and L. van Wesenbeeck (2019). Inclusive agribusiness under climate change: A brief review of the role of finance. *Current Opinion in Environmental Sustainability*, 41, 18–22. DOI: https://doi.org/10.1016/j.cosust.2019.09.014.

Orsenigo, L. (2001). The (failed) development of a biotechnology cluster: The case of Lombardy. *Small Business Economics*, 17(1/2), 77–92.

Oshima, K. (1984). Technological innovation and industrial research in Japan. *Research Policy*, 13(5), 285–301.

Özalp, H. (2024). Heterogeneous development paths to growth and innovation: The evolution of the video game industry across four hubs. *WIPO Economic Research Working Paper No. 84*. World Intellectual Property Organization.

Pandey, A., A. Aggarwal, R. Devane and Y. Kuznetsov (2006). The Indian diaspora: A unique case? In Kuznetsov, Y. (ed.), *Diaspora Networks and the International Migration of Skills*. World Bank Institute Development Studies, 71–97.

Pardey, P.G., C. Chan-Kang, S.P. Dehmer and J.M. Beddow (2016). Agricultural R&D is on the move. *Nature* 537(7620), 301–303. DOI: https://doi.org/10.1038/537301a.

Parikh, A. (1979). Estimation of supply functions for coffee. *Applied Economics*, 11(1), 43–54. DOI: https://doi.org/10.1080/758520522

Patel, D., J. Sandefur and A. Subramanian (2021). The new era of unconditional convergence. *Journal of Development Economics*, 152, 1026687. DOI: https//doi.org/10.1016/j.jdeveco.2021.102687.

Pinheiro, F.L., D. Hartmann, R. Boschma and C.A. Hidalgo (2021). The time and frequency of unrelated diversification. *Research Policy*, 51(8), 104323.

Pinheiro, F.L., P.A. Balland, R. Boschma and D. Hartmann (2022). The dark side of the geography of innovation: relatedness, complexity and regional inequality in Europe. *Regional Studies*, 1–16. DOI: 10.1080/00343404.2022.2106362.

Pitts, R. (2014). How the team behind The Witcher conquered Poland. Polygon. Available at: www.polygon.com/features/2014/7/16/5884227/cd-projekt-the-witcher-3.

Polanyi, M. 1966. *The Tacit Dimension*. Chicago: University of Chicago Press, 4.

Porter, J.R., Challinor, A., Cochrane, K., Howden, S.M., Iqbal, M.M., Lobell, D.B., Travasso, M.I., 2014. Food security and food production systems. In Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York.

Pritchett, L. (1997). Divergence, big time. *Journal of Economic Perspectives*, 11(3), 3–17. DOI: https//doi.org/10.1257/jep.11.3.3.

Pugliese, E., G. Cimini, A. Patelli, A. Zaccaria, L. Pietronero and A. Gabrielli (2019). Unfolding the innovation system for the development of countries: Coevolution of Science, Technology and Production. *Scientific Reports*, 9, 16440. DOI: https://doi.org/10.1038/s41598-019-52767-5.

PwC (2023). Perspectives from the Global Entertainment and Media Outlook 2023–2027. Available at: www.pwc.com/gx/en/industries/tmt/media/outlook/insights-and-perspectives.html.

Rada, N. (2013). Assessing Brazil's Cerrado agricultural miracle. *Food Policy*, 38, 146–155. DOI: https://doi.org/10.1016/j.foodpol.2012.11.002.

Raitzer, D.A., A.H. Sparks, Z. Huelgas, R. Maligalig, Z. Balangue, C. Launio, A. Daradjat and H.U. Ahmed (2015). *Is Rice Improvement Still Making a Difference? Assessing the Economic, Poverty and Food Security Impacts of Rice Varieties Released from 1989 to 2009 in Bangladesh, Indonesia and the Philippines*. Rome, Italy: CGIAR Independent Science and Partnership Council. [A report submitted to the Standing Panel on Impact Assessment (SPIA)]. Consultative Group on International Agricultural Research (CGIAR). Available at: https://research.usq.edu.au/item/q4418/is-rice-improvement-still-making-a-difference-assessing-the-economic-poverty-and-food-security-impacts-of-rice-varieties-released-from-1989-to-2009-in-bangladesh-indonesia-and-the-philippines.

