# Understanding Firm-level Adoption of Technology in Ethiopia*

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**Abbreviations and Acronyms**

| | |
|---|---|
| ABF | All Business Functions |
| AI | Artificial Intelligence |
| CAD | Computer-Aided Design |
| CPSD | Country Private Sector Diagnostic |
| CRM | Customer Relationship Management |
| DHS | Demographic and Health Surveys |
| EDRI | Ethiopian Development Research Institute |
| EPA | Environmental Protection Agency? (Ethiopia) |
| ERP | Enterprise Resource Planning |
| GBF | General Business Functions |
| GPT | General Purpose Technologies |
| HGER | Homegrown Economic Reform |
| HPP | High-Pressure Processing |
| HVAC | Heating, Ventilation and Air Conditioning |
| ICT | Information and Communication Technology |
| IoT | Internet of Things |
| ISO | International Organization for Standardization |
| KPI | Key Performance Indicators |
| LEED | Leadership in Energy and Environmental Design |
| MoTI | Ministry of Trade and Industry |
| MSME | Micro, Small and Medium Enterprises |
| NDC | Nationally Determined Contributions |
| NPC | National Planning Commission? (Ethiopia) |
| PEF | Pulsed Electric Field |
| RCS | Recycled Claim Standard |
| SME | Small and Medium Enterprises |
| SNNPR | Sidama-Dire Dawa-Harari-Somali (regions) |
| SRM | Supplier Relationship Management |
| SSBF | Sector-Specific Business Functions |
| TFP | Total Factor Productivity |
| VAV | Variable Air Volume |
| WEF | World Economic Forum |
| WIPO | World Intellectual Property Organization |

# 1 Introduction

Over the last two decades, Ethiopia has achieved remarkable progress toward social and economic development. A growing economy with a population of over 100 million located in the conflict-affected Horn of Africa region, Ethiopia experienced average growth rates of 10.4 percent between 2004 and 2019, becoming one of the most dynamic economies in Sub- Saharan Africa and globally. At the same time, the country achieved strong poverty reduction, with the share of the population below the national poverty line dropping from 39 percent in 2004 to 24 percent in 2016 (which is the latest available data). Ethiopia aims to reach lower-middle-income status by 2025; this will require more investment and greater productivity growth, which could be accelerated by increases in investment in technology and innovation.

However, and despite growth in the last two decades, Ethiopia has consistently lagged behind its neighbors in selected measures of technology adoption and innovation. At present, innovation, and the adoption of technology among Ethiopian firms is limited and not suited for significant increases in competitiveness; and available skills and capabilities are limited. Ethiopian firms lag in the adoption of technologies to perform general business functions and sector-specific technologies more efficiently, with innovation activity varying a great deal between small and larger firms. Larger firms constitute the lion's share in innovation activity as compared with small firms (Gebreeyesus et al. 2018; World Bank 2016). Although this is a common finding in all countries, in Ethiopia it may be partially explained by the failure of smaller firms to connect to export markets, thereby forfeiting opportunities for learning and quality upgrading. Not surprisingly, the technological divide has negative implications on employment growth and productivity among small and medium-sized enterprises (SMEs). Despite an evident gap in access to technologies, a recent study on the performance of manufacturing firms in Ethiopia and Tanzania suggests that the problem might lie more in the nature of the technologies available to African firms and less on whether a firm has access to a given technology, or uses it frequently (Diao et al. 2021). This may be the case for both large and small firms that employ production techniques that may not be particularly suited to the local economy.

This study describes the current status and analyzes the drivers and barriers of technology adoption practices across and within Ethiopian firms. The analysis relies on the new Firm-Level Adoption of Technology survey (FAT) data, implemented in 2022, which identifies the purpose for which technologies are used. This comprehensive survey, which is the first to be implemented in Ethiopia, includes a representative random sample of 1,476 firms in four regions focusing on firms with five or more employees across eight sectors. The data analyzed allows to measure at a very granular level what the main technology gaps in Ethiopian firms are, what technologies are being effectively used, and more importantly, the perceived barriers that may explain this lack of adoption.

The paper is structured as follows. **Section 2** presents the country context and outlines government efforts to promote innovation and technology adoption in Ethiopia. **Section 3** discusses the links between technology, productivity, and employment and presents existing evidence from Ethiopia. **Section 4** briefly describes the firm-level technology adoption survey (FAT). **Section 5** presents standard measures of technology such as Electricity, Information and Communication Technology (ICT), and next-generation technologies **Section 6** describes the new measures related to the use of technologies applied to general business support functions (GBFs) and sector-specific business functions (SBFs). **Section 7** presents an overview of the adoption of green technologies, while **Section 8** describes Ethiopia in the global context. **Section 9** discusses the main barriers to the adoption of technology, as has been observed across and within firms. Drawing on the survey findings, **Section 10** discusses the relationship between the adoption of technology and performance. Finally, **Section 11** concludes by providing some policy recommendations for boosting firm-level technology innovation.

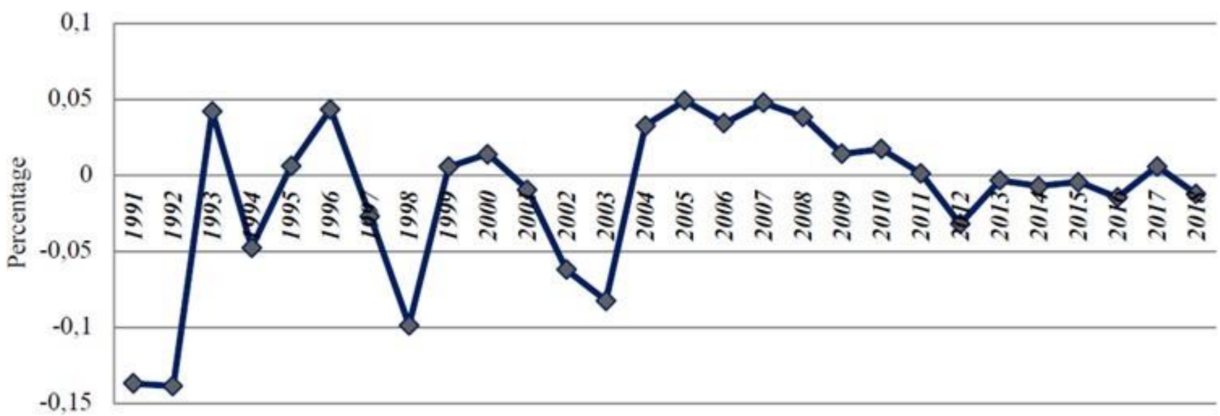
## 2 Country Background

Ethiopia has been one of the fastest growing economies in the world, with GDP growth averaging 10 percent on annual basis, and GDP per capita in purchasing power parity terms doubling in the same period. Rapid economic growth was driven by public investment in infrastructure and supported by a conducive external environment. Between 2010 and 2018, Ethiopia became a favored destination for foreign direct investment, with net inflows quadrupling in this eight-year period. Structural change in the form of labor shifts from low productivity agriculture to higher-productivity services and construction activities also contributed; this included the government-led industrial parks development program to support the nascent export-oriented manufacturing sector. While agriculture, construction, and the service sectors fueled this boom, the role of the manufacturing sector was limited, with its share of GDP remaining substantially below regional and aspirational benchmarks (Goldstein 2020).

Despite witnessing dynamism in the liberalization of certain sectors such as energy and telecom in recent years, Ethiopia's digital divide is wide, and limited innovation has hampered productivity growth and economic progress. Anecdotal evidence suggests that Ethiopian firms are lagging behind their competitors in international markets in terms of technological advancement and digital skills; a factor that is negatively affecting the performance of general business functions and overall productivity. Several indicators further confirm Ethiopia's low level of technology adoption and managerial capabilities, which may partially explain the failure of domestic firms to connect to export markets. As illustrated by the

Global Competitiveness Index, Ethiopia is lagging behind its regional peers in terms of entrepreneurial culture, managerial capabilities, and business dynamism (Figure 2). Similarly, the country ranks 117th in the Global Innovation Index out of 132 countries tracked by this indicator (Figure 3). As suggested inthe World Bank Group's Country Private Sector Diagnostic (CPSD), which was completed in 2019, Ethiopia's poor performance on these fronts calls for policies that will support innovation, agglomeration, and network economies; the development of managerial capabilities and worker skills; and links to external markets, as channels for sustaining the growth and competitiveness of firms.

