Economic Research Working Paper No. 82/2024

Innovation Complexity in AgTech

The case of Brazil, Kenya and the United States of America

Intan Hamdan-Livramento, Gregory D. Graff, Alica Daly

WIPO

Innovation Complexity in AgTech: The case of Brazil, Kenya and the United States of America

Intan Hamdan-Livramento*, Gregory D. Graff‡ and Alica Daly⁂

Abstract

This paper illustrates successful policies and incentives that build on local innovation capabilities across three agricultural innovation hubs at different income levels and across different geographical regions. It makes the case for how countries highly complex innovation ecosystems, which refer to the diversity and sophistication of local innovators and the types of innovation they produce, tend to have more opportunities to shift their technological path to the frontier. The paper focuses on three agricultural hubs across different income levels and geography to illustrate how smart policies that focus on building local capabilities can help countries diversify and create their own agricultural technological paths. These hubs include: São Paulo in Brazil, Nairobi in Kenya and Colorado in the United States of America.

JEL classification: O34, O38, Q16

Keywords: agriculture, innovation complexity, technologies, intellectual property

Acknowledgements

The authors thank Debisi Araba, Ron Boschma, and Leontino Rezende Taveira and for their helpful comments, feedback, and review on earlier drafts of this paper. We also thank the team at the Innovation Economy Section of WIPO, in particular, Julio Raffo, Federico Moscatelli, Thiago Negrão Chuba, Maryam Zehtabchi, Clement Sternberger, and Sergio Martinez for their insights. Aida Dolotbaeva provided important comments on the intellectual property protection aspects of agricultural innovation. All errors are our own.

We would also like to thank Keith Fuglie and his co-authors at the U.S. Department of Agriculture for kindly sharing their latest data on world agricultural productivity.

Disclaimer

The views expressed here are those of the authors, and do not necessarily reflect those of the World Intellectual Property Organization (WIPO) or its Member States.

* Senior Economist. Department for Economics and Data Analytics, World Intellectual Property Organization (WIPO). Corresponding author, e-mail at: intan.hamdan-livramento(at)wipo.int.
‡ Professor. Agricultural and Resource Economics, Colorado State University.
⁂ Senior Policy Officer on Artificial Intelligence and Data. IP and Frontier Technologies Division, WIPO.

1 Introduction

Local innovation capabilities determine the ability of a country's innovation ecosystem to generate new science and technologies. Recently, economic scholars have shown that countries with highly complex economic capabilities are likely to have diverse and sophisticated range of local industries and highly skilled and knowledgeable workforce. These complex capabilities then help generate long-run economic growth for the country (Hidalgo et al., 2007; Hidalgo and Hausmann, 2009). In innovation, this translates into the ability of the country's labor force to generate innovation across diverse and complex science and technological fields.

In agriculture, a country's level of innovative capabilities is a determining factor of its agricultural technology (AgTech) trajectory (see Box 1 on how we define AgTech). It can explain why countries with similar conditions observe different agricultural productivity levels, which in turn affects their economic growth. Agricultural sectors in economies with higher economic complexity will tend to benefit from the diversity and sophistication of their innovation ecosystems. How they do so will depend on many factors, including the institutional framework, as well as market and technological opportunities.

Box 1: Defining agricultural technologies (AgTech)

We employ the term "AgTech" to refer to technological-based solutions that address challenges in agriculture. It includes innovation that increase land productivity, for example through higher crop yield per hectare and irrigation, labor-saving such as using mechanization tools, costs-savings through better and more efficient use of scarce resources for example through precision agriculture tools, and plant varieties adapted to climate change or diseases such as drought- and pest-resistant plants.

Institutional innovation, such as agricultural cooperatives or intermediaries, that facilitate the coordination and knowledge-sharing platforms between the public sector, universities and researchers, farmers, agribusinesses and non-governmental organizations, to name a few, are not included. Examples of these institutional innovation efforts include those by organizations such as the International Service for the Acquisition of Agri-biotech Applications (ISAAA) in helping disseminate crop biotechnologies. Kingiri and Hall (2012) offer examples on how innovative institutions and platforms can help facilitate the commercialization of AgTech research.

The aim of this paper is to illustrate how different AgTech hubs build on their innovation capabilities and experience different innovation paths in agriculture. It uses a novel indicator developed by a team of economists at WIPO in collaboration with the Harvard Growth Lab, which captures innovation along three dimensions: science, technology and production (Moscatelli et al., 2024). This paper focuses on the evolution of three global agricultural innovation hubs chosen based on their income and geographical differences: Colorado in the United States of America (US), São Paulo in Brazil, and Nairobi in Kenya.

There are three main takeaways from this paper. First, innovation in agriculture is increasingly complex across commodities, value segments and economic agents. However, the innovation in the agricultural is sector context and agro-ecologically specific. This means that technological advances in agriculture must be adapted to the conditions of soil, landform, and climatic characteristics of the growing region, as well as other cultural, political, and market factors that shape the regional farming systems.[1] Second, the public sector is pivotal in creating the necessary conditions to build local agricultural capabilities and facilitate knowledge sharing between the innovation stakeholders. Third, market and technological opportunities help determine the innovation path for the private sector, as long as the private sector has the ability to recover their investments into innovation.

The paper structure is as follows: the next section provides insights on the evolution of innovation in the agriculture sector. It first makes the case that agricultural innovation is different from the other sectors and points to the importance of the public sector. It then shows how agricultural innovation is increasingly complex. The three following sections thereafter focus on the evolution experienced by the three different countries and their respective AgTech innovation hubs. Each of the innovation hubs illustrate how local innovation capabilities, alongside policies and initiatives from the government, pave the way for each country's AgTech trajectories. The last section concludes with key insights, policy considerations and future direction for research.

2 How agricultural innovation is increasingly complex

Agriculture is important to every country. It is the key to addressing food security, nutrition, and sustainability challenges. In fact, global food consumption accounts for nearly half of agriculture's fruits of labor (OECD, 2023).

What countries produce and how much they produce depend on their abilities to allocate and combine scarce resources efficiently. Differences in this ability help explain why countries have different levels of agricultural productivity, even if they share similar natural resource endowments.

[1] See chapter 2 of FAO (1996) for further details on agroecological conditions and Dixon *et al*. (2001) on farming systems.

Innovation is the driver of agricultural productivity. It helps farmers to produce more, given their limited resources. Agricultural innovations have, historically, included new technologies and know-how that were labor-saving (steam-powered machines, combustion engines), land-improving (fertilizers, crop rotations, reduced tillage), yield-improving (dairy herd breeding, drought-tolerant crops), and more.

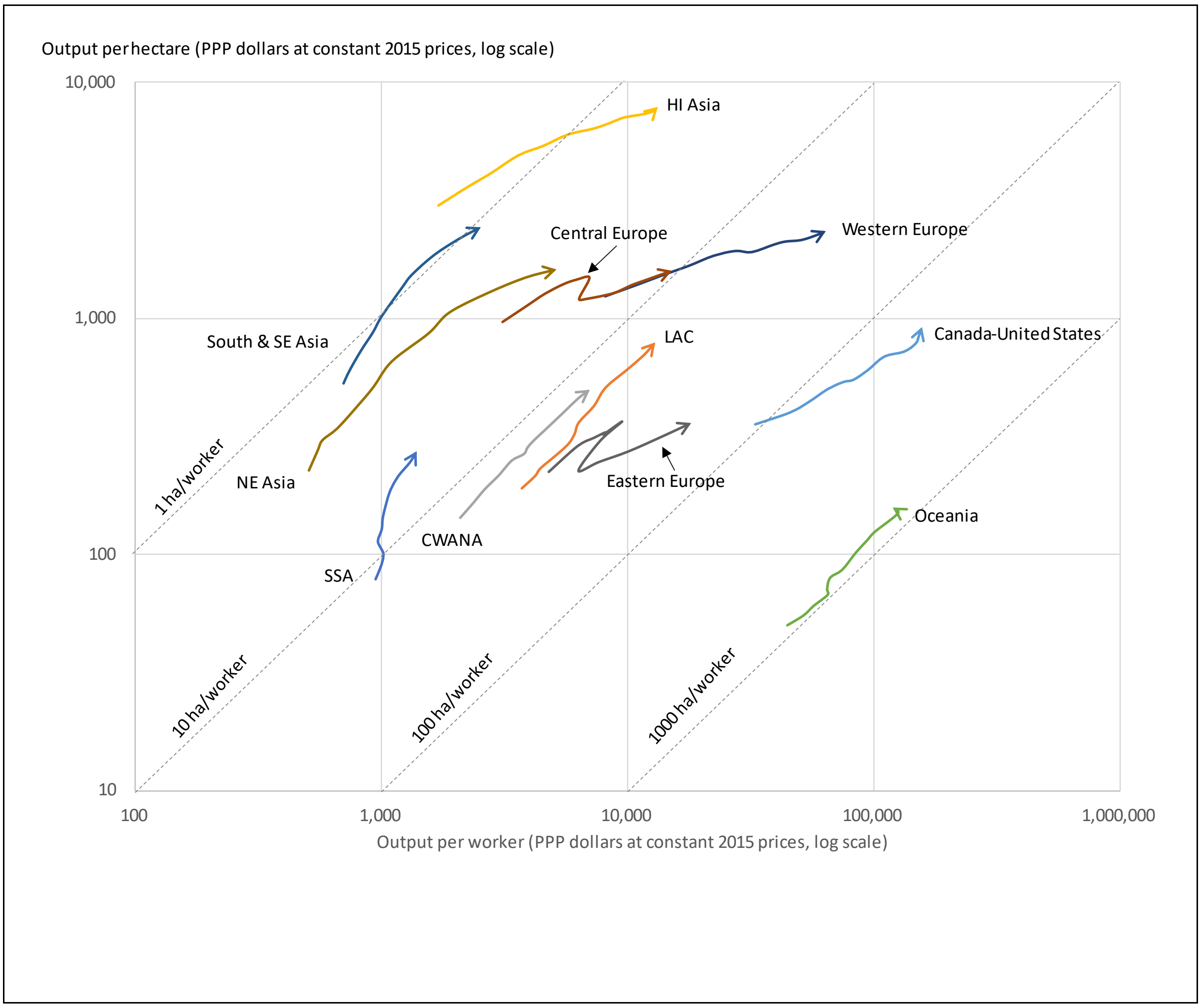
More importantly, the ability to produce agricultural commodities efficiently and sustainably depends on a country's or region's local "innovative capabilities". Innovative capabilities refer to the set of skills and knowledge that are built up through scientific, technological, and productive activities. They are defined as, "the ability of a country to deliver competitive outputs of a certain field of innovation process. These include skills and knowledge (often tacit) that are embedded into individuals and, in contrast to tools or codes, cannot be shipped or shared, respectively. Innovative capabilities are, hence, the scientific, technological, and productive know-how that innovation ecosystems in each country or region have" (Moscatelli et al., 2024).

Highly productive countries tend to have greater innovative capabilities. They are better able to adapt and implement complementary technologies that arise from around the world, benefit from diversification, and enjoy dynamic benefits of specialization in a world where even agriculture is characterized by increasing economic and technological complexity (Balland et al., 2022). This is what explains divergence in countries' agricultural productivity levels and their abilities to sustain economic growth.

Figure 1 illustrates the variation in agricultural productivity across major regions globally. Regions in the upper-right quadrant of the figure have improved their productivity levels across both land and labor factors. Simply put, Europe, and North American regions as well as high-income Asian countries can produce more farm output per land area and worker than others.

Agricultural productivity varies across regions, with high-income countries leading

Figure 1: Agricultural land and labor productivity



Note: Diagonal lines represent constant land-labor (A/L) ratio.

Source: Fuglie *et al.* (2024)

2.1 How AgTech innovation is different but similar

Innovation in agriculture is different from other sectors in some ways and similar in others (Srinivas and Vieira Filho, 2015).

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. In contrast, farming areas greater than 50 hectares are farmed by the largest one percent of farms (Lowder et al., 2014).

In addition, farmers face risks and uncertainty when making their decisions on crops or livestock to produce. This is because they have to make decisions and investments with limited information and then wait for payoffs in the future, if at all (FAO, 1996). Moreover, their profits are tied to yields, which can be adversely affected by factors outside their control such as the weather, pests, disease, conflict, and global market prices. For example, the cost to Kenyan rose growers choosing the ”wrong” type of rose to plant can be up to USD $160,000 per hectare (Whitaker and Kolavalli, 2006).

Second, agricultural commodities and activities tend to exhibit the economic properties of public goods. Benefits such as ensuring food safety and security, adequate nutrition for public health, and environmental sustainability require public sector support. Recognizing such needs, the U.S. Department of Agriculture (USDA) and the Land Grant agricultural research universities were established in 1862 (Wright, 2012). In underscoring the importance of increasing plant varieties to ensure food security in the United States, Wright (2012) documents how politicians sometimes smuggling in new plants to add to the country’s plant culture.