Rigby, D.L., C. Roelser, D. Kogler, R. Boschma and P.-A. Balland (2022). Do EU regions benefit from Smart Specialisation principles? *Regional Studies*, 56(12), 2058–2073. DOI: https://doi.org/10.1080/00343404.2022.2032628.

Romer, P.M. (1990). Endogenous technological change. *Journal of Political Economy*, 98(5, part 2), S71–S102.

Salary Explorer. (2023). *Game Developer Average Salary in Japan 2023*. Salary Explorer. Available at: https://www.salaryexplorer.com/average-salary-wage-comparison-japan-game-developer-c107j10578#:~:text=Average%20Monthly%20Salary%0A%0A471%2C000%20JPY%0A%0A,735%2C000%20%20%20%0AJPY

Saxenian, A. (2006). *The New Argonauts: Regional Advantage in a Global Economy*. Harvard University Press.

Schumpeter, J.A. (1942). *Capitalism, Socialism and Democracy*. Harper and Brothers.

Shin, H., D. F. Kogler and K. Kim (2023). The relevance of scientific knowledge externalities for technological change and resulting inventions across european metropolitan areas. *Review of Regional Research*, 1–17. DOI:10.1007/s10037-023-00190-9.

Shrider, E.A., M. Kollar, F. Chen and J. Semega (2021). *Income and Poverty in the United States*: 2020. United States Census Bureau. Available at: www.census.gov/library/publications/2021/demo/p60-273.html.

Simtowe, F., D. Makumbi, M. Worku, H. Mawia and D.B. Rahut (2021). Scalability of Adaptation strategies to drought stress: The case of drought tolerant maize varieties in Kenya. *International Journal of Agricultural Sustainability,* 19(1), 91–105. DOI: https://doi.org/10.1080/14735903.2020.1823699.

Smart, A. and J.-Y. Hsu (2004). The Chinese diaspora, foreign investment and economic development in China. *The Review of International Affairs*, 3(4), 544–566. DOI: https://doi.org/10.1080/1475355042000241511.

Soh, H.S., Y. Koh and A. Aridi (eds) (2023). *Innovative Korea: Leveraging Innovation and Technology for Development*. Washington, DC: World Bank. Available at: http://hdl.handle.net/10986/40234.

Solow, R.M. (1956). A contribution to the theory of economic growth. *Quarterly Journal of Economics*, 70(1), 65–94. DOI: https//doi.org/10.2307/1884513.Statista (2023). Revenue of the eSports market in selected countries worldwide in 2023.

Statista. Available at: www.statista.com/forecasts/1130696/esports-revenue-share-country.

Stattman, S.L., O. Hospes and A.P.J. Mol (2013). Governing biofuels in Brazil: A comparison of ethanol and biodiesel policies. *Energy Policy*, 61, 22–30. DOI: https://doi.org/10.1016/j.enpol.2013.06.005.

Swim, W.B. (1967). The History of Japanese Motorcycles. *Cycle World*, November 1, 1967. Available at: https://magazine.cycleworld.com/article/1967/11/01/the-history-of-japanese-motorcycles.

The Economist (2023a). Firms are exploring sodium batteries as an alternative to lithium. *The Economist*, October 28. Available at: www.economist.com/science-and-technology/2023/10/25/firms-are-exploring-sodium-batteries-as-an-alternative-to-lithium.

The Economist (2023b). Forget Teslas, India's EV revolution is happening on two wheels. *The Economist*, April 20. Available at: www.economist.com/asia/2023/04/20/forget-teslas-indias-ev-revolution-is-happening-on-two-wheels.

The Economist (2023c). How Japan is losing the global electric-vehicle race. *The Economist*, April 16. Available at: www.economist.com/asia/2023/04/16/how-japan-is-losing-the-global-electric-vehicle-race.