Figure 1: Growth in Total Factor Productivity, 1991-2018

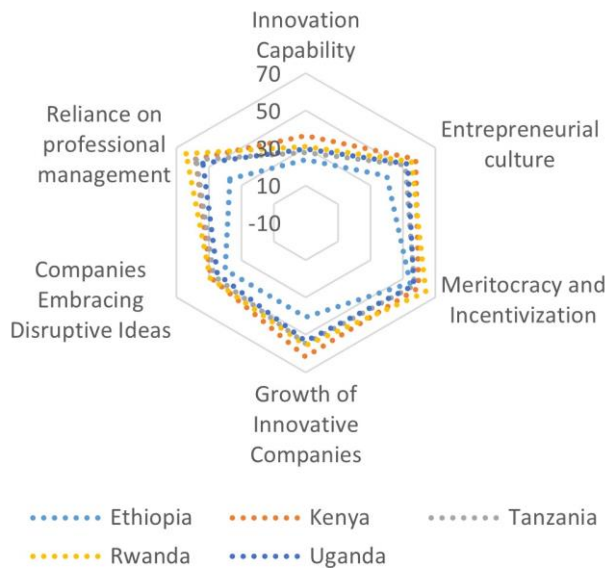



The substantial role of innovation and the digital economy is of vital importance in bringing inclusive growth to Ethiopia and reducing poverty. Unlocking digital technologies and introducing the use of more sophisticated technologies in products and processes could act as triggers of productivity, job creation, and the country's competitiveness in international markets.

To build Ethiopia's technological capabilities and digital economy, a National Innovation and Technology Development Plan has been adopted within the 10-year Homegrown Economic Reform (HGER) program, and themed "Ethiopia: An African Beacon of Prosperity." HGER has a central objective of sustaining the rapid economic growth registered over recent years; maintaining a stable macroeconomic environment by reducing debt vulnerabilties; and creating adequate and sustainable job opportunities. Furthermore, it has as its priorities ICT as an engine of inclusive economic growth and job creation, along with the development of agriculture, manufacturing, mining, and tourism. (NPC 2020).

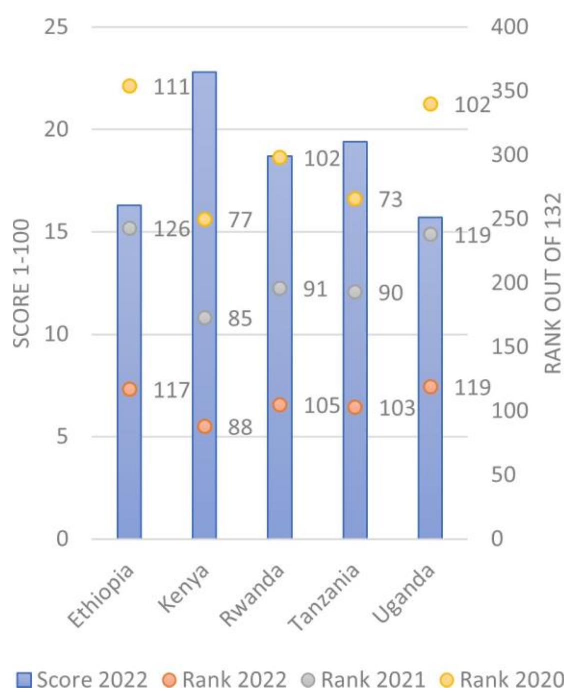
The National Innovation and Technology Development Plan of the HGER aims to: i) develop national innovation and technological capabilities and infrastructures with the cross-cutting institutions and institutional capacity; ii) strengthen human resource capacity; iii) establish operating procedures; and iv) build a national data center to increase awareness of the economic and social benefits of the creation of a digital economy and joining the fourth Industrial Revolution.

Figure 2: Competitiveness by Country




*Source*: World Economic Forum (WEF) 2019, Global Competitiveness Index.

Figure 3: Innovation by Country




*Source*: World Intellectual Property Organization (WIPO), Global Innovation Index 2022.

For instance, to ensure that there is an enabling infrastructure for the development of innovation and technology, the government has set a target of building nine infrastructure installations, twenty new innovation and research centers, and eight technology incubation centers. The major targets set by HGER to achieve the objectives of the innovation and research development plan are summarized in Table 1.

Table 1: Major Innovation and Technology Development Plans Targeted by HGER

| Key Objectives | Targets Set by HGER |
|---|---|
| Expand infrastructures for innovation and technology | Build 9 infrastructural installations; 20 innovation, research, and technology incubation centers; and 8 technology centers. |
| | In view of implementing the Treaty on the Prohibition of Nuclear Weapons, build 1 radionuclide station and 50 nonstop remote-sensing satellite ground stations. |
| | Build 450 basic (Zero Order) ground data control points; 1,000 first-order ground information control points; 1 geospatial laboratory; and one geospatial server room. |
| Building innovation and technological capacity | Increase the human resource budget in R&D to $5.7 million. |
| | Increase the number of national data centers to 3. |
| | Increase the number of towns that use a standard system of addresses to 73. |
| | Raise coverage of public institutions to a 95 percent electronic network system. |
| Expand and strengthen innovation and technology development | Establish 20 space technology enterprises. |
| | Establish 36 enterprises in technology adoption and transfer. |
| | Induce 50 emerging technology enterprises. |
| Ensure full access to mobile networks and the internet for all firms in Ethiopia. | |

*Source*: NPC (2020)

As noted by HGER, the move to an inclusive digital economy can unlock significant growth and productivity gains for the country. These need to be complemented with micro-level policies to strengthen firms' capabilities and enhance innovation. Recent research from the World Bank covering several countries, including Brazil, Ghana, Kenya, Korea, Senegal, and Vietnam shows a correlation between the adoption of technology adoption, productivity, and inclusivejob growth (Cirera et al. 2022). Indeed, the evidence suggests that cross-firm variation in technology accounts for a third of cross-firm differences in productivity and a fifth of the agricultural versus nonagricultural gap in cross-country differences in firm productivity.In this context, the World Bank is supporting digitization and financial support schemes to deepen the adoption of technology through several initiatives. Supporting digital businesses and technology adoption in Ethiopia is a relatively new vector for development assistance, but one where the World Bank is beginning to engage. The Ethiopia Digital Foundations Project, approved in 2021, expands access to risk capital for entrepreneurs and digital businesses while cofounding capacity- building programs to build managerial capabilities and digital skills. This study aims to contribute to building the analytical base on the key constraints affecting the adoption of technology in the country, and eventually generating the knowledge to inform future lending and policy-based operations. Supporting digital businesses and technology adoption in Ethiopia is a relatively new vector for development assistance, but one where the World Bank is beginning to engage. The Ethiopia Digital Foundations Project, approved in 2021, expands access to risk capital for entrepreneurs and digital businesses while cofounding capacity-building programs to build managerial capabilities and digital skills. This study aims to contribute to building the analytical base on the key constraints affecting the adoption of technology in the country, and eventually generating the knowledge to inform future lending and policy-based operations.

# 3 Technology and Productivity

The link between technology, productivity and employment is central to the study of economic development. The literature finds evidence that variation in technology accounts for a large share of differences in GDP per capita and average salaries of workers with similar characteristics across countries (Comin and Mestieri, 2018). In this sense, if firms use more sophisticated technologies to produce items or provide services, they can produce more and/or better quality with the same inputs, which ceteris paribus, allow for the increase in remuneration of all factors involved in production.

There are three channels through which better technology can boost productivity over time: i) Labor reallocation from low-productive to high-productive firms; ii) Within firm technology upgrading; 3) Entry and exit of firms. Estimates for Ethiopia suggest that within firm performance upgrade may account for a large share of productivity gains over 2000s. Indeed, in the 2000-2007 period as much as 60 percent of the contribution to physical factor productivity growth comes from within the firm itself. Increases in internal capabilities, including managerial skills, workforce skills, innovation capacity, and technology adoption, is the key determinant for productivity growth. In other words, the firm is considered the main creator of value added in the economy, as over half of overall productivity growth is achieved by innovating, adopting new technologies, and implementing best managerial practices.