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 (OECD, 2023). 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 national guidelines before being adopted and planted in farmers’ fields. The hybrid corn technology, for example, took a total of at least 60 years in total from its initial introduction to the maximum level of widespread adoption (Alston et al., 2023; Griliches, 1957).

Fourth, agricultural innovation has to be adapted to the local context and agro-ecological conditions. According to the United Nation's Food and Agriculture Organization (FAO), regions sharing the same agro-ecological zones have "similar combinations of climate and soil characteristics, and similar physical potentials for agricultural production" (FAO, 1996). This means that an agricultural innovation that is developed for one region, with specific agroecological conditions, is not easily transferred and used in another region with different agroecological conditions. Instead, the innovation would have to be adapted to the region with its specific conditions while respecting its biodiversity and environmental requirements.

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 the genetic innovator may need to either license to the owners of the germplasm or cultivars or otherwise collaborate with them to develop and adapt the technology to local conditions. This adaptation requirement leads to extra costs and hurdles for innovation stakeholders with limited budgets or limited access to supporting institutions (Graff and Hamdan-Livramento, 2019).

But innovation in agriculture is also like other sectors. In the United States, the private sector started participating in agricultural innovation when they were able to recover their investments into investing in innovation. This appropriability means, such as through protecting their investments through IP rights, provided an exclusive right to the for-profit businesses and allowed them to profit from their inventions.

2.2 How AgTech innovation is increasingly complex

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

2.2.1 New sources of knowledge

Innovation in the agricultural sector can come both from the sector itself as well as adjacent sectors. Innovation in agricultural-adjacent sectors such as non-food, bioeconomy[2], downstream processing and manufacturing, and even agricultural inputs affect the agricultural value chain as seen in Figure 1 below.

Scientific and technological breakthroughs from the chemical, biology and biotechnology fields have led to better agricultural inputs such as fertilizers, pesticides and plant varieties for crops, and livestock genetics, medicines, vaccines and veterinary care for animal health. Mechanical innovations such as the steam engine and internal combustion engine that have 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 those that facilitate real-time access to weather information, water use and land surveillance, for example, are also transforming the industry. Even advances in the packaging, storage, and manufacturing of agricultural products feed into the sector's general productivity improvements.

Clancy and co-authors (2020) find that most of the productivity improvements in the agricultural sector are sourced from knowledge outside the sector. The authors examined knowledge flow from other industries into the agriculture sector by using citations of patent documents to (i) other patents, (ii) academic journals, and (iii) text-based concepts of potential technological applications in agriculture, and subsequently grouped them into six categories of animal health, biocides, fertilizers, machinery, plants and research tools. They find that most of the productivity improvements in the agricultural sector are innovation in animal health, fertilizers, and machinery subsectors. The source of knowledge for these three majors AgTech subsectors came from non-agricultural knowledge disciplines.

In addition, the uptake of these scientific and technological breakthroughs can be attributed to the fact that the development of these technologies can be easily adapted to the agricultural sector.

2.2.2 Diversified end use

The end use of these agricultural products has diversified. Traditionally, people farmed for food. Today, the final use of agricultural products can be in one of three categories: food, livestock feed consumption and renewable sources of energy. The last two

[2] Bioeconomy refers to crops that are not grown for food, and whose production may compete with food crops for water, land, labor and capital. These crops may include non-food uses of food such as corn and soybeans. They also include forestry or agroforestry.

categories account for 26 percent and 8 percent of total global use, respectively, while food consumption accounts for most of the end use (OECD, 2023). Each of these agricultural final consumption categories can require different sets of skills and specialties and they require separate standards and regulations.

2.2.3 Know-how spillover to other segments creating opportunities in other areas

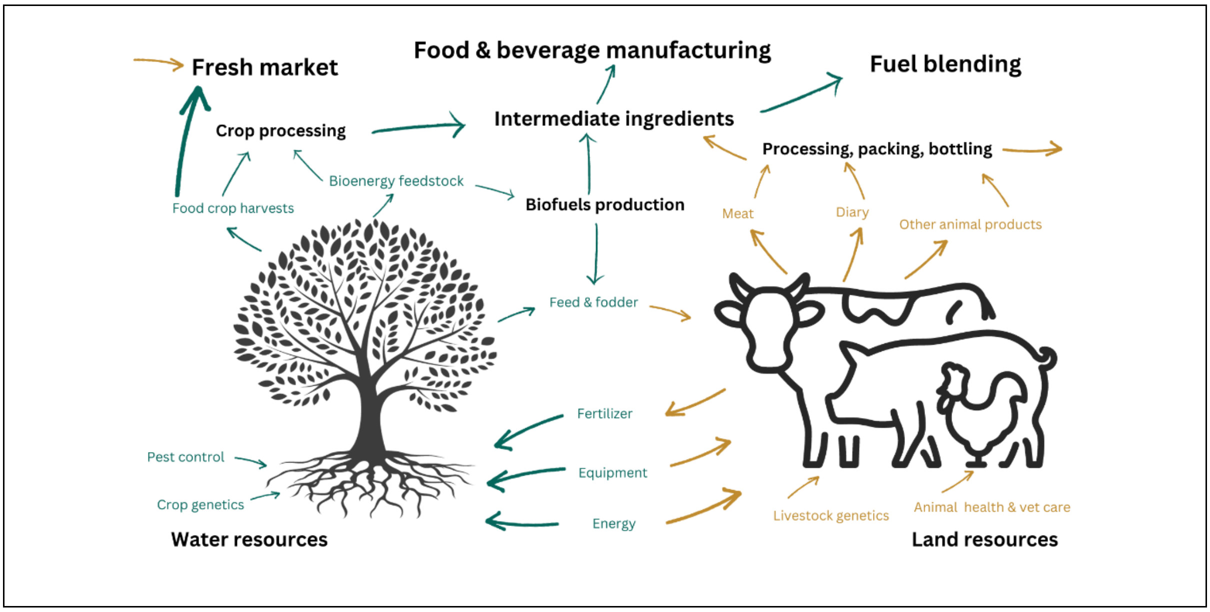
The agricultural value chain has strong internal connections. A change in one value segment can impact others along the chain. For example, the feed and fuel developments of agriculture can be in direct competition with food production for the allocation of scarce resources of land and water, as well as labor and capital. The OECD-FAO (2023) report estimates that the growth in livestock feed and fuel consumption is likely to outpace that in food consumption.

However, the innovation and developments in these non-food categories can help build the innovation ecosystem's local innovative capabilities and may shift its AgTech innovation trajectory. Wiggins *et al.* (2015) point to three possible complementarities between the farming of non-food crops and the food crops. Firstly, there may be direct crossover benefits in that buyers of non-food crops may provide individual farmers with inputs, such as fertilizers, and train them to grow both for food and non-food crops. Secondly, there may be indirect crossovers whereby individual farmers may use the earnings from growing and selling these feed and fuel crops to finance buying inputs for food crops, thereby overcoming credit limits. Thirdly, there may be regional synergies. At village or district level, non-food crop production may stimulate the private provision of inputs, farm services, and marketing services that can expand to food crops. This may also encourage the government to invest in local roads and other infrastructure.

Figure 2 illustrates the potential of each segment of the agricultural value chain with its different economic agents as a source of innovation that can transform the sector. It shows how innovation can come from either within the agricultural sector or from the agriculture-adjacent sectors. Moreover, innovation in each value segment can have spillover effects to other segments in the value chain.

The agricultural value chain is a complex web of complexity and interdependence

Figure 2: Linkages between the different value segments of the agricultural value chain



Source: Authors' own illustration.

New AgTech can also have an impact outside the agricultural sector. Preliminary examination of the associated technological fields for AgTech patents show how these technologies influence innovation in other fields. Figure 3 (top) illustrates the co-occurrences of the International Patent Classification (IPC) related to AgTech - "A01" – with other IPC subclasses, while the bottom of the figure shows the top eleven IPC subclasses. In general, AgTech tend to be associated with innovation related to medical or veterinary science (A61), organic chemistry/fertilizer (C07), genetic engineering (C12), food stuff (A23), and physical or chemical processes (B05).

Figure 3: AgTech "A01" correlation with other IPC subclasses

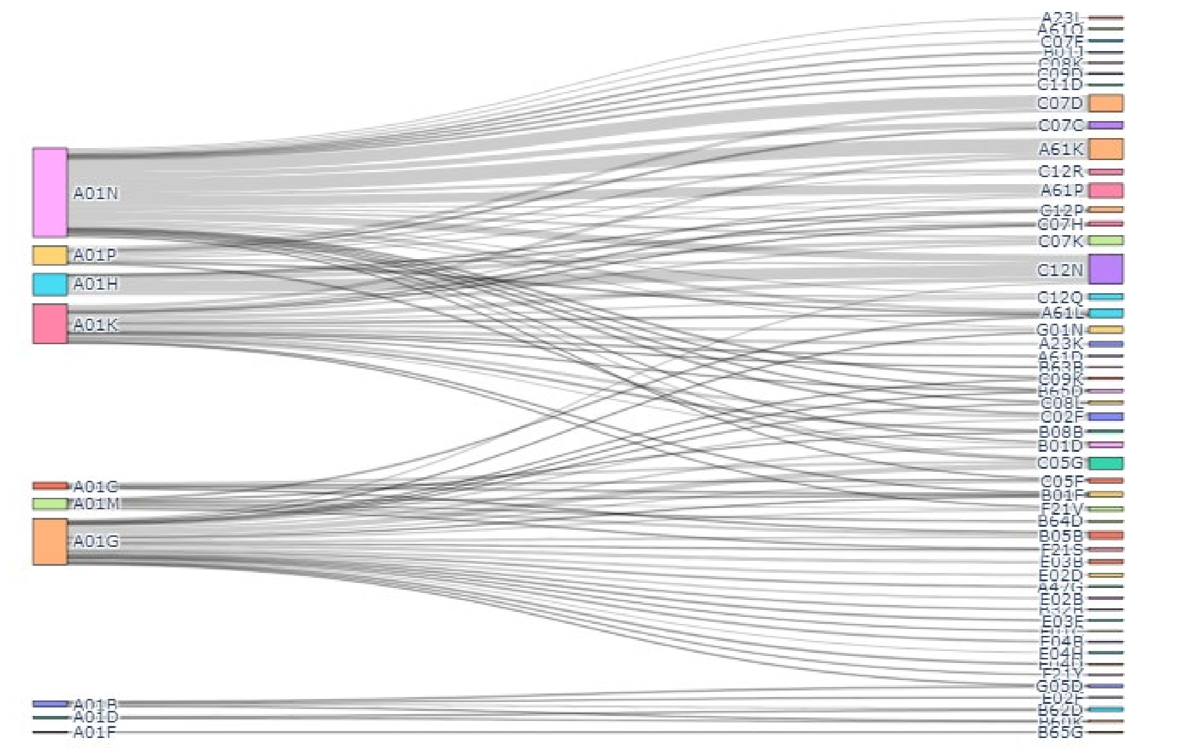
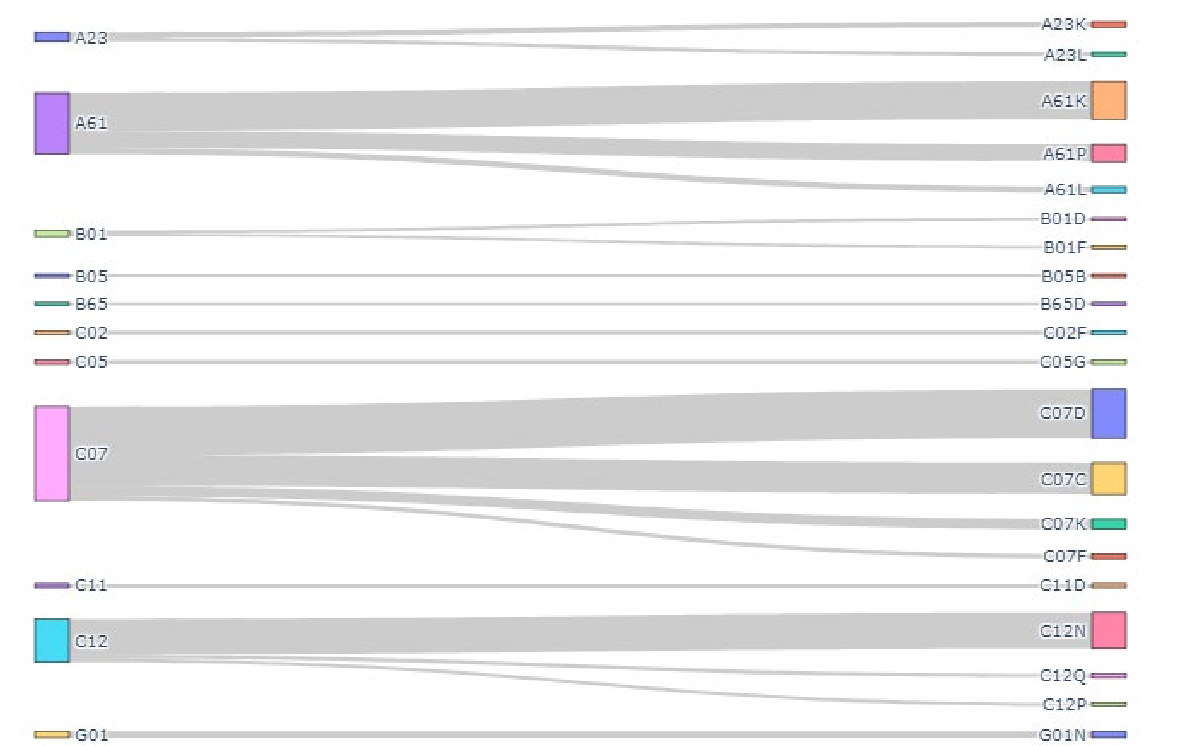