Torrisi, S., A. Gambardella, P. Giuri, D. Harhoff, K. Hoisl and M. Mariani (2016). Used, blocking and sleeping patents: Empirical evidence from a large-scale inventor survey. *Research Policy*, 45(7), 1374–1385. DOI: https://doi.org/10.1016/j.respol.2016.03.021.

Tragatsch, E. (2000). *The New Illustrated Encyclopedia of Motorcycles*. Edison, NJ: Quantum Publishing.

Tripsas, M. and G. Gavetti (2017). Capabilities, cognition, and inertia: Evidence from digital imaging. *The SMS Blackwell Handbook of Organizational Capabilities*, 393–412.

Tschang, F.T. (2007). Balancing the tensions between rationalization and creativity in the video games industry. *Organization Science*, 18(6), 989–1005. DOI: https://doi.org/10.1287/orsc.1070.0299.

Tushman, M.L. (1992). Organizational determinants of technological change: Toward a sociology of technological evolution. *Research in Organizational Behavior,* 14, 311–347.

Tushman, M.L. and P. Anderson (2018). Technological discontinuities and organizational environments. In *Organizational Innovation*. Routledge, 345–372.

Weber, V.S., A.E. Melchinger, C. Magorokosho, D. Makumbi, M. Bänziger and G.N. Atlin (2012). Efficiency of managed-stress screening of elite maize hybrids under drought and low nitrogen for yield under rainfed conditions in Southern Africa. *Crop Science*, 52(3), 1011–1020. DOI: https://doi.org/10.2135/cropsci2011.09.0486.

Weitzmann, M.L. (1998). Recombinant growth. *The Quarterly Journal of Economics*, 113(2), 331–360. DOI: https//doi.org/10.1162/003355398555595.

Wezel, F.C. and A. Lomi (2009). 'Built to last 'or 'new and improved'? Trajectories of industrial evolution in the European motorcycle industry, 1885–1993. *European Management Review*, 6(2), 107–119.

Whitaker, M. and S. Kolavalli (2006). Floriculture in Kenya. In Chandra, V. (ed.), *Technology, Adaptation, and Exports: How Some Developing Countries Got It Right*. World Bank. DOI: https://doi.org/10.1596/978-0-8213-6507-6.

Wiggins, S., G. Henley and S. Keats (2015). *Competitive or complementary? Industrial crops and food security in sub-Saharan Africa*. Overseas Development Institute (ODI). Available at: https://www.jstor.org/stable/resrep50756.

Williamson, J. (1990). What Washington means by policy reform. In Williamson, J. (ed.), *Latin American Adjustment: How Much Has Happened?* Washington, DC: Institute for International Economics, 7–20.

WIPO (2011). *World Intellectual Property Report 2011: The Changing Face of Innovation*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=227.

WIPO (2015). *World Intellectual Property Report 2015: Breakthrough Innovation and Economic Growth.* Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=3995.

WIPO (2019). *World Intellectual Property Report 2019: The Geography of Innovation*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4467.

WIPO (2022a). *World Intellectual Property Report 2022: The Direction of Innovation*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4594.

WIPO (2022b). *Global Innovation Hotspots: Singapore's Innovation and Entrepreneurship Ecosystem*. Geneva: World Intellectual Property Organization. Available at: www.wipo.int/publications/en/details.jsp?id=4623.

Wright, B.D. (2012). Grand missions of agricultural innovation. *Research Policy,* 41(10), 1716–1728. DOI: https://doi.org/10.1016/j.respol.2012.04.021

Wuchty, S., B. F. Jones and B. Uzzi (2007). The Increasing Dominance of Teams in Production of Knowledge. *Science*, 316(5827), 1036–1039. https://doi.org/10.1126/science.1136099.

Yamamura, E., T. Sonobe and K. Otsuka (2005). Time path in innovation, imitation, and growth: The case of the motorcycle industry in postwar Japan. *Journal of Evolutionary Economics*, 15, 169–186.

The 2024 edition of the *World Intellectual Property Report* introduces a new data-driven methodology designed to help policymakers make informed decisions by leveraging existing local innovation capabilities.

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