Following this literature, this report will examine in Section 10 the association between various technology indexes and firm-level productivity measured as the log of value added per worker, anticipating a positive and statistically significant relationship between technology indexes and productivity for both general business and sector-specific business functions. Before deepening this discussion, we present the Firm-Level Adoption of Technology survey (FAT).

# 4 The Firm-Level Adoption of Technology Survey

The Firm-Level Adoption of Technology survey (FAT) systematically collects measures of technologies at the business function level.[1] Specifically, it offers an innovative tool for measuring the adoption and use of technologies at the firm level through three critical angles: (i) standard measures of technology related to general-purpose technologies (GPTs); (ii) the use of technologies applied to general business functions (GBFs); and (iii) the use of sector-specific business functions (SBFs).

The standard firm-level measures of technologies refer to traditional measures of the adoption of general-purpose technologies (GPTs) that enable firms to apply more technologies to nonspecific tasks. It includes access to and use of GPTs such as electricity, phone, computers, the internet, cloud computing, and digital platforms. GBFs are defined as those tasks that are necessary in any firm, regardless of the sector; this includes business administration, production planning, marketing, sales, payment methods, and quality control. In contrast, sector-specific functions (SBFs) are those linked to industry-specific business functions, such as land preparation in agricultural industries, or input testing in the food processing industry. Based on this structure, the survey collects information on the adoption and use of more than 300 technologies across almost 50 business functions.[2]

For each business function, the survey examines the adoption of each technology, from the rudimentary to the most sophisticated, moving up the ladder of technological sophistication. In this setting, for each business function, two technology measures are constructed: extensive and

[1] The survey has been implemented in several countries across different income levels, including Bangladesh, Brazil, Chile, Georgia, India, Kenya, Korea, Poland, Senegal, and Vietnam. For further details on the technology adoption survey methodology, please see Cirera et al. (2020) and Cirera et al. (2022).

[2] There are seven different business functions defined as GBFs: 1) businesses administration; 2) production planning; 3) sourcing and procurement; 4) marketing; 5) sales; 6) payment; and 7) quality control. For SBFs, the FAT survey collects information on eleven sectors: 1) Agriculture – Crops, 2) Livestock, 3) Food processing, 4) Wearing apparel, 5) Leather and footwear, 6) Automotive, 7) Pharmaceutical, 8) Wholesale and retail, 9) Land transportation, 10) Financial services, 11) Healthcare services.

intensive margins. The extensive margin captures the adoption of the most sophisticated technology used in the given business function for a firm, while the intensive margin reflects the sophistication of the most widely used technology. To illustrate the differences between the two, a given firm would use different levels of technology, both on the extensive margin (if they use it or not) and the intensive margin (which technology is the most used) to perform business administration tasks related with accounting, _finance and human resources. It is expected that many firms would use standard software (e.g., excel) to perform this task (extensive margin) and use it commonly with a high frequency (intensive margin). However, we would expect to see significant differences in terms of technology sophistication between a standard excel software and specialized resource planning software in terms of the capabilities to perform, the efficiency gains of the processes, and the outputs produced. But there are also significant differences in terms of just using a technology (the extensive margin) or using it intensively as the most used technology (intensive margin).

To capture the sophistication of technology at the firm level, we construct technology indices in which each business function has around five technologies in the order of sophistication level for both extensive and intensive margins. We assign the rank 1 to n from the least to most sophisticated technologies and construct relative rank by rescaling each rank to be from 1 to 5. Then, we aggregate technology measures by averaging them across (i) general business functions (GBFs); (ii) sector-specific business functions (SBFs); and (iii) all business functions (ABFs). The indices provide a summary of the average sophistication of technologies adopted and used by a firm. The extensive (EXT) margin captures the most advanced technologies adopted by a firm, whereas the intensive (INT) margin reflects the technologies that are most widely used by a firm. For instance, if a firm performs a business administration function through the first two technologies (handwritten processes and computers with standard software) among five available technologies, the extensive margin index is equal to 2, which reflects more advanced technology. If the same firm uses handwritten process as the most frequently used method, the intensive margin index becomes equal to 1. The technology sophistication indices are roughly aligned with automation process. The index of 1 reflects manual process, 2 to 3 reflect semi-automated process, and 4 to 5 reflect close to or fully automated process in a given business function.

By employing the survey, this study digs deeper into the drivers and barriers of technology adoption practices among Ethiopian firms. The surveywas implemented by the World Bank in Ethiopia from May to October 2022. It includes a nationally representative random sample of 1,476 firms, and is focused on firms with five or more employees, excluding micro firms with less than five employees. The sampling frame was the list of all firms available in the latest Business Registry administered by the Ethiopian Ministry of Trade and Industry (MoTI). It was stratified by three groups: small (5 to 19 employees); medium (20 to 99 employees); and large (100 or more employees). It was also stratified by eight sectors (Agriculture, Food Processing, Wearing Apparel and Leather, Wholesale and Retail, Land Transport, Accommodation, Other Manufacturing, and Other Services), and by four regions (Addis Ababa; Amhara; Oromia; and other regions, including Sidama, Dire Dawa, Harar, and Somali). The sample is made out mostly of private firms with a negligible number of State-Owned Enterprises. Furthermore, the survey is at the establishment level. In the case of multi-establishment firms, the establishment with the largest share of production/ sales were selected for the survey.

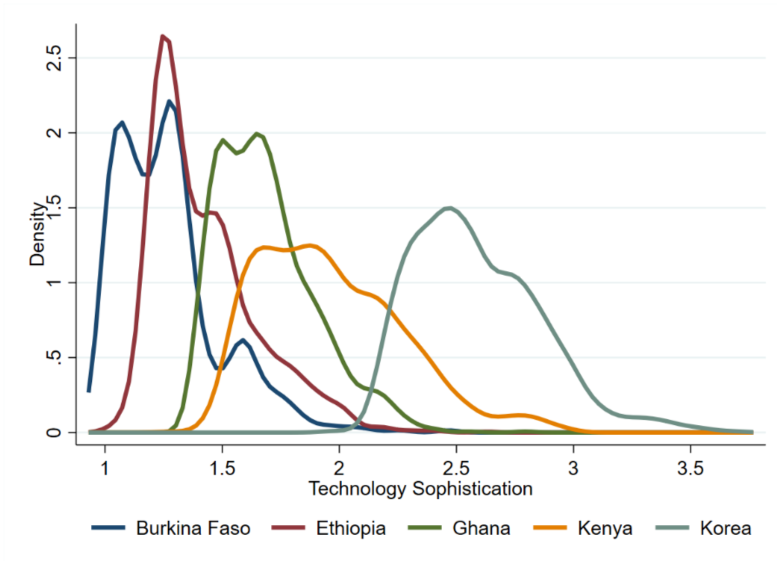
The survey applied a standardized process of data collection and quality checks to ensure accuracy in the responses and the comparability of the data collected across countries. For Ethiopia, the survey was conducted through computer-assisted telephone interviews (CATI) mode. The survey questionnaire was programmed through an electronic open data kit (ODK) platform, ensuring that several verification conditions such as skipping conditions, missing values, and expected range of numerical variables were checked in an automated way. In addition, before the data collection started the questionnaire was piloted with a random sample of firms, and the World Bank team provided a standardized training session and implementation manual to supervisors and enumerators to ensure that data collection protocols, quality standards and key concepts were clear and well understood by all members of the survey implementation team. During data collection, the World Bank team has also conducted additional quality checks at 10, 25, 50, 75 and 100 percent of data collected using standard algorithms to analyze the consistency of the data and provide continuous feedback. If abnormal responses were identified during this process, supervisors were notified and required to review problematic responses and conduct follow-up interviews to correct the problem. The implementation team were instructed to apply the questionnaire with the top manager of the firm and/or the employee who has more in-depth knowledge of the tools and equipment used in its operations.

All of the graphs presenting the survey results in this report include sampling weights. Advancing some of the results, the analysis points to three main challenges, based on perceived obstacles for the firms: (i) lack of capabilities and skills; (ii) lack of demand and uncertainty; and (iii) inadequate access to frontier finance technologies. Interestingly these constraints consistently surfaced across firms of different sizes and sectors.