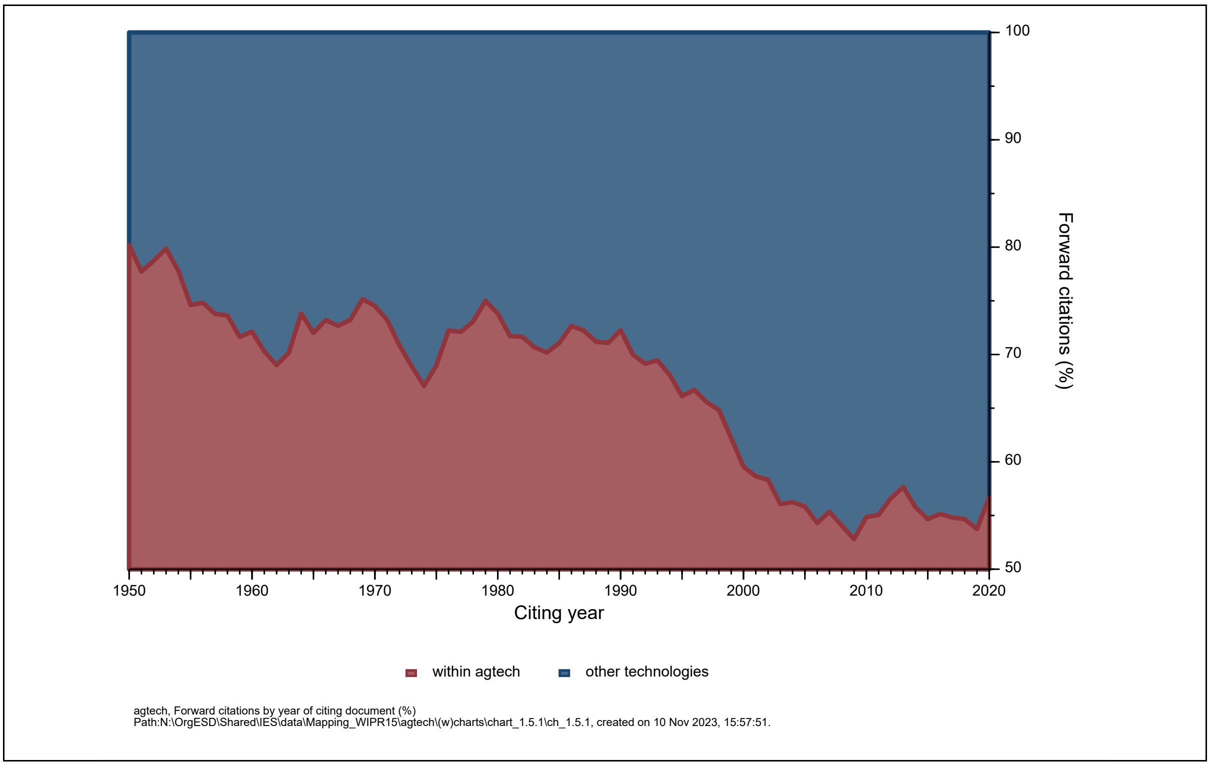
Figure 3b: Top IPC subclasses in AgTech



Source: EPO PATSTAT; WIPO.

In addition, forward citations for AgTech patents show how innovation in the agricultural sector is increasingly being cited in non-agricultural sector. Figure 4 illustrates the share of forward citations of AgTech patents within the agricultural sector against forward citations of AgTech patents outside of the sector. In 1950, 80% of the AgTech patents are cited within the agricultural sector, but by 2020 this share drops down to 55%. While most of the forward citations are still within the agricultural sector, it suggests that innovation in this "traditional" economic sector is influencing "newer" economic sectors.

Figure 4: Share of agricultural to non-agricultural forward citations



Source: EPO PATSTAT; WIPO.

2.3 How innovation activities are increasingly concentrated into hubs

There is a tendency of these different segments of the value chain to concentrate geographically in regions of a country, typically in urban areas (Graff and Hamdan-Livramento, 2019; Srinivas and Vieira Filho, 2015; WIPO, 2019). This is because of the complexity and interdependence of the different segments of the agricultural value chain, the need for coordination of physical production activities, and the higher potential for knowledge spillovers.

Innovation hubs, or hotspots, have a pool of skilled labor across different skill sets and technologies, a pool of diverse and innovative firms, both large and small, as well as firms that offer support services, such as banking, legal, IT, or marketing. By locating within an innovation hub, a firm can gain easier access to highly skilled labor across many different technological and professional fields. Most universities and research institutions that conduct cutting-edge, frontier-expanding research are located in large cities, drawing from and adding to the region's talent pool. Over time there is a virtuous cycling, as innovative companies that move to co-locate near these research institutions attract other innovative companies to do the same.

Therefore, for innovative agricultural firms, co-locating in an agricultural innovation hub encourages knowledge spillovers, and potentially generates further benefits to those innovative firms that move there (WIPO, 2019). The knowledge spillovers and potential innovation breakthroughs can contribute to pushing the industry's technological trajectories toward or to the frontier.

2.4 How private sector is increasingly conducting R&D

The public sector is the largest contributor to agricultural research and development (R&D) worldwide. The market failure arguments explained in subsection 2.1 explains why this is the case. Studies show that governments that invest heavily in agriculture see stronger economic growth, declining poverty rates and better nutritional status (see Badiane and Makombe (2015) and Fuglie *et al.* (2020). Concretely, researchers at the United States Department of Agriculture (USDA) found that between 1900 and 2011, every dollar spent on public agricultural R&D generated USD $20 to the U.S. economy (Baldos et al., 2019).

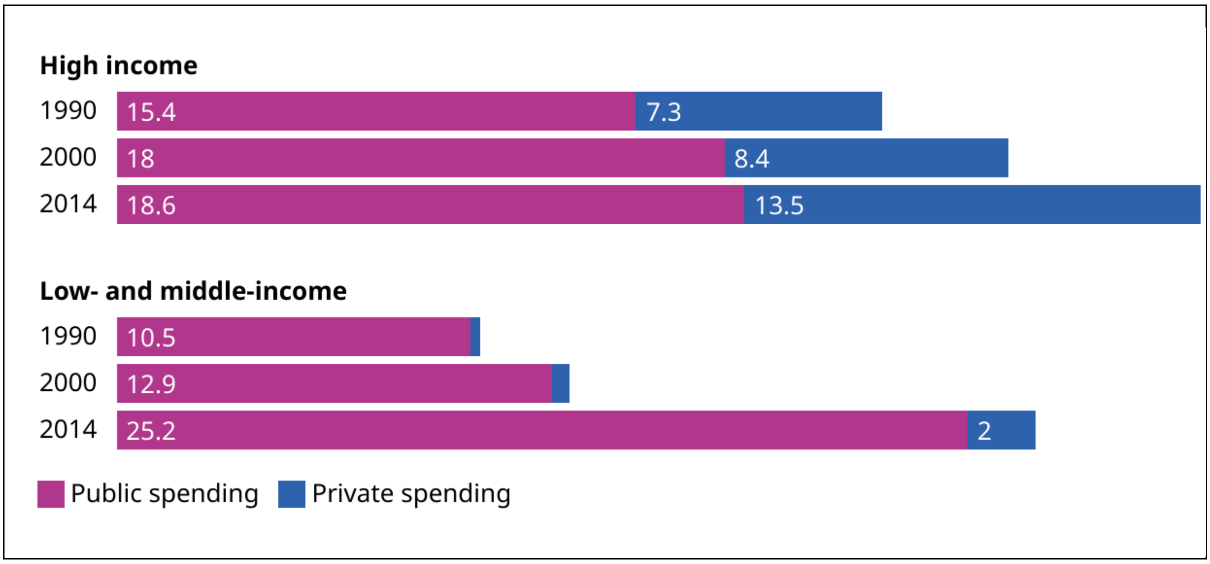
In addition, raising agricultural productivity can have a positive impact on the welfare of millions of people currently living in poverty. Several studies show how growth in agriculture can improve income levels, which leads to better health, nutrition and access to education. Among findings are estimated 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 (Kassie et al., 2018; Raitzer et al., 2015).

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 their findings through education, extension, training collaboration with, and technology transfer to the private sector. In fact, the public sector provides the institutional framework for learning in the country. Second, governments create the enabling conditions that provide incentives and support to innovative activities by the private sector. And third, governments can set policies or mission-oriented targets to boost innovative capabilities in agriculture.

According to the Global Agricultural Update (2020) produced by the Agricultural Science and Technology Indicator (ASTI) network, global R&D spending in AgTech totaled nearly USD 47 billion in 2016. 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 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 majority, if not almost all, of the agricultural R&D (Pardey et al., 2016).

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

Figure 5: Comparison of agricultural R&D spending (in billions 2011 PPP) by the public and private grouped by country income-levels, 1990, 2000 and 2004



Source: Beintema *et al.* (2020)

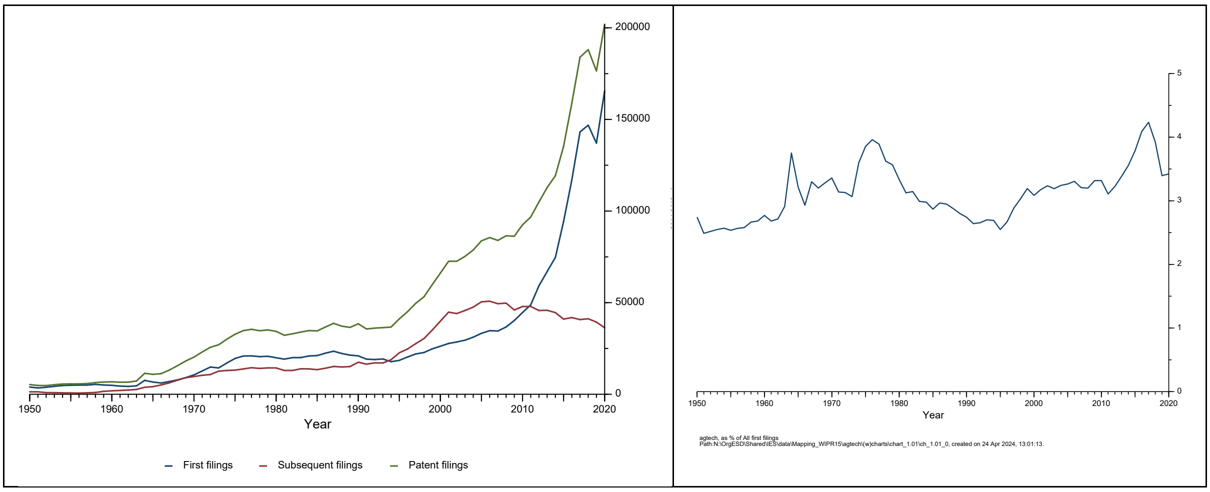
Figure 5 provides a snapshot of public to private sector share of spending on R&D across different income levels in 1990, 2000 and 2014. It shows how governments have been the main investors in agricultural R&D across all income levels.

Over the past decade, government spending on R&D has been stagnant in most high-income countries. In the US, for example, the private sector has overtaken the public sector in regards to their R&D spending since 2011 (Fuglie, 2016; Fuglie et al., 2012). In this regard, innovation in the agricultural sector is starting to mirror innovation in other sectors, particularly manufacturing, where most of the innovation are undertaken by the private sector.

Figure 6 shows the aggregate AgTech patent applications filed worldwide. The figure on the left side plots the total number of AgTech patent documents filed between 1950 to 2020. The blue line illustrates the number of AgTech patent families filed.[3] The right hand side of the figure shows the share of growth in AgTech patent filings to total patent filings. It shows that in the last two decades, AgTech patent filings have grown faster than total patent filings across all technologies by approximately 3.5%.

AgTech patent applications have been growing steadily over the years

Figure 6: Global AgTech patent applications, 1950-2020.



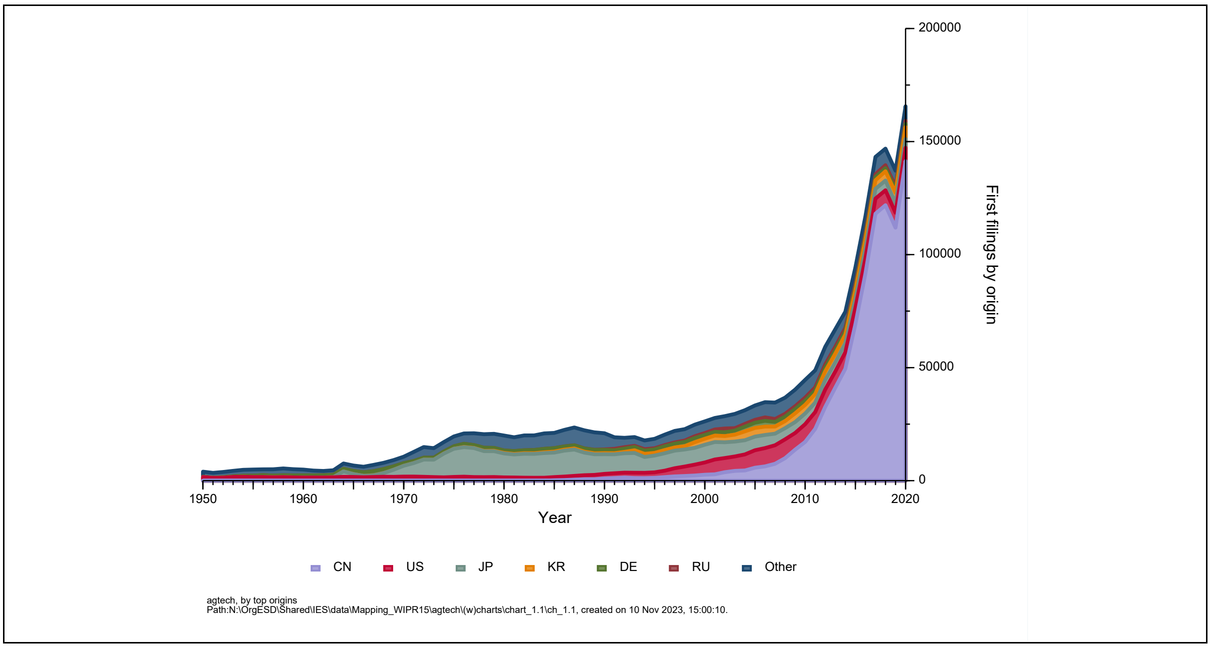
Source: EPO PATSTAT; WIPO.

The increasing participation of the private sector in AgTech can be traced back to their abilities to recover their investments into innovation in agriculture. In economics, this is known as appropriability, where intellectual property (IP) protection is a means to do so.

Six countries drive most of the AgTech patent applications worldwide

[3] Most economists use this line to showcase how many AgTech patents have been filed. This is because patents documents that are filed in one country may also be filed in other countries so the applicants may also benefit from the patent rights outside their countries. Most IP researchers would link these patent documents through their priority date.

Figure 7: AgTech patent application by top six countries

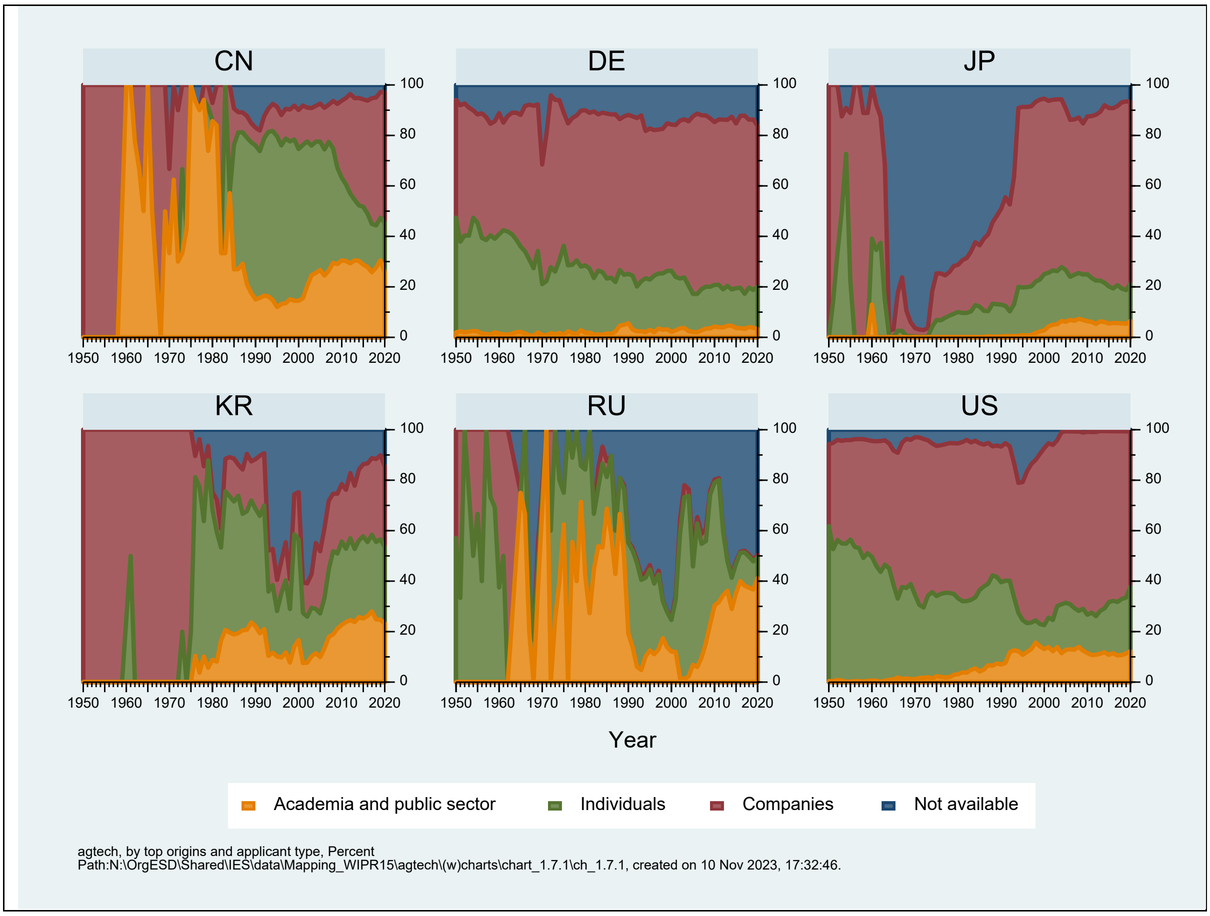


Source: EPO PATSTAT; WIPO.

Figure shows the top six countries that have filed for AgTech-related patent applications. These countries include China, Germany, Japan, Russia, Republic of Korea South Korea, and the US. Figure shows how most of the applicants who have filed for patent protection on their AgTechs tend to be from the private sector.

The private sector drives most of IP-related AgTech patent applications

Figure 8: Share AgTech applicant by type



Source: EPO PATSTAT; WIPO.

Interestingly, the agriculture industry is increasingly concentrated, particularly in the upstream of the agricultural value chain. There are fewer and larger firms actively conducting R&D due to consolidation in the industry. Graff and Hamdan-Livramento (2019) document how this consolidation is particularly the case for the agricultural input industry, including for companies that produce seeds, chemical and fertilizers, to name a few. However, a report by the OECD (2018) found little evidence on the adverse impact of the seed industry's consolidation on agricultural innovation.

2.5 How sustainability concerns affect the AgTech landscape

One of the challenges in the agriculture sector is the need to be more sustainable. As climate change induces extreme weather conditions and threatens our livelihoods, there is a consensus that the world needs to be more sustainable.

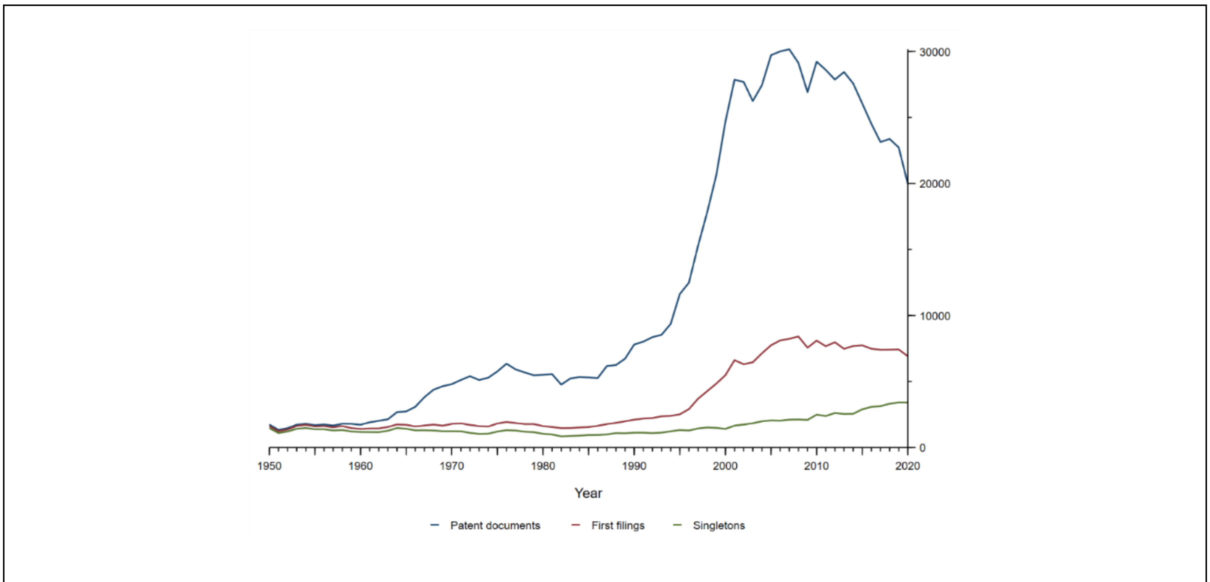
Paradoxically, activities that have improved agricultural productivity, such as farming specific high-value crops and raising livestock, have contributed to soil erosion, water pollution, greenhouse gas emissions and general environmental degradation. Agricultural activities account for 21 percent of global greenhouse gas emissions (FAO, 2020). These in turn affect future agricultural development. These external factors that affect the agriculture sector would cascade into higher global food prices and decrease access to nutritious food for the poor (Porter et al., 2014).

One of the ways to overcome the waste and pollution generated by agricultural activities is to adopt precision agriculture technologies. Precision agricultural technologies refer to a set of digital technologies that leverage large amounts of data collected through sensors, weather forecasts and the like to farm more efficiently.

3 How Colorado is harvesting AgTech from fertile US soil

The US is the largest exporter of agriculture commodities worldwide. In this regard, most American AgTech producers enjoy global market opportunities. It is therefore not surprising that the country has also been innovating significantly in the sector and has been filing for patent protection on its AgTech inventions both at home and worldwide.

Figure 9: Total AgTech patent filing in the US, 1950-2020



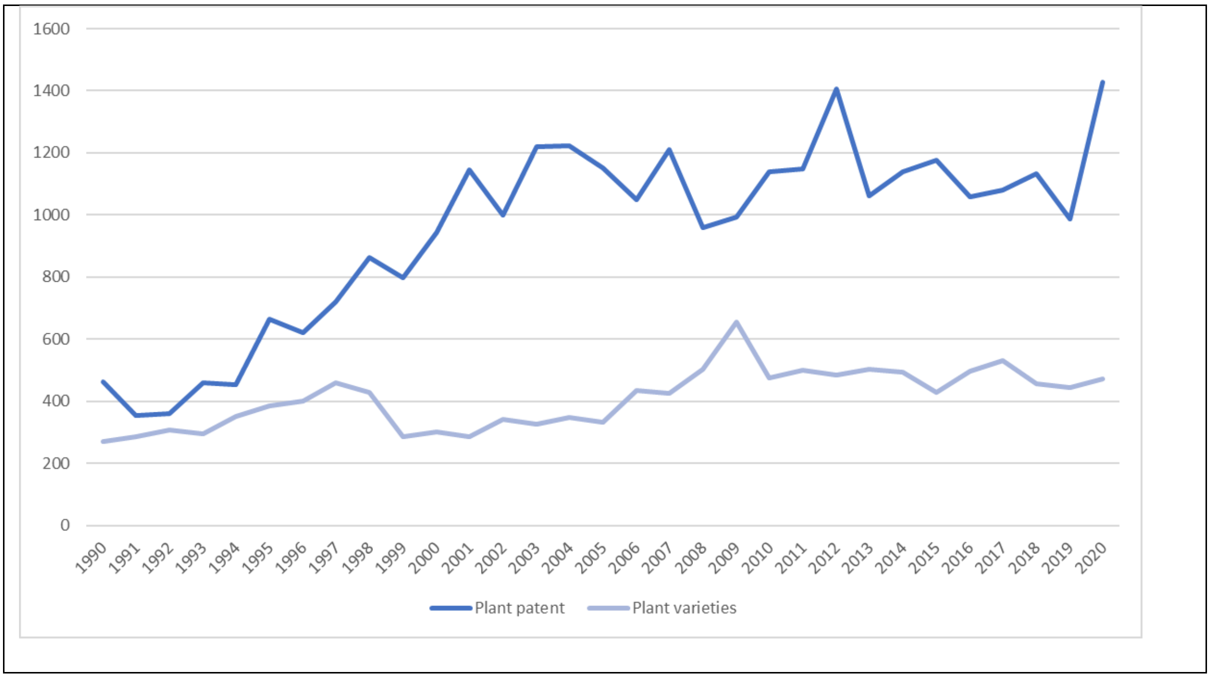
Notes: Singletons refer to patent applications that only remain in the US. The difference between patent documents and first filings represents patent applications that were first filed in the US and then subsequently filed elsewhere.