# 5 Ethiopia in the Global Context

A key question is how the low level of adoption rates of more sophisticated technologies in Ethiopia compares to peer countries. This section presents cross-country comparisons with data collected from the Firm-Level Adoption of Technology (FAT) survey globally. As shown in Figure 4, the distribution of technological sophistication across countries varies with income level, providing a characterization of potential differences in the distribution of technological sophistication. Ethiopia's firms are largely concentrated at very low levels of technological sophistication, being at a lower level than other firms in Africa. The levels of technological sophistication in Ethiopia are higher than Burkina Faso, but lower than Ghana or Kenya. In addition, the right tail of these distributions is thicker, indicating that a larger number of firms in Ghana and Kenya are adopting advanced technologies. This suggests that Ethiopia is lagging behind these peer countries in terms of its adoption of technology.

Figure 4: Distribution of Technological Sophistication




Most firms, especially in developing countries such as Ethiopia, are far from the technological frontier. Figure 5 presents the estimated country average of technological sophistication in agricultural, manufacturing, and service-sector firms.[3] First, the figure shows that the average firm (represented by the blue dot) in each country is far from the frontier (starting in darker gray area).[4] Second, using the top 20 percent of manufacturing firms in Korea as a benchmark, most firms in developing countries, including the best firms (those with the red dot), are far from the frontier. The country rankings, based on average technological sophistication, tend to coincide with per capita income levels. On average, Ethiopian firms are above their country peers with less per capita income (for example, Burkina Faso), but below those in Malawi; and well below peers with higher per capita income, like Ghana and Kenya. More importantly, the top firms' technology sophistication in Ethiopia is not distant from those in Burkina Faso. The problem of low technology adoption in Ethiopia is not only

[3] Estimates control for sector, size, formal status, and age. The sample covers firms including Korea, Burkina Faso, Ethiopia, Ghana, and Kenya.

[4] The analysis considers the frontier to be above an average of 3.5, which loosely corresponds to firms using digital technologies for most or all of their business functions and using some frontier technologies in sector- specific business functions, and using those intensively. A score of 5.0 corresponds to the use of frontier technologies for all business functions, which in our sample occurs for only two firms in Korea.

one of lagging firms, but that ***all*** firms are lagging in their use of technologies, especially the best firms.

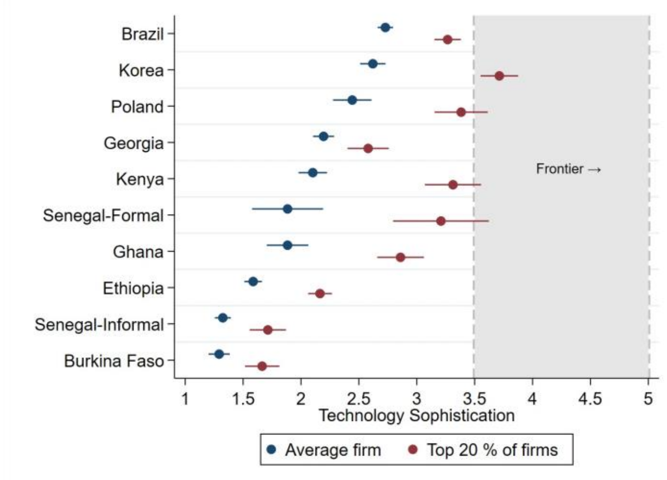
Agricultural and services firms are also far from the technological frontier (Figures 5a and c). There are important peculiarities about these sectors. In agriculture, the top firms in Brazil and Kenya tend to be relatively closer to the top firms in Korea and Poland, compared to manufacturing firms (Figure 5b). This suggest that exportation and specialization matters; and in some developing countries where agricultural exports are important, firms are relatively closer to the frontier than they are in manufacturing. Services show a different pattern, similar to agriculture and less correlated to a country's per capita income. In the case of Ethiopia, there are significant gaps also in the export subsectors in agriculture and manufacturing.

Ethiopian firms are among the least technologically sophisticated of the surveyed countries in their adoption of digital solutions for more advanced business functions such as enterprise management, logistics, sales, and payments. While the adoption of software for enterprise resource planning (ERP)[5] is generally low in most of the surveyed countries, almost ***no*** firms in Ethiopia reported using them. Peer countries such as Ghana and Kenya show signs of greater exposure to such solutions, with 10-20 percent of firms reporting extensive use of them; however, the share of firms relying on them intensively remains low.

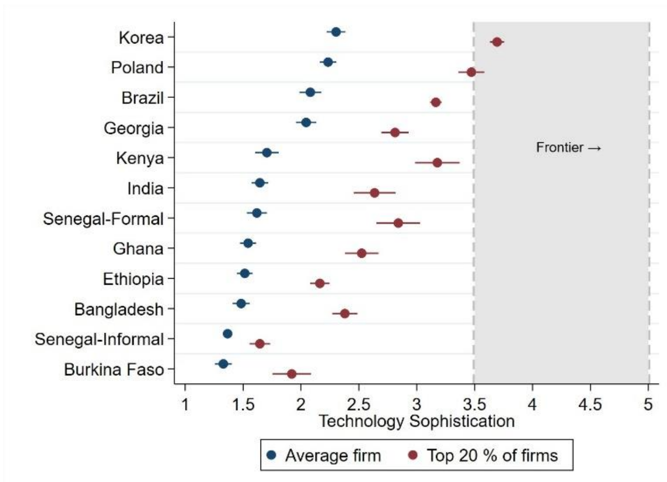
Overall, as Figure 4 illustrated, the Ethiopian economy is characterized by the use of basic technologies, mainly manual, but the technology gap with other countries, including other African countries, is larger on the right-hand side of the distribution, which includes exporters and larger firms. To understand what type of technologies lag behind and the factors affecting the adoption of technologies, the following sections investigate the details of technology adoption and use across general purpose, general business function, and sector-specific business function technologies in Ethiopia. The sections also examine the relationship between factors and technology adoption as well as the impact of technology adoption on productivity and job creation.

Figure 5: Technology Adoption Index: Average vs. Top Firms

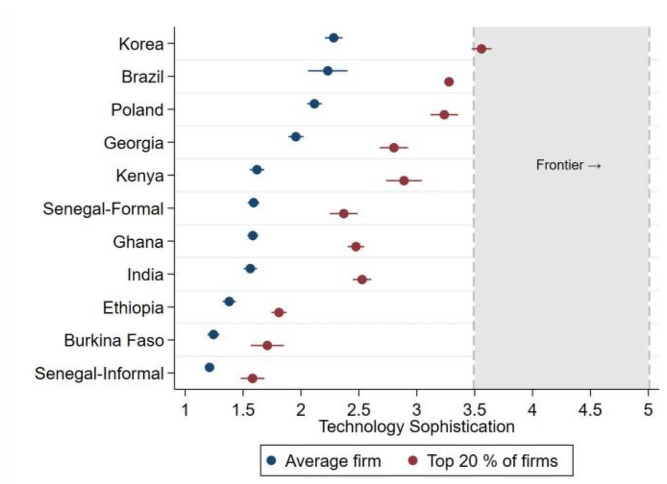
[5] Results are similar for supplier relationship management (SRM) and customer relationship management (CRM) systems.




(a) Agriculture




(b) Manufacturing




(c) Services

Note: Marginal effect estimates are based on a weighted sample controlling for sector, country, formality, size, and age of the firm.

# 6 Standard Measures of Technology: Electricity, ICT, and Industry 4.0

This survey provides various standard measures of the general-purpose technologies that are relevant to different stages of industrial revolutions. To examine the extent of the adoption of GPTs in Ethiopia, we summarize these technologies for Industry 2.0, 3.0,and 4.0.

## 6.1 Industry 2.0: Electricity

Industry 2.0 was based on the use of electricity- fueled technologies, which are necessary for modern production processes, and allowed for greater and faster production. A large share of Ethiopian firms have access to electricity, but the level and quality of access varies significantly with firm size and sector. Table 2 shows access to electricity, frequency of power outages, and ownership of generators by various sized groups and sectors. On average, 74 percent of firms have access to electricity in Ethiopia. Compared to medium or large firms, small firms have much lower access to electricity (69 percent).In terms of sectoral variation, in the manufacturing sector most firms have access to electricity (99 percent), while in agriculture only 54 percent do.