Source: EPO PATSTAT; WIPO.

Figure 9 shows how innovators residing in the US have filed for patent protection in AgTech at the United States Patent and Trademark Office (USPTO). Patent applications filed by American innovators tend also to be filed in other national patent offices as seen by the difference between the first filing (red) line and the total patent document (blue) line. This gap indicates that the US-resident innovators intend to commercialize their inventions in other jurisdictions as well. The reasons for this can be wide-ranging. But oftentimes, applicants file for IP protection in other jurisdictions to protect their important markets from competition.

The US also affords protection on AgTech through plant patents and the *sui generis* plant varieties protection (see Figure 10).

Figure 10: Total applications filed through plant patents and plant varieties equivalent protection in the US, 1990-2020



Source: UPOV Plant Variety Database

3.1 Public mission to spur AgTech across the continent

Colorado's rise as an agricultural innovation hub was rooted in the US government's investments in agriculture beginning in the 19th century, with the establishment of agricultural state universities and agricultural experiment stations. The state's innovation in irrigation technology, beginning a century ago, include the Parshall flume 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 more efficiently fattening beef cattle before slaughter.

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 (Nelson and Fuglie, 2022). For example, the US government funded much of the basic research extending applications of molecular biotechnology into agriculture (Graff and Hamdan-Livramento, 2019). Most of the research results generated by the 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 startups.

Colorado has been, on a *per capita* basis, the largest research performer under USDA funding in the US. In 2011, it received the third highest total USDA funding, trailing just California and Texas. The region is home to several USDA branch laboratories. In addition, the universities in Colorado have major programs in biosciences, water resources, agricultural science and food science, making it one of the regional leaders in agricultural and food knowledge. According to recent inventory, it is also home to 550 agricultural innovators, of which 460 are private-sector (corporate and startup) companies, and 90 are public- (federal, state and local) organizations (Graff et al., 2014).

3.2 Encouraging private sector investment

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

In the U.S., IP protection was one of the factors that incentivized the private sector to invest in innovation in the sector. The government also enacted the Bayh-Dole Act, which allowed for universities to take title to IP over technologies developed using federal funding. These two factors enhanced the appropriability mechanisms that encourage the private sector to innovate in agriculture. One study has attributed the surge in private agricultural investments in the life sciences, in addition to the R&D investments in the machinery and chemical sectors, to changes in IP rights for biological innovations (Wright and Pardey, 2006).

IP protection has also created an incentive mechanism for the private sector to work closely with the public research labs. For governments, collaborating with the private sector helped to ensure that their research work was commercialized. This was evidenced in the uptake of crop biotechnology in the US (Graff and Hamdan-Livramento, 2019).

In the US, many of the agricultural biotechnology innovations were developed in publicly funded research labs and commercialized by start-ups or through public-private partnership contracts with private companies (Kenney, 1988). This was in contrast with the general trends in Europe, where major chemical and pharmaceutical companies preferred to conduct their own research and commercialization activities internally.

Innovators also emerged in the processing of agricultural commodities, with some of the region's agribusinesses growing into global leaders in food and beverage manufacturing, such as Coors Brewing (today Molson Coors), Monfort Meats (acquired by JBS), Leprino Foods, and Celestial Seasonings (today Hain Celestial). These corporate leaders have more recently been followed by a sort of counterrevolution of consumer-driven food and beverage companies focused on quality, health, and environmental attributes.

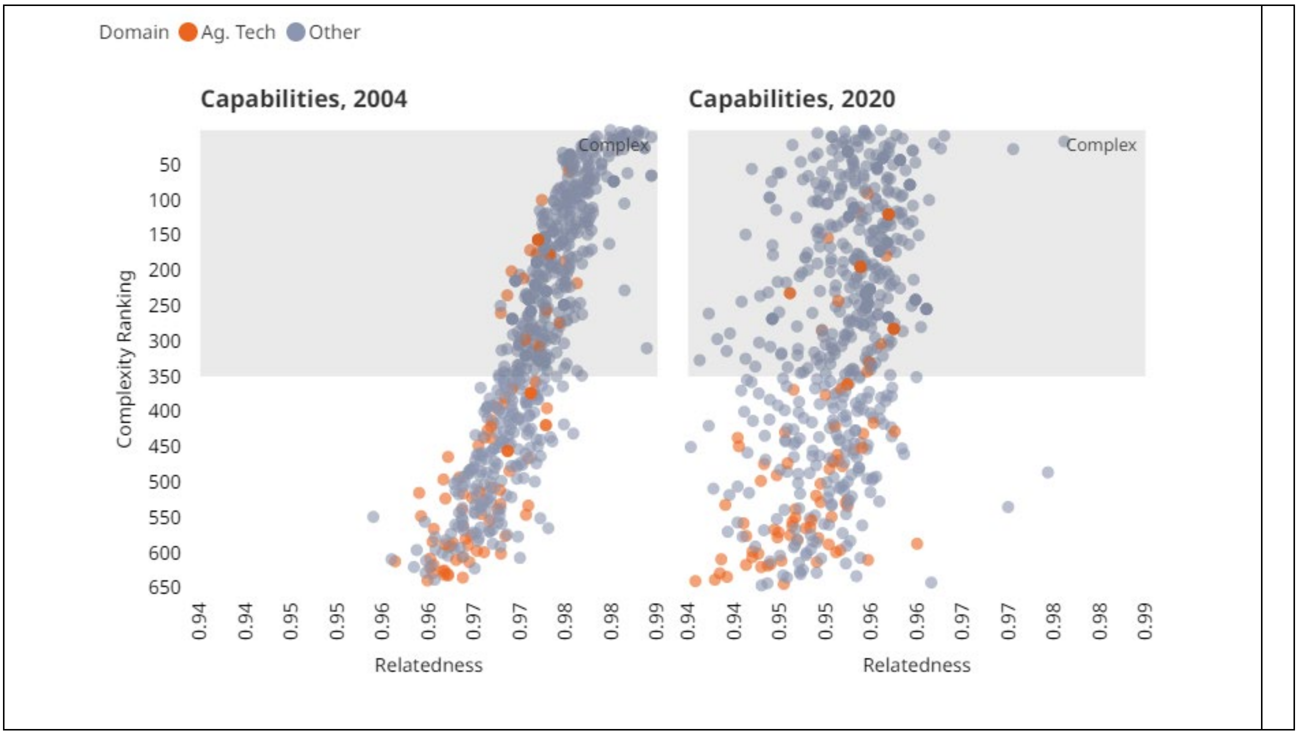
In addition, Colorado became a major region for aerospace, satellite, and atmospheric research, due to the regional concentration of U.S. military facilities and federal laboratories such as the National Oceanic and Atmospheric Administration (NOAA) and the National Center of Atmospheric Research (NCAR), modelling and predicting weather for agriculture, among others, and applications such as remote sensing.

3.3 How having frontier capabilities implies diversity and sophistication

The US economy is considered to be at the frontier of innovation. Unsurprisingly, it is also a frontier innovator in AgTech. Figure 11 compares the economy's capabilities across diverse production, scientific publications, and technology dimensions between 2004 and 2020 and shows how the specialization fields are related and concentrated together. The US has the know-how to develop rare and sophisticated technologies, which helps to explain why the country is the largest agricultural exporter in the world.

The US has diverse and sophisticated innovation capabilities

Figure 11: Complexity and relatedness of AgTech and other capabilities in the US, 2004 and 2020



Note : 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and exports data.

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

As a biotechnology hub, the U.S. was able to build its local capabilities based on the interactions between its strong public research center and institutions on one hand and incentivized private sector on the other hand. The appropriability conditions, such as through IP protection, also helped facilitate the private sector's investments into agricultural R&D. A breakthrough in agricultural biotechnology development in the U.S. led to its specialization in the technology. Developing recombinant deoxyribonucleic acid (rDNA) technologies in bacteria at Stanford University and the University of California, San Francisco, provided the basic approach to working with DNA at the molecular level. By mid-1970, the medical field had adopted and adapted these biotechnology tools and techniques.

It took about a decade for this tool and technique to find its way into agriculture. This was partly because there was almost no knowledge spillover between the medical research using the technologies and the AgTech researchers (Graff and Hamdan-Livramento, 2019). The first application of biotechnology tools was to veterinary science for animal health and it was only later applied to plant breeding.

Colorado is the second largest agricultural and food innovation hub in the US, tied with New York, and second only to Silicon Valley (Startup Genome, 2022). Its innovation ecosystem consists of a broad range of public sector research institutions, corporations, and a vibrant start-up community. Some of these new start-ups are focused on leveraging the latest wave of digital technologies and adapting them to the sector. Precision agriculture is a field of AgTech focused on using digital technologies that collect large data to optimize farming conditions and processes. There is also a thriving agribusiness in the region. These agribusinesses include 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 (Graff et al., 2014).

4 How São Paulo is building an ethanol empire

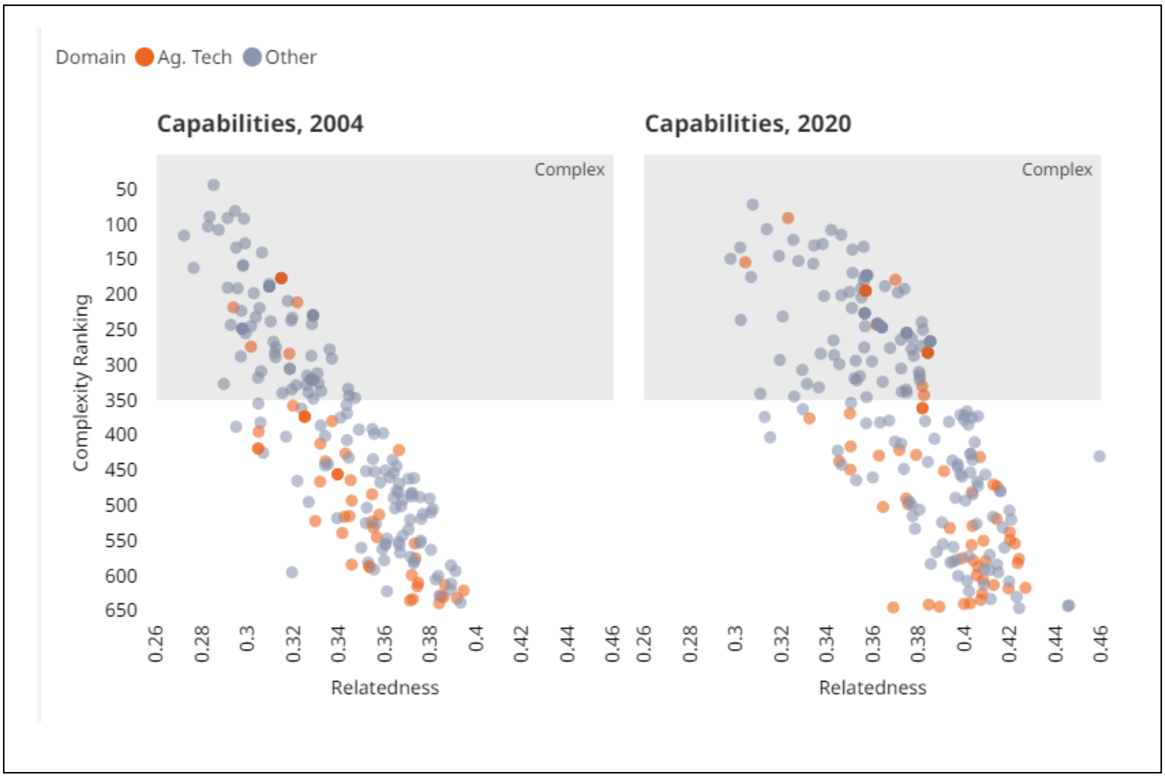
Brazil stunning growth in agriculture transformed it from a net agricultural importer in the 1960s to a net agricultural exporter in the 1980s. One of this remarkable transformation can be seen in its ability to become a world-class ethanol producer.

Brazil has been able to build its AgTech hub from an agricultural net importer to a world-class ethanol producer through strong government support and entry of the private sector when the industry started maturing.

Figure 12 shows how the Brazilian economy has built its innovation capabilities from 2004 to 2020. In particular, Brazilian innovators have been able to build their AgTech-specific complex capabilities – these are the set of capabilities that many other countries do not have and are thus rare, but also diverse and sophisticated in the sense that these capabilities can easily be applicable across different industries.

Innovation capabilities in Brazil are progressing to the frontier

Figure 12: Complexity and relatedness of AgTech and other capabilities in Brazil, 2004 and 2020.



Notes: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and exports data.

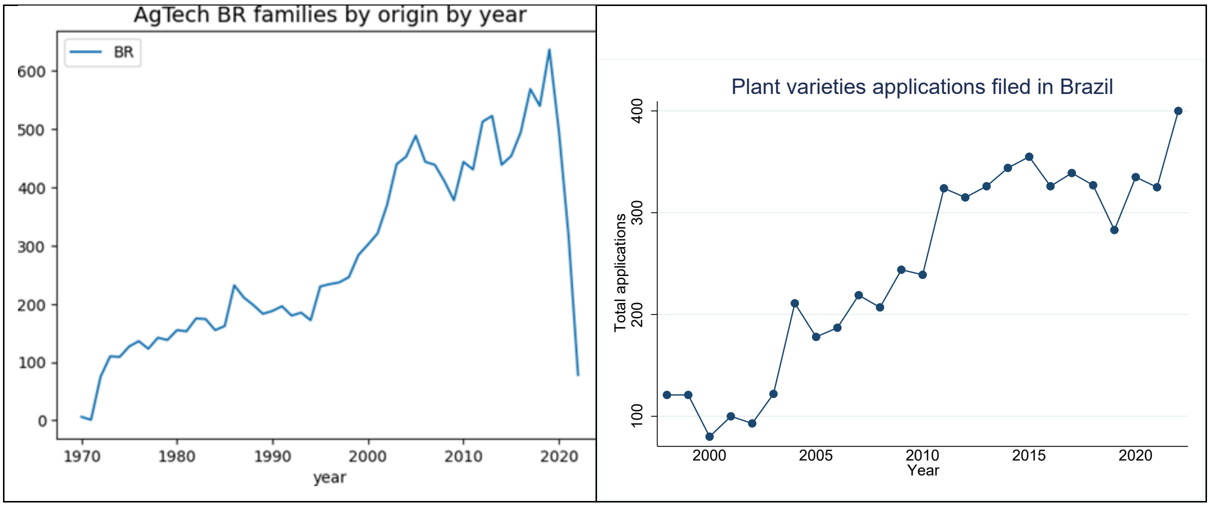
Source: EPO PATSTAT ; UN COMTRADE ; WIPO and WoS SCIE.

The increasing innovation capabilities of São Paulo can be seen in how it has evolved from a predominantly coffee and sugarcane producing state into a world leader in ethanol. São Paulo's rise as an agricultural innovation hub is due to a combination of many factors. First, the abundance of good quality and fertile agricultural land, water and weather are conducive to produce agricultural crops, including sugarcane. Second, São Paulo invested in better roads, transportation, and energy infrastructure, which helped it become well connected to the larger Brazilian and international markets. In contrast, the lack of roads in the Northeast of Brazil, where sugarcane was also grown, was an impediment to that region's development, and solidified São Paulo's dominance (Rada, 2013).

Similarly, applications for IP-protected agricultural innovation in Brazil is increasing. Figure 13 show how Brazilian innovators are steadily relying on patent and utility model protection for their agricultural inventions. Since 2000, Brazil became a member of the International Union for the Protection of New Varieties of Plants (UPOV). This international convention affords plant varieties protection on certain AgTech.

IP-protected AgTech applications have been increasing steadily over the past years

Figure 13: Total number of patent and utility model applications (left) and plant varieties equivalent application (right) in Brazil



Source: EPO PATSTAT; UPOV Plant Variety Database; WIPO.

More importantly, São Paulo was able to diversify its agricultural crop from coffee to sugarcane because of the Black Frost (*Geada Negra*) that wiped out most of the coffee crops across the state's plantations in 1975 (Parikh, 1979).

4.1 When public policy paved the diversification path

In 1975, the Brazilian government introduced its National Alcohol Program (*Programa Proálcool*) in response to the oil crisis in the 1973. The program aimed to reduce the country's dependency on petroleum-based fuels by focusing on ethanol, derived from sugar cane, as a substitute. The objectives of the program were two-folds: (i) to reduce its dependency on petroleum-based fuels and (ii) to encourage the production of ethanol, derived from sugarcane, as its substitute.

The Brazilian government managed to meet its objective of reducing its dependence on oil through various schemes of influencing the demand and supply of ethanol. On the supply side, the government provided financial incentives for its companies to produce ethanol for fuel. The program raised the country's sugar production by 20 times over the course of 16 years. On the demand side it subsidized the price of ethanol fuel and reduced taxes for consumers who purchase ethanol for their cars.

Today, Brazil is one of the largest and most competitive ethanol producers. Its ethanol exporters cater to the global market demand for biofuel. Sugarcane ethanol produces is more productive and cheaper in comparison to ethanol from either corn or beets.

Sugarcane produces 6,314 liters per hectare of ethanol versus corn's 2,729 liter per hectare (Donke et al., 2017). In addition, sugarcane ethanol costs 50 to 60 percent less than producing corn ethanol (Manochio et al., 2017).

A few universities and public research institutions located in São Paulo were researching the 2G technology. These were the University of São Carlos and Agronomy Institute of Campinas (IAC). The first two start-up companies, CanaVialis and Alleyx, were founded by researchers from these two institutions. Due to São Paulo's efficient production of sugar and the access to researchers in ethanol technology production, several multinational companies moved into the region. The now-acquired Monsanto, for example, purchased both CanaVialis and Alleyx. Other multinational companies soon followed, including Syngenta, BASF and Shell.

The large-scale bioethanol production using 2G ethanol technology is risky, even with government support. Only two of the six large-scale bioethanol plant productions established worldwide in 2000 remain. They are both in Brazil (de C. L. e Penalva Santos et al., 2023).

The National Alcohol Program helped many of the farmers and agribusinesses that depend on coffee to switch to farming sugarcane and producing ethanol (Parikh, 1979).

São Paulo has numerous universities as well as public research institutes that focus on agricultural research, some of which are the most prolific in publishing agricultural research in the country (de Castro, 2014). This state, along with the state of Rio de Janeiro, hosts the greatest number of research campuses of the Brazilian Agricultural research organization (EMBRAPA - *Empresa Brasileira de Pesquisa Agropecuária*). EMBRAPA is the research arm of the Brazilian Ministry of Agriculture. These centers conduct research on diverse agricultural topics including agroclimatology, bioinformatics, pesticide toxicology, tropical horticulture, instrumentation, geospatial informatics, geotechnology, and range management, to name a few.

Finally, EMBRAPA invested heavily in educating and training its workforce to build up the country's innovative capabilities. Between 1974 and 1982, EMBRAPA allocated approximately 20 percent of its budget on education (Correa and Schmidt, 2014).

4.2 Increasing participation from the private sector

In Brazil, the private sector now funds approximately a third of agricultural innovation in Brazil whether conducted in privately-held R&D centers or in collaboration with public institutions (Dalberg, 2021). Local companies co-exist, both competing and collaborating with foreign-based multinational companies in the sugar and ethanol market.

In the case of developing sugarcane ethanol in Brazil, initially, government support was needed to help build up domestic firms' capabilities to produce ethanol and later to develop and implement biorefining technologies for 2G biofuels. EMBRAPA, universities in the Sao Paulo region, and research institutes focused on sugarcane, ethanol, and 2G biofuel technologies worked closely in transferring their technologies to the private sector. At the same time, foreign multinational companies as well as foreign universities were partnering with Brazilian ethanol companies to leverage their technologies for 2G biofuels. One such collaboration was between Syngenta, Australia's Queensland University, and the Agronomy Institute of Campinas to develop technology for cellulosic ethanol from sugarcane bagasse.

There was a strong supply of entrepreneurial businessmen in Sao Paulo, thanks to its long establishment as a coffee-producing region. These businessmen, mostly coffee farmers, responded to the Brazilian government's financial incentives to purchase land and started farming using modern technologies and infrastructure (Mueller and Mueller, 2016).

São Paulo has a critical number of dynamic local and foreign companies. In fact, local companies in Sao Paolo were able to build their capabilities through collaboration and licensing-in of foreign technologies. Moreover, these companies also have a high domestic market share, which contributes to their competitiveness. Brazilian local companies tend to have a high level of government support (da Silva Medina and Pokorny, 2022). However, they also suffer from the government's intervention of sugar and ethanol pricing in the local market.

Along with the concentration of research and university campuses, this region has a critical number of dynamic local and foreign companies specializing in agricultural production and processing, including the world's highest concentration of expertise in sugarcane and ethanol production. It is also the headquarters for some of the world's largest agribusinesses.

São Paulo has a thriving scene of agricultural startups. According to reports analyzing startup ecosystems worldwide, São Paulo is known as the largest innovation and entrepreneurship center in Latin America. In addition, it has a relatively mature fintech and banking system. This allows it to provide much needed capital to the startups (BBVA, 2022; Startup Genome, 2023).

4.3 Market and technological opportunities set the way

Three factors help explain how São Paulo was able to build its innovation capabilities in ethanol production. First, the public sector's National Alcohol Program provided incentives for the private sector to diversify into producing ethanol. Secondly, the government also helped build the local know-how on sugarcane and ethanol production by investing in universities and research centers, but also in facilitating technology transfer and knowledge sharing between the universities and the private sectors. Thirdly, there were relevant breakthrough technologies that helped the Brazilian government realize their objectives.

One of the first inventions that was licensed in was the Ford Corporation's hybrid fuel car. This technology allowed for the mixing of ethanol and gas to power vehicles. The Brazilian government and private sector collaborated with foreign technology owners to develop and introduce flex-fuel cars to the local market. The government even imported the technology to produce vehicles that run on ethanol from the American company. However, the sharp oil price drop in 1986 made the program difficult to sustain, and the Brazilian government suspended the program.

But then in 2003, there was a technological breakthrough for the Brazilian market. A combination of the Bosch's pioneering flex fuel vehicle technology and the success of Magneti Marelli's software sensor technology in Brazil encouraged the use of ethanol for powering motor vehicles again (Yu et al., 2010). Brazilian 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 (ANFAVEA, 2010; de Castro, 2014). By 2017, nearly nine out of ten vehicles sold in Brazil were flexible-fuel cars (ANFAVEA, 2017).

Around the same time, there was renewed interest by the government in producing ethanol because the prices of oil were increasing and the perception of using renewable energy sources was slowly gaining acceptance. By this point, a few local companies were producing ethanol using 1G technology.

In the past decade, the European market has been pushing for greener technologies, and in order to stimulate demand, created a mandate for use of more efficient biofuels. This in turn created opportunities for second-generation (2G) ethanol production from Brazil. Whereas 1G ethanol is produced simply from crushing sugarcane, 2G ethanol produces ethanol based on the 1G ethanol technique plus the utilization of its "waste" called bagasse, which is the discarded stalk of sugarcane after the sugars has been squeezed out.

The 2G ethanol technology is thus more environmentally friendly as it reduces industrial waste while using more of the energy embodied in the sugarcane plant to produce ethanol.

The 2G ethanol technology is new to Brazil. It uses both 1G ethanol and the leftovers from 1G production to produce ethanol, reducing waste and helping address climate change concerns. 1G ethanol is produced simply from crushing sugarcane; 2G ethanol produces ethanol 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. As in the past, the Brazilian companies licensed in the 2G technology.

At the same time, a few universities and public research institutions located in São Paulo were researching the 2G technology. These were the University of São Carlos and Agronomy Institute of Campinas (IAC). The first two start-up companies, CanaVialis and Alleyx, were founded by researchers from these two institutions. Due to São Paulo’s efficient production of sugar and the access to researchers in ethanol technology production, several multinational companies moved into the region. The now-acquired Monsanto, for example, purchased both CanaVialis and Alleyx. Other multinational companies soon followed, including Syngenta, BASF and Shell.

The demand for 2G ethanol from European market, which commands premium prices, as well as the growing know-how of 2G process in the Brazilian universities and public sector provided the right opportunity and incentive for the private sector to adopt this new technology.

However, large-scale bioethanol production using 2G ethanol technology is risky, even with government support. Only two of the six large-scale bioethanol plant productions established worldwide in 2000 remain. They are both in Brazil (de C. L. e Penalva Santos et al., 2023).