The quality of electricity is poor in Ethiopia, with close to 90 percent of the establishments that have access to electricity experiencing at least one power outage in the previous year. This high percentage of power outages is consistent across firm sizes and sectors. At the same time, only small number of firms have generators to provide reliable back-up, (28 percent on average), and it is even lower for small businesses (17 percent) and in the services sector (26 percent).[6] This suggests that power outages could be hindering business operations and production in Ethiopia. But more importantly, poor quality access to electricity could also slow the adoption of new technologies by reducing the incentives to invest in more advanced technologies that could not be operated during power outages.

Table 2: Access to and Quality of Electricity

| Technology | Mean | S.D. | Small | Medium | Large | Agr. | Manuf. | Serv. |
|---|---|---|---|---|---|---|---|---|
| Have Electricity | 74% | 0.44 | 69% | 92% | 87% | 54% | 99% | 73% |
| Power Outages | 89% | 0.31 | 85% | 98% | 100% | 96% | 99% | 88% |
| Have a Generator | 28% | 0.45 | 17% | 60% | 83% | 31% | 51% | 26% |

[6] As a comparison, Ghana and Kenya also have access to electricity, but with poor quality. In Ghana 95.3 percent of firms, and in Kenya 99.4 percent of firms face regular power outages, with most firms facing at least four incidents in a typical month. As a result of the lack of reliable electricity, 30 to 55 percent of firms in Ghana and Kenya have a generator, especially among medium- and large-size firms.

*Note*: Columns 1 and 2 present the overall mean and standard deviation across the economy. Columns 3-5 present this information disaggregated by firm size, and Columns 6-8 show this information disaggregated by sector. Numbers are weighted by the sampling weight.

The access to and reliability of electricity in Ethiopia varies significantly across regions. Most firms in Addis Ababa (92 percent) have access to electricity, but access is lower in Amhara (70 percent) and in other regions is 83 percent. Specifically, in Oromia only less than half of the businesses have access to electricity (44 percent) and nearly all firms experience power outages (97 percent), but only a small fraction of firms have generators (12 percent). These results illustrate that there are significant regional disparities in access to and the reliability of electricity in Ethiopia.

## 6.2 Industry 3.0: Information and Communications Technology

Industry 3.0 technologies, such as information and communication technology (ICT), have made it possible to advance automation processes, although these technologies still rely on human interactions. In terms of mobile phone, computer, smartphone, and internet penetration, Table 4 shows that access to ICT in Ethiopia is very heterogeneous across sizes and sectors. About 47 percent of all firms own a computer, varying from 35 percent of small firms to 92 percent of large ones. The adoption of smartphones is also relatively low, with only about one in four firms having a smartphone, but this share increases with firm size. Firms inthe manufacturing sector are more likely to own computers or smartphones, as compared to those in services or in the agriculture sector.[7]

Access to the internet shows similar patterns; it is still relatively low; only about 34 percent of firms in the entire economy have access. Internet penetration is particularly low among small firms (only 23 percent), while 80 percent of large firms have access to the internet. Following this trend, there is a clear and positive association between firm size and having a website or a social media presence. Since larger firms are more likely to have internet access, they are also more likely to have a website and use social media. However, due to the low level of access to the internet, the overall share of firms that have a website or use social media is relatively low; only 11 percent have a website, and about 25 percent use social media for business. This weak use of digital platforms and tools indicates a lack of readiness for adjustments became necessary for businesses during and after the COVID-19 pandemic. More importantly, not having computers or mobile phones implies the inability to use digital technologies.

[7] In Kenya access to mobile phones is high (97.1 percent), as is access to computers (81.4 percent) and smartphones (81.3percent). In Ghana, access to mobile phones is 88.7 percent, access to computers 70.9 percent, and smartphones 68.6 percent.

Table 3: Access to Information and Communications Technology

| **Technology** | **Mean** | **S.D.** | **Small** | **Med.** | **Large** | **Agr.** | **Manuf.** | **Serv.** |
|---|---|---|---|---|---|---|---|---|
| Have a Computer | 46.9% | 0.5 | 35.2% | 82.8% | 91.7% | 24.8% | 50.6% | 47.5% |
| Number of Computers | 3.4 | 70.4 | 0.9 | 5.5 | 89.4 | 1.1 | 3.1 | 3.5 |
| Have a Smartphone | 27.0% | 0.4 | 24.0% | 36.2% | 41.6% | 22.8% | 32.8% | 26.8% |
| Number of Smartphones | 0.8 | 2.4 | 0.5 | 1.3 | 5.5 | 0.5 | 1.1 | 0.8 |
| Have Internet | 33.7% | 0.5 | 23.2% | 65.2% | 80.2% | 12.8% | 40.0% | 34.0% |
| Type: Dial-Up Internet | 0.1% | 0.0 | 0.0% | 0.1% | 0.5% | 0.0% | 0.5% | 0.0% |
| Type: DSL Internet | 46.3% | 0.5 | 35.1% | 58.9% | 54.0% | 13.2% | 56.7% | 45.9% |
| Type: Wireless Internet | 52.5% | 0.5 | 63.1% | 40.7% | 44.7% | 86.8% | 41.4% | 53.0% |
| Type: BPL Internet | 0.2% | 0.0 | 0.0% | 0.3% | 0.5% | 0.0% | 0.5% | 0.1% |
| Acquisition of software | 2.6% | 0.2 | 1.0% | 5.8% | 34.4% | 0.9% | 6.3% | 2.4% |

*Note*: BPL = Broadband over power lines.

## 6.3 Industry 4.0: Advanced Digital Technologies

Industry 4.0 technologies integrate advanced digital technologies into machines and physical devices; this includes artificial intelligence (AI), robots, the Internet of Things (IoT),Big Data analytics, 3D printing, and cloud computing; these tools facilitate more automated systems, autonomously gather and exchange information, make decisions, and control systems without human intervention.

The survey findings confirm that he prevalence and adoption among Ethiopian firms of the next generation of technologies under Industry 4.0, which will include precision agriculture, is low (Table 4). The most widely used advanced technology is cloud computing, which was reported as being used by 4.3 percent of all firms. In the manufacturing sector, firms that adopted robots or 3D printing are rare, but a few firms (1.2 percent) adopted other advanced manufacturing technologies. Finally, Big Data analytics, artificial intelligence, and precision agriculture were not reported as being used by any of the firms in the sample.

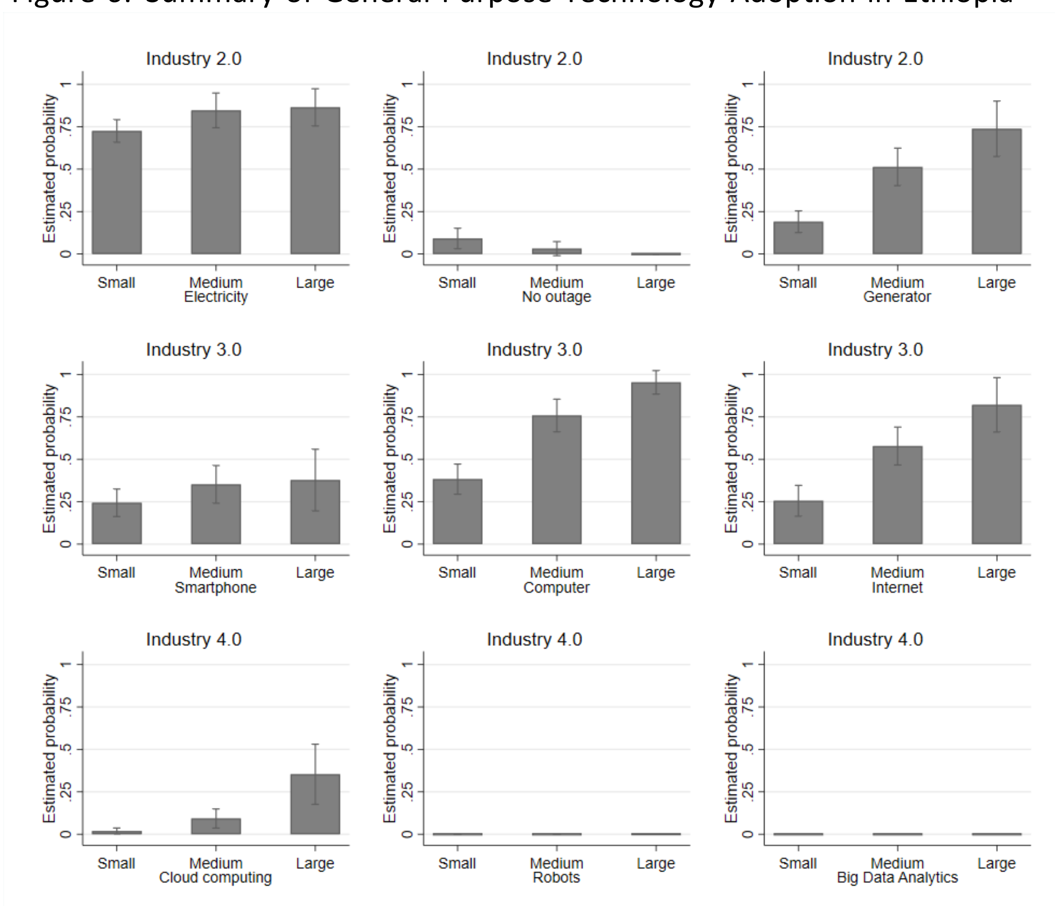
Table 4: Industry 4.0 Technologies

| Technology | Mean | S.D. | Small | Medium | Large | Agr. | Manuf. | Serv. |
|---|---|---|---|---|---|---|---|---|
| Cloud Computing | 4.3% | 20.2 | 1.9% | 10.1% | 32.7% | 1.4% | 9.3% | 4.0% |
| Big Data Analytics/AI | 0.0% | 0.0 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Robots | 0.0% | 1.7 | 0.0% | 0.0% | 0.3% | n.a. | 0.0% | n.a. |
| Additive Manufacturing/3D Printing | 0.0% | 1.5 | 0.0% | 0.0% | 0.2% | n.a. | 0.0% | n.a. |
| Other Advanced Manufacturing | 1.2% | 10.8 | 0.0% | 0.3% | 11.5% | n.a. | 1.2% | n.a. |
| Precision Agriculture (IoT) | 0.0% | 0.0 | 0.0% | 0.0% | 0.0% | 0.0% | n.a. | n.a. |

*Note*: Questions about robots, additive manufacturing/3d printing, and other advanced manufacturing are asked for firms operating in manufacturing. Questions about precision agriculture (IoT) was asked for firms in agriculture.

Figure 6 summarizes the adoption of general purpose technologies in Ethiopia across three generations of technological advancement, by technology and firm size in Ethiopia. The overall results indicate that Ethiopian firms are struggling to access and effectively use the basic technologies that form the foundation of the digital economy. This represents a significant obstacle to the adoption of technology and productive use and is likely to be a binding constraint on the development of the digital economy in Ethiopia. Universal access to electricity is still not a reality. Although the probability of having electricity is over 70 percent for all size groups in Ethiopia, this is lower than the global average. Reliability is also an issue, with very few firms reporting no outages, and is also reflected in a greater share of medium and large firms having to have generators to cope with outages. While the estimated probability of a large firm in Ethiopia having a computer is over 95 percent, it is only 76 percent for medium firms, and less than 40 percent for small firms. Internet access is even lower: an estimated 82 percent of large, 58 percent of medium, and only 25 percent of small firms. In contrast, the estimated probability of having a computer or access to the internet for a firm in the global sample is over 80 percent, whether it is small, medium, or large.

Figure 6: Summary of General Purpose Technology Adoption in Ethiopia




*Note*: This figure presents the predicted probability of firm sizes (Small = 5 to 19 employees, Medium

= 20 to 99 employees, and Large = 100+ employees) for different types of technologies (from Industry 2.0 to 4.0), while controlling for sectors and regions.

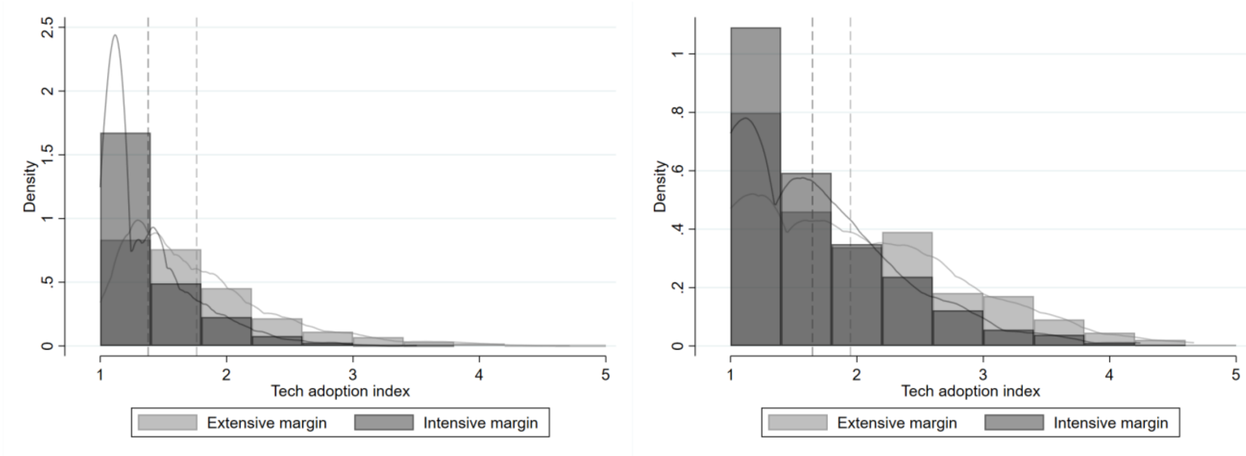
On a positive front, large firms in Ethiopia are not too far behind the average large firm in the other countries surveyed. The adoption of cloud computing among large firms in Ethiopia is almost on a par with the average of other surveyed countries (35 percent).

# 7 New Measures of Technology Adoption and Use: Linking Technologies to Business Functions

As detailed in Section 3, the technology adoption survey offers an innovative tool for measuring the adoption and use of technologies at the firm level through new angles, such as the use of technologies applied to general business support functions (GBFs), and the use of sector-specific technologies (SBFs). For each business function, two technology measures are constructed: extensive and intensive margins. **The first captures the adoption of the *most sophisticated technology*** used in the given business function, while **the second reflects the sophistication of the *most widely used technology***. As a summary measure we use a simple index ranging from 1, where a manual technology is used, to 5, which is the frontier technology for that business function.

Figure 7 presents the histogram and kernel distribution of both extensive and intensive margins of the technology indexes in Ethiopia across firms, for GBFs and SBFs separately. In Figure 7a, both the extensive and intensive margin distributions in the GBF are right-skewed, which suggests that only a small share of firms are adopting and using digital technologies. More importantly, most firms are still relying on very rudimentary manual technologies to conduct their GBFs. Figure 7b shows that SBFs have more densities in the middle level of technologies, compared to GBFs. However, the overall patterns are still right-skewed, which implies that many firms are also relying on basic technologies to conduct their SBFs.

Figure 7: Technology Adoption: Firm-Level Distribution



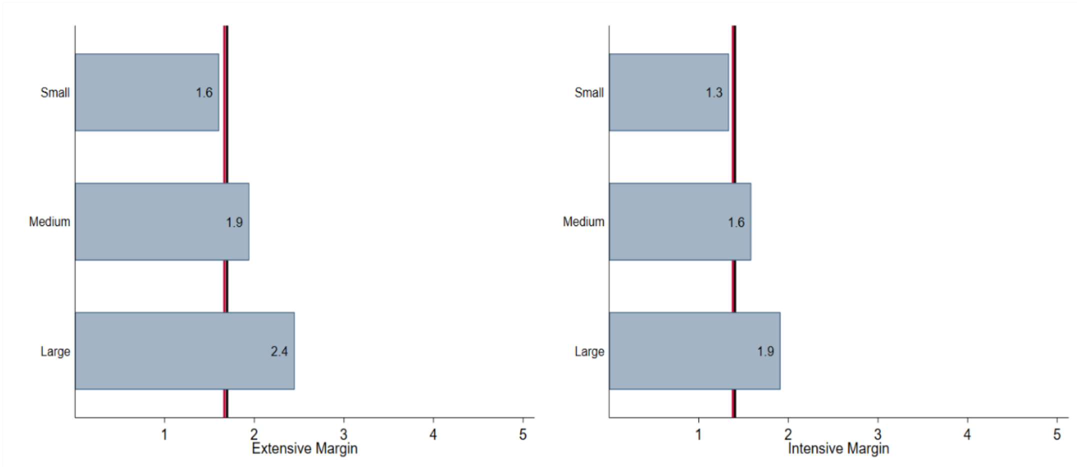

(a) General Business Function (b) Sector-Specific Business Function

*Note*: The vertical dotted lines show the averages for the extensive and intensive margins.