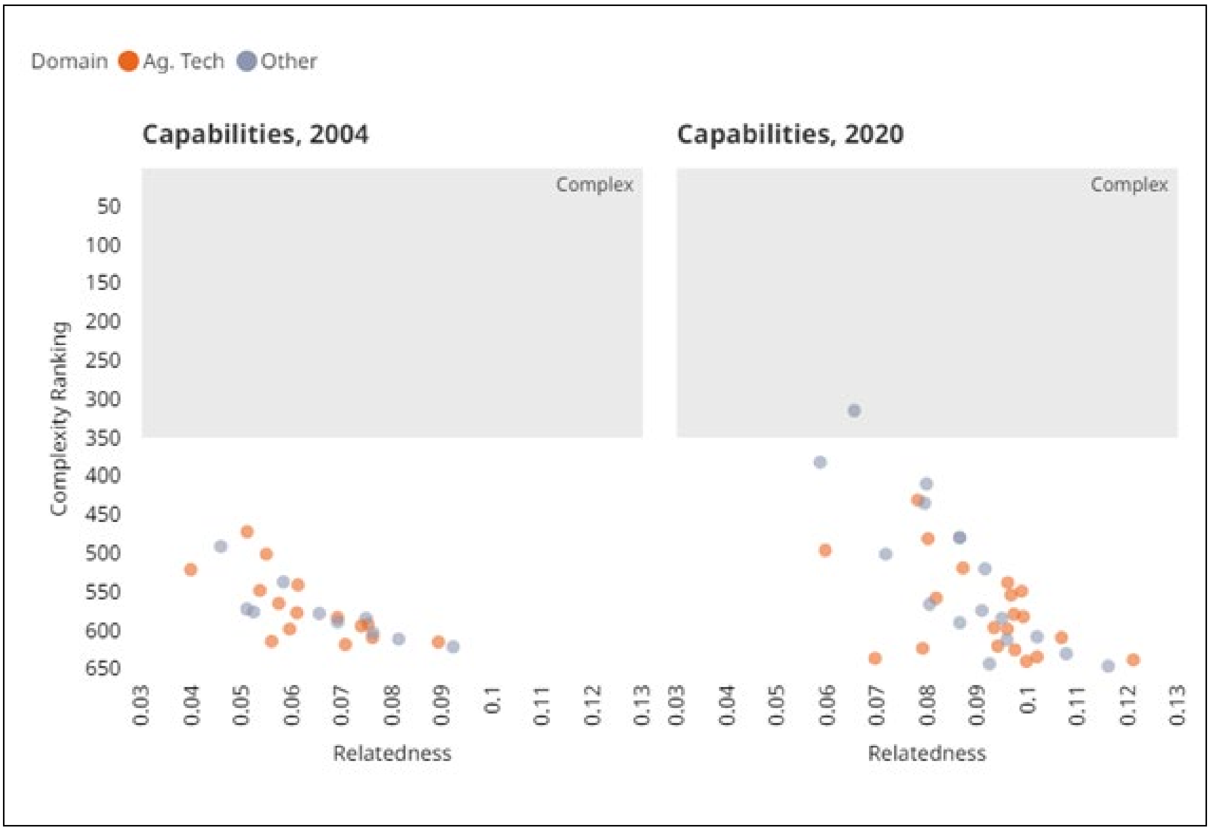
5 How Nairobi is planting the seeds of change for African AgTech

Agricultural production in Kenya is diversified, with main products for domestic consumption being maize, wheat, rice, and beans and main products for export being tea, coffee, sugar, and horticultural crops such as cut flowers, fruits, and vegetables. Because of its fair-weather conditions, soil fertility with adequate sun exposure and proximity to Europe, Kenya has become the largest producer of flowers in Africa. Between 1995 and 2003, the value of Kenya's floriculture exports increased by 300 percent despite the stagnation in the rest of its agricultural sector (Whitaker and Kolavalli, 2006).

Kenya’s local innovative capabilities are less diverse, related or rare than the other two AgTech hubs. This is reflected in its simple and complex strengths matrices, as seen in Figure 14.

Local capabilities in Kenya are simple but improving from a nascent stage

Figure 14: Complexity and relatedness of AgTech and other capabilities in the Kenya, 2004 and 2020



Notes: 626 innovation capabilities based on scientific fields, IPC subclasses and product classification in scientific publications, international patent applications and exports data.

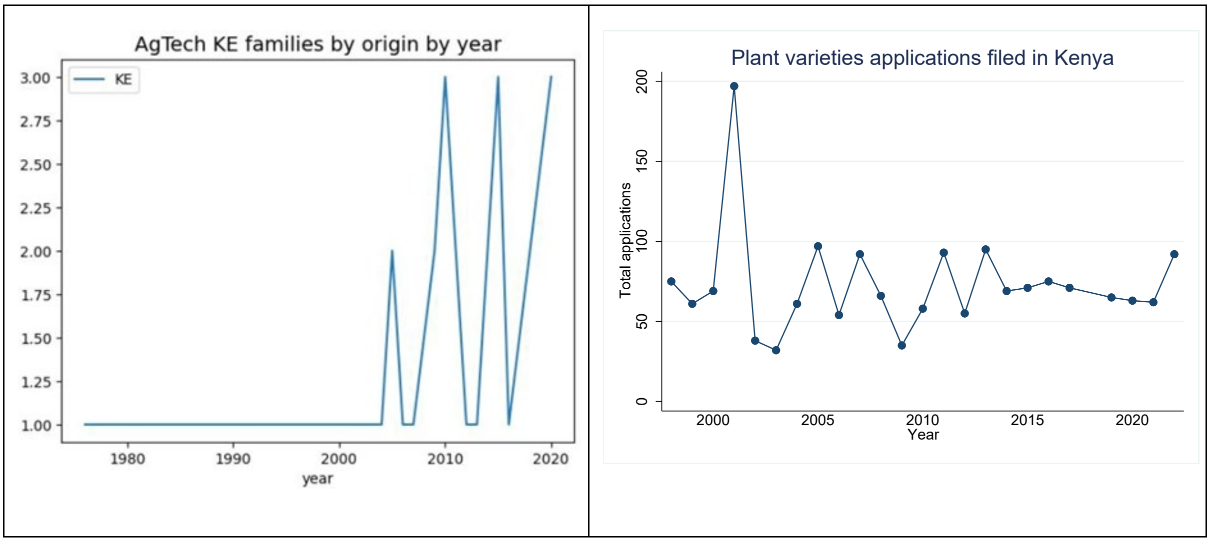
Source: EPO PATSTAT ; UN COMTRADE ; WoS SCIE ; WIPO.

A survey by the FAO in 2007 showed how Kenya has some capabilities to develop conventional and transgenic plant varieties (Badiane and Makombe, 2015). In fact, it is one of the few African countries with a research agenda in biotechnology. However, it has not developed sufficient capacity to provide technological solutions to its agricultural problems (Kingiri, 2022).

Kenyan agricultural innovators rely on plant varieties protection system more than patents and utility model protections. Figure 15 show Kenyan innovators have only applied for a handful of patents and utility model applications over the last few years. This may partly reflect the CGIAR's stance on keeping the innovation it has developed open for public use.

Kenyan innovators, however, seem to use apply for plant varieties protection more than with patents and utility models.

Figure 15: Total patent and utility model, and plant varieties applications in Kenya



Source: EPO PATSTAT; UPOV Plant Variety Database; WIPO.

Nairobi, Kenya's capital, is building its local capabilities as a plant varieties breeder for the African region through its collaboration with CGIAR research centers. 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 trade and distribution hub for agricultural products for the country as well as the African continent.

5.1 Plant breeding capabilities

Kenya has a long history of plant breeding and has built its innovative capability in this field among others. The government's support programs, investments in R&D and infrastructure helped build this capability. Kenya's agriculture research center, the

However, the country faces challenges such as limited access to irrigation, high costs 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 (D'Alessandro et al., 2015). Some of the issue of land irrigation is offset by the development of Kenya's horticulture industry. Flower producers in Kenya sometimes subcontract part of their flower production to other producers. In doing so, they help subsidize the cost of providing irrigation to non-irrigated land (Krishnan and Foster, 2018; Neven and Reardon, 2004). But the challenge persists.

5.2 Collaborating with an agricultural global innovation network

Kenya's collaboration with international agricultural research centers, such as CGIAR (formerly known as the Consultative Group of International Agricultural Research), help to overcome this challenge where most of its land is arid. For example, maize is a major food crop in the country. It accounts for 40 percent of the crop area and most of the staples grown. However, the maize yield levels are low. To overcome this problem, Kenya's agricultural center, the Kenya Agricultural and Livestock Research Organization (KALRO) collaborated with the International Maize and Wheat Improvement Center (CIMMYT – *Centro Internacional de Mejoramiento de Maíz y Trigo*) – another CIGAR research center – and backed by non-governmental organizations such as the African Agricultural Technology Foundation (AATF) to develop, test and convince Kenyan farmers to farm the drought-tolerant maize variety (Simtowe et al., 2021). Moreover, CIMMYT has access to a global innovation network of agricultural researchers worldwide. It also maintains the connection to private seed companies by working on developing abiotic stress hybrids in 17 countries over nine years (Boyer et al., 2013; Weber et al., 2012).

In addition, this collaboration with CGIAR has further helped its national agricultural research institutions such as Kenya Agricultural Research Institute (KARI) and KALRO to address global challenges in agriculture. In doing so, the country has been able to build its innovative capabilities in plant breeding and has begun cultivating some of its newly bred crops. The country is building on its accumulated conventional plant breeding know-how to move towards more advanced breeding and biotechnologies to develop improved plant varieties.

In Kenya, the establishment of two CGIAR centers, ILRI and ICRAF-CIFOR, in Nairobi helped to train the local researchers and scientists. Then, with those local innovative capabilities established, when conventional crop breeding technologies were developed by the CGIAR network they could be transferred to local firms for further development and adaptation to the agroecological conditions and farming systems of Kenya.

Instead, Kenya has been able to take advantage of the developments in the African region to develop its AgTech synergies. In building its capabilities as a plant varieties producer, KALRO collaborated with the CGIAR research centers to create the plant varieties that it needs. Moreover, funding from non-profit organizations helped to train, diffuse and share the benefits of new plant varieties to its farmers.

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 their maize crop production in 2011. This disease was equally disastrous for other maize producers in the African region. In response, the CGIAR's CIMMYT research center was able to derive four MLN-tolerant hybrid varieties. It transferred these varieties among both 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 to stop the spread of the disease across sub-Saharan Africa. Other collaborators included the International Institute of Tropical Agriculture (IITA), AGRA and 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.

Another way that the country is overcoming the constraints and challenges of engaging in agriculture is through the recent increase in AgTech start-ups. Nairobi is known as the "Silicon Savannah", due to its technologically inclined ecosystem (Startup Genome, 2023). 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. This success has led to a subsequent proliferation of other fintech startups in the region. Related to this, Nairobi is emerging as a top region for agricultural technology startups in Africa, among which are innovators in agricultural fintech, digital supply chain management, and agribusiness B2B marketplaces specialized to the needs and conditions of African farming and business (AgFunder, 2023).

The Kenyan AgTech specialization on plant breeding is likely to expand. This is because in 2015, the government lifted its ban on importing genetically modified foods. This ban was in place partly because many of the richer economies for Kenyan exports ban the importation of transgenic crops. The government has also allowed for research in genetically modified and engineered crops. The Kenyan National Biosafety Authority has approved several transgenic crops such as corn, cotton, cassava, sorghum and sweet potatoes. None of these approved crops is exported to Europe, where there is a ban on transgenic crops, including genetically engineered ones.[4] Moreover, a few operators have applied for open-field transgenic corn and cotton cultivation. In addition, the Kenyan government has enacted several agricultural-specific laws to transform the country's agriculture sector. 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.

5.3 How mobile banking platform is transforming Nairobi's value chain

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 leveraged mobile phone technology and enabled secure electronic cash transfer through short messaging services (SMS), which is available on almost all SIM-card mobile phones. Since mobile phones were ubiquitous in Kenya, where the telecom infrastructure was relatively poor, the technology was easy to adopt and adapt.

M-PESA is disrupting the agriculture value chain. It provides access to finance and credit for agricultural producers and generates significant benefits (Oostendorp et al., 2019). It has also opened the floodgates for new start-up AgTech entrants that built on the M-PESA platform. The unique identification provided by the SIM card allows for a reliable identification system and unleashed exchanges of products and services in the AgTech sector. For example, *Hello Tractor* is a new AgTech start-up, which rents out its tractors to farmers who need them.

6 Conclusion

How can we ensure countries continue to invest in agricultural innovation to improve their productivity? This chapter tries to illustrate how countries can try to build their innovative capabilities by using the case of three agricultural innovation hubs, namely São Paulo, Brazil, Nairobi, Kenya, and Colorado, US.