## 7.1 Use of Technology in General Business Functions

Figure 8 shows the average indexes for the extensive and intensive margin by size. The results show that there is evidence of a positive relationship between both the indexes and the firm size. The difference is particularly large between small and large firms at the extensive margin, suggesting that large firms in Ethiopia are exploring and adopting more sophisticated technologies. Results for the intensive margin show quite similar patterns. On average, the intensive margin in GBFs is about 1.3 for small, and about 1.8 for large firms in Ethiopia. For example, in a business function such as either business administration or production planning, this result suggests that a large share of small businesses still rely mainly on manual processes, but that large firms are widely using computers to conduct these administrative business functions. Despite these differences, larger firms are still far from adopting and using frontier technologies for GBFs such as enterprise resource planning (ERP) or supplier resource management (SRM) (see below).

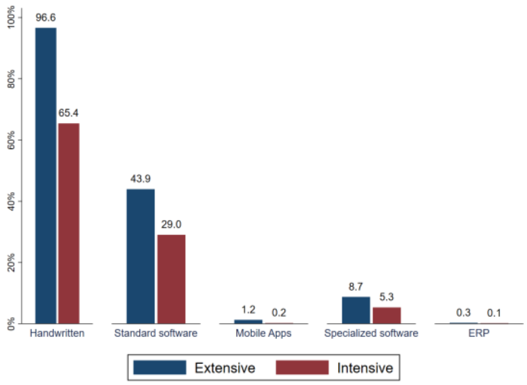
Figure 8: General Business Functions: Extensive and Intensive Margin by Size



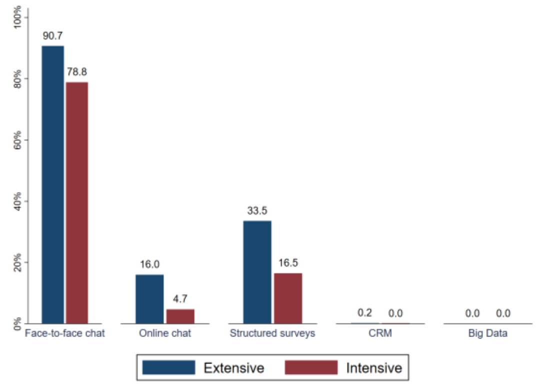

*Note*: Black and red vertical lines show the average and median index, respectively. Small = 5 to 19 employees, Medium = 20 to 99 employees, Large = 100+ employees.

Figure 9 details the extensive and intensive margins for selected general business functions. For most business functions, technology use is concentrated in low-sophistication technologies that are uses along with manual methods or computers, but without specialized software. Most firms still adopt and use rudimentary technologies in many of their business functions, such as business administration, planning, sourcing, and quality control, but sophistication is increasing in both the adoption and use of technologies for payment, sales, and marketing. Also, for these business functions, there are only small gaps between the extensive and intensive margins for payment methods and sales, which suggests that firms are not just adopting more advanced technologies, but also using them for these business functions.

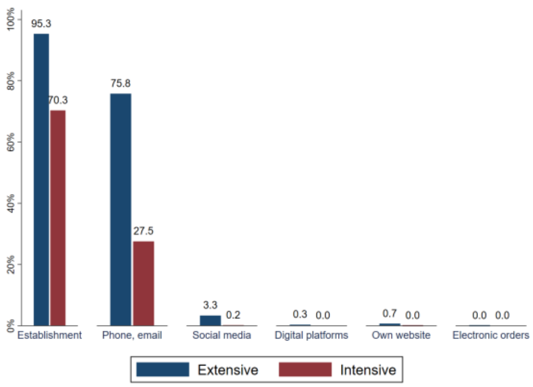
Figure 9: Share of Firms Using Technologies Applied to General Business Functions



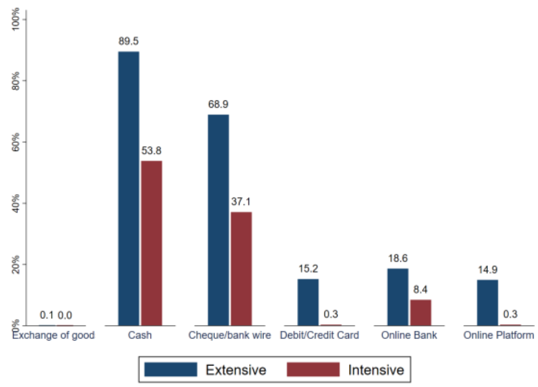

(a) Business administration processes related to account, finance, and HR



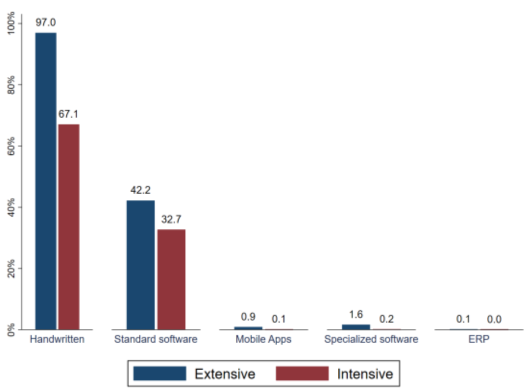

(b) Customer information for marketing and product development



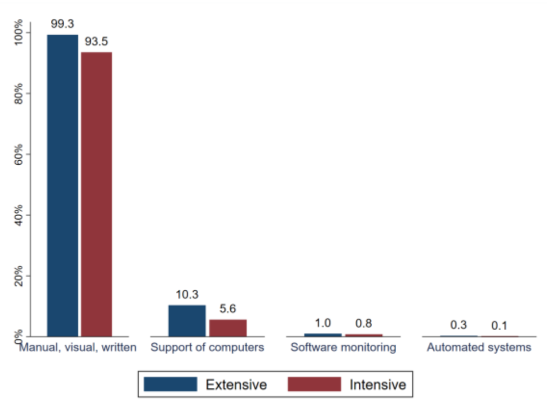

(c) Sales methods




(d) Payment methods




(e) Production or service operations planning




(f) Quality control inspection

## 7.2 Sector-Specific Business Functions

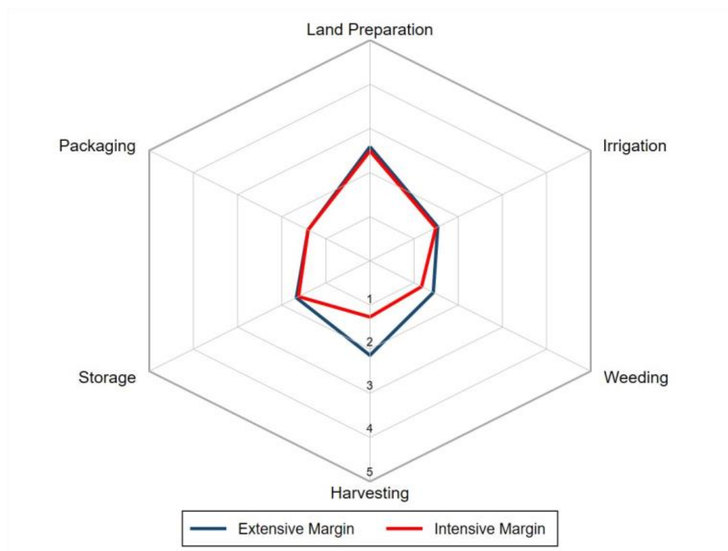
As detailed in Section 3, sector-specific business functions (SBFs) reflect the level of technologies that are specifically related to core production processes, or service provision. Overall, the results show significant heterogeneity in the level of technology used across business functions within Ethiopian firms in different sectors.