Lessons learned from the hubs can be grouped in three points. First, innovation in agriculture is agroecological specific. This means that technological advances in agriculture

[4] The major agricultural exports from Kenya to the European market are tea, coffee, flowers, vegetables, fruits and horticultural products.

must be adapted to the conditions of its soil, landform, and climatic characteristics. Second, the public sector plays a pivotal role in building innovative capabilities. In addition, they are responsible for creating the framework and incentives that would enable and facilitate the private sector to participate in agricultural innovation. This is why 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 these innovative activities in AgTech hubs leads to knowledge and know-how spillovers in the sector, either from other value segments of the agricultural value chain or in a related and adjacent field. Third, a country’s ability to shift its agricultural innovation trajectory toward the frontier depends on the local capabilities of its innovation ecosystem, which describes a complex environment of innovation-related stakeholders and their relationships and interactions within the system.

Countries with more opportunities to shift their technological path tend to have highly complex innovation ecosystems.

Works cited

AgFunder, 2023. Africa AgriFood Tech Investment Report 2023. AgFunder.

Alston, J.M., Pardey, P.G., Serfas, D., Wang, S., 2023. Slow Magic: Agricultural Versus Industrial R&D Lag Models. Annu. Rev. Resour. Econ. 15, 471–493. https://doi.org/10.1146/annurev-resource-111820-034312

ANFAVEA, 2017. National Association of Automakers Annual Report (Associaçao Nacional dos Fabricantes de Veículos Automatores Relatório Anual) (Annual Report). Associaçao Nacional dos Fabricantes de Veículos Automatores (ANFAVEA), São Paulo.

ANFAVEA, 2010. National Association of Automakers Annual Report (Associaçao Nacional dos Fabricantes de Veículos Automatores Relatório Anual). National Association of Automakers Annual Report (Associaçao Nacional dos Fabricantes de Veículos Automatores (ANFAVEA), São Paulo.

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.

Baldos, U.L.C., Viens, F.G., Hertel, T.W., Fuglie, K.O., 2019. R&D Spending, Knowledge Capital, and Agricultural Productivity Growth: A Bayesian Approach. Am. J. Agric. Econ. 101, 291–310. https://doi.org/10.1093/ajae/aay039

Balland, P.-A., Broekel, T., Diodato, D., Giuliani, E., Hausmann, R., O'Clery, N., Rigby, D., 2022. Reprint of The new paradigm of economic complexity. Res. Policy, Special Issue on Economic Complexity 51, 104568. https://doi.org/10.1016/j.respol.2022.104568

BBVA, 2022. São Paulo, the largest innovation ecosystem in Latin America - BBVA. BBVA Spark Open Innov. 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.

Boyer, J.S., Byrne, P., Cassman, K.G., Cooper, M., Delmer, D., Greene, T., Gruis, F., Habben, J., Hausmann, N., Kenny, N., Lafitte, R., Paszkiewicz, S., Porter, D., Schlegel, A., Schussler, J., Setter, T., Shanahan, J., Sharp, R.E., Vyn, T.J., Warner, D., Gaffney, J., 2013. The U.S. drought of 2012 in perspective: A call to action. Glob. Food Secur. 2, 139–143. https://doi.org/10.1016/j.gfs.2013.08.002

Clancy, M., Heisey, P., Ji, Y., Moschini, G., 2020. The Roots of Agricultural Innovation: Patent Evidence of Knowledge Spillovers, in: Moser, P. (Ed.), Economics of Research and Innovation in Agriculture. University of Chicago Press, pp. 21–75.

Correa, P., Schmidt, C., 2014. Public Research Organizations and Agricultural Development in Brazil: How Did Embrapa Get It Right?, Economic Premise no. 145. World Bank Group, Washington, D. C.

da Silva Medina, G., Pokorny, B., 2022. Agro-industrial development: Lessons from Brazil. Land Use Policy 120, 106266. https://doi.org/10.1016/j.landusepol.2022.106266

Dalberg, A., 2021. Case Study: Brazil’s investment in innovation for sustainable agricultural intensification. Commission on Sustainable Agricultural Intensification, Sri Lanka.

D’Alessandro, S.P., Caballero, J., Lichte, J., Simpkin, S., 2015. Kenya: Agricultural Sector Risk Assessment.

de C. L. e Penalva Santos, D., Correa, C., Amaral Alves, Y., Gomes Souza, C., A. Mancebo Boloy, R., 2023. Brazil and the world market in the development of technologies for the production of second-generation ethanol. Alex. Eng. J. 67, 153–170. 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 (No. Texto para Discussão, No. 1952a). Instituto de Pesquisa Econômica Aplicada (IPEA), Brasilia.

Dixon, J.A., Gibbon, D.P., Gulliver, A., Nations, F. and A.O. of the U., 2001. Farming Systems and Poverty: Improving Farmers’ Livelihoods in a Changing World. Food & Agriculture Org.

Donke, A., Nogueira, A., Matai, P., Kulay, L., 2017. Environmental and Energy Performance of Ethanol Production from the Integration of Sugarcane, Corn, and Grain Sorghum in a Multipurpose Plant. Resources 6, 1. https://doi.org/10.3390/resources6010001

Falck-Zepeda, J.B., Zambrano, P., Cohen, J.I., Borges, O., Guimaraes, E.P., Hautea, D., Kengue, J., Songa, J., 2008. Plant genetic resources for agriculture, plant breeding, and biotechnology, IFPRI Discussion Paper. International Food Policy Research Institute.

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, Rome.

FAO, 1996. Agro-ecological Zoning Guidelines, FAO Soils Bulletin 73. Food and Agriculture Organization of the United Nations, Rome.

Fuglie, K., 2016. The growing role of the private sector in agricultural research and development world-wide. Glob. Food Secur. 10, 29–38. https://doi.org/10.1016/j.gfs.2016.07.005

Fuglie, K., Heisey, P., King, J., Pray, C.E., Schimmelpfennig, D., 2012. The Contribution of Private Industry to Agricultural Innovation. Science 338, 1031–1032. https://doi.org/10.1126/science.1226294

Fuglie, K., Morgan, S., Jelliffe, J., 2024. World Agricultural Production, Resource Use, and Productivity, 1961-2020 (Economic Research Service), Economic Information Bulletin No. 268. U.S. Department of Agriculture, Washington, D.C.

Fuglie, K.O., Gautam, M., Goyal, A., Maloney, W.F., 2020. Harvesting Prospertiy: Technology and Productivity Growth in Agriculture. World Bank, Washington, D. C.

Graff, G.D., Berklund, A., Rennels, K., 2014. The emergence of an innovation cluster in the agricultural value chain along Colorado’s Front Range. Colorado State University, Fort Collins.

Graff, G.D., Hamdan-Livramento, I., 2019. Global roots of innovation in plant biotechnology.

Griliches, Z., 1957. Hybrid Corn: An Exploration in the Economics of Technological Change. Econometrica 25, 501–522. https://doi.org/10.2307/1905380

Hidalgo, C.A., Hausmann, R., 2009. The building blocks of economic complexity. Proc. Natl. Acad. Sci. 106, 10570–10575. https://doi.org/10.1073/pnas.0900943106

Hidalgo, C.A., Klinger, B., Barabási, A.-L., Hausmann, R., 2007. The product space conditions the development of nations. Science 317, 482–487. https://doi.org/10.1126/science.1144581

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. J. Agric. Econ. 69, 76–95. https://doi.org/10.1111/1477-9552.12221

Kenney, M., 1988. Biotechnology: The University-Industry Complex. Yale University Press, New Haven.

Kingiri, A.N., 2022. Exploring innovation capabilities build up in the deployment of crop biotechnology innovation in Kenya. Innov. Dev. 12, 305–324. https://doi.org/10.1080/2157930X.2021.1884934

Kingiri, A.N., Hall, A., 2012. The Role of Policy Brokers: The Case of Biotechnology in Kenya. Rev. Policy Res. 29, 492–522. https://doi.org/10.1111/j.1541-1338.2012.00573.x

Krishnan, A., Foster, C., 2018. A quantitative approach to Innovation in agricultural value chains: Evidence from Kenyan horticulture. Eur. J. Dev. Res. 30, 108–135.

Lowder, S.K., Skoet, J., Singh, S., 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). Food and Agriculture Organization of the United Nations, Rome.

Manochio, C., Andrade, B.R., Rodriguez, R.P., Moraes, B.S., 2017. Ethanol from biomass: A comparative overview. Renew. Sustain. Energy Rev. 80, 743–755. https://doi.org/10.1016/j.rser.2017.05.063

Moscatelli, F., Chacua, C., Gadgin Matha, S., Hartog, M., Hernandez Rodriguez, E., Raffo, J.D., Yildirim, M.A., 2024. Can we map innovation capabilities? (WIPO Economic Research Working Paper No. 81). World Intellectual Property Organization, Geneva.

Mueller, B., Mueller, C., 2016. The political economy of the Brazilian model of agricultural development: Institutions versus sectoral policy. Q. Rev. Econ. Finance, Special Issue: Is there a Brazilian Development “Model”? 62, 12–20. https://doi.org/10.1016/j.qref.2016.07.012

Nelson, K.P., Fuglie, K., 2022. USDA ERS - Investment in U.S. Public Agricultural Research and Development Has Fallen by a Third Over Past Two Decades, Lags Major Trade Competitors. Amber Waves.

Neven, D., Reardon, T., 2004. The Rise of Kenyan Supermarkets and the Evolution of their Horticulture Product Procurement Systems. Dev. Policy Rev. 22, 669–699. https://doi.org/10.1111/j.1467-7679.2004.00271.x

OECD, 2023. OECD-FAO Agricultural Outlook 2023-2032. Organisation for Economic Co-operation and Development, Paris.

OECD, 2018. Concentration in Seed Markets: Potential Effects and Policy Responses. Organisation for Economic Co-operation and Development, Paris.

Oostendorp, R., van Asseldonk, M., Gathiaka, J., Mulwa, R., Radeny, M., Recha, J., Wattel, C., van Wesenbeeck, L., 2019. Inclusive agribusiness under climate change: a brief review of the role of finance. Curr. Opin. Environ. Sustain., Sustainability Science: Inclusive business: A multi-Stakeholder issue 41, 18–22. https://doi.org/10.1016/j.cosust.2019.09.014

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

Parikh, A., 1979. Estimation of supply functions for coffee. Appl. Econ. 11, 43–54. https://doi.org/10.1080/758520522

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.

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

Raitzer, D.A., Sparks, A.H., Huelgas, Z., Maligalig, R., Balangue, Z., Launio, C., Daradjat, A., Ahmed, H.U., 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)), CGIAR Independent Science and Partnership Council. CGIAR, Rome, Italy.

Simtowe, F., Makumbi, D., Worku, M., Mawia, H., Rahut, D.B., 2021. Scalability of Adaptation strategies to drought stress: the case of drought tolerant maize varieties in Kenya. Int. J. Agric. Sustain. 19, 91–105. https://doi.org/10.1080/14735903.2020.1823699

Srinivas, S., Vieira Filho, J.E.R., 2015. Farms versus Firms in Economic Development: The Assumptions and Consequences of Learning Dynamics in Agriculture and Manufacturing (Discussion Paper No. 207), IPEA Discussion Paper. Institute for Applied Economic Research (IPEA-Brazil), Brasilia.

Startup Genome, 2023. The Global Startup Ecosystem Report 2023 [WWW Document]. URL https://startupgenome.com/ecosystems/sao-paulo (accessed 4.25.24).

Startup Genome, 2022. The Global Startup Ecosystem Report Agtech & New Food Edition. Startup Genome.

Weber, V.S., Melchinger, A.E., Magorokosho, C., Makumbi, D., Bänziger, M., Atlin, G.N., 2012. Efficiency of Managed-Stress Screening of Elite Maize Hybrids under Drought and Low Nitrogen for Yield under Rainfed Conditions in Southern Africa. Crop Sci. 52, 1011–1020. https://doi.org/10.2135/cropsci2011.09.0486

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

Wiggins, S., Henley, G., Keats, S., 2015. Competitive or complementary? Industrial crops and food security in sub-Saharan Africa. ODI.

WIPO, 2019. World Intellectual Property Report 2019: The Geography of Innovation: Local Hotspots, Global Networks, World Intellectual Property Report. World Intellectual Property Organization, Geneva.

Wright, B.D., 2012. Grand missions of agricultural innovation. Res. Policy, The need for a new generation of policy instruments to respond to the Grand Challenges 41, 1716–1728. https://doi.org/10.1016/j.respol.2012.04.021

Wright, B.D., Pardey, P.G., 2006. The evolving rights to intellectual property protection in the agricultural biosciences. Int. J. Technol. Glob. 2, 12–29. https://doi.org/10.1504/IJTG.2006.009124

Yu, A.S.O., de Souza Nascimento, P.T., Nigro, F.E.B., Frederick, B.W.B., Varandas, A., Vieira, S.F.A., Rocha, R.L., 2010. The evolution of flex-fuel technology in Brazil: The Bosch case, in: PICMET 2010 TECHNOLOGY MANAGEMENT FOR GLOBAL ECONOMIC GROWTH. Presented at the PICMET 2010 TECHNOLOGY MANAGEMENT FOR GLOBAL ECONOMIC GROWTH, pp. 1–11.