### 7.2.1 Agriculture: Crops

Businesses operating in the crop subsector of agriculture uses low- sophistication technologies, with no large differences across functions. Ethiopia is known for some of its agricultural exports, for example, coffee beans and pulse seeds. Yet despite the importance of some of these cash crops for Ethiopia's economy, production remains mostly based on manual processes, with only slightly more advanced technologies being used for land preparation.

Figure 10 shows the extensive and intensive margin indexes for six different SBFs in agriculture. In the extensive margin, the index varies from 1.40 for packaging to 2.59 for land preparation. The intensive use of more sophisticated technologies is slightly lower, with the index ranging from 1.17 (for weeding) to 2.49 (for land preparation).The higher index for land preparation is consistent with the shortage and fragmentation of arable land in the country, due to the fact that increasing agricultural productivity is needed in order to addresspersistent poverty and food insecurity in the region.

Figure 10: Agriculture: Crops




Most farms adopt less sophisticated technologies and rely primarily on manually operated machines for their business functions. As the most-often used packing method, farms use manual packing (70 percent) or human-operated equipment (30 percent). Most firms store their products in precarious conditions. Close to half of farms store their products either wholly exposed to sun, rain, and wind (38 percent) or without controlled temperature (62 percent). Weeding and pest control are also carried out with less advanced technologies. Manual application of chemical herbicide is the most used method and is used by all firms: only 8 percent rely mainly on the mechanical application of chemical herbicide, and 4 percent use biological fertilizing methods.

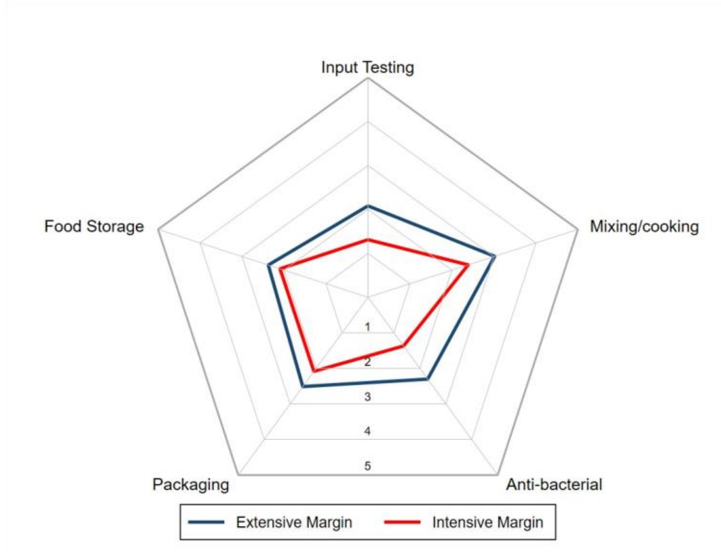
For tasks related to land preparation and harvesting, firms are more likely to use manually operated machines. For land preparation, 43 percent intensively use manual plowing with simple tools, and about 57 percent are using either animal-aided instruments (2.5 percent) or tractors or equipment that are manually operated (55.5 percent). In harvesting, 2.4 percent of farms rely on human-operated machines, 1.6 percent on animal-aided instruments, and over 89 percent still perform manual harvesting. About 7 percent rely on mechanized processes with machines or tractors that are operated by workers. But *no* firms reported using automated processes with machines or tractors that combine multiple functions and are supported by digitally-enabled technologies. Overall, these results suggest that farms in Ethiopia are mainly relying on basic technologies to perform these tasks.

### 7.2.2 Food Processing

After agriculture, food processing is the largest employer in Ethiopia. Compared to agriculture, firms operating in the food processing sector are more likely to rely on machines with some human interactions, while only a few firms are using methods with minimal human interaction. Figure 11 shows the extensive and intensive margin indexes for five sector- specific business functions that are used in food processing. In the extensive margin, the index varies from 2.08 for input testing, to 2.3 for antibacterial processes, to 3.02 for mixing/cooking. As expected, the indexes for the intensive margin are significantly lower, ranging from 1.31 to 2.39 for input testing and mixing/cooking, respectively.

Antibacterial processing is the SBF with the lowest index in the sector. Over 95 percent of establishments use either minimal-processing preservation methods (77 percent) or antibacterial wash or soaking (18 percent). Only 4 percent use thermal processing technologies, and less than 1 percent use advanced methods such as high-pressure processing (HPP) or pulsed electric field (PEF) as the most used technology. For packaging, 24 percent of firms still rely on manual packing, while 71 percent use human-operated machines as the most frequently used technology. Lastly, 46 percent of firms still store their products with minimal protection and some exposure to the elements; 26 percent use ambient conditions in closed buildings; and 28 percent use some climate control (partial/seasonal) in a secured building. None use fully automated climate control, which is the mostadvanced.

Figure 11: Food Processing



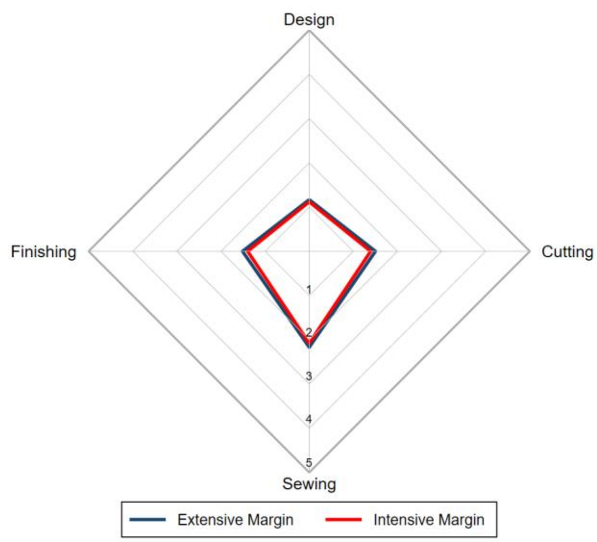

In food processing, there is a gap in the adoption of technology across different sized firms. Both the extensive and intensive margins of the technology adoption indexes significantly increase as firm size grows. At the extensive margin, the gap between large and small firms is 1.26 and 1.61 for packaging and antibacterial processes, respectively. Although the gap in these business functions is smaller at the intensive margin (0.87 and 1.22, respectively), it is still significant. Nevertheless, even large companies are far from the frontier, especially in businessfunctions such as the antibacterial and input-testing processes.

### 7.2.3 Wearing Apparel

Despite being one of the largest export sectors in the country, firms in the wearing apparel sector are far from the frontier in all business functions. Figure 12 details the two indexes for four different business functions in the sector: design, cutting, sewing, and ironing. The indexes are all below 3 in the extensive margin, and in the intensive margin, only the index for design is above 2. Overall, these low indexes suggest that the tasks associated with each business function are either being performed manually, or with manually operated machines, which implies specialization in low value-added segments of the apparel value chain.

For instance, only 2 percent of Ethiopian firms have adopted computer aided design ( CAD) for design drawing, and even fewer (1.5 percent) are applying it as the most used technology. 96 percent of firms still rely on manual design and drawing by hand, and 3 percent design with specialized 2D drawing software. In addition, only a few establishments perform cutting, sewing, and ironing using technologies with little human interaction. For cutting, only 3 percent of businesses have adopted automatic or computerized machines, and only 1 percent are using it intensively. Most firms still rely either on manual cutting (69 percent) or manually operated machines (25 percent). We observe similar results in the remaining business functions. For sewing and joining parts, 85 percent use manually operated machines as the most used technology. In contrast, only 0.13 percent use automated machines, and 1.13 percent use3D knitting machines. Lastly, for ironing, over 99 percent of firms use either basic manual ironing (62 percent) or electric high-pressure steam irons (37 percent).

Figure 12: Wearing Apparel




Even though the adoption of technology adoption in the sector is positively associated with firm size, large firms are also still far from the frontier. Large companies adopt more advanced methods for most business functions. For instance, the gap between large and small companies ranges from 1.56 for cutting to close to 1.0 for sewing. However, the intensive use of these sophisticatedtechnologies is much smaller. Even within large companies, the intensive margin index is less than 3 for all functions.

### 7.2.4 Retail

The average sophistication level of technologies adopted in the retail sector is close to the level of manually operated machines across business functions, and shows slight variation across firm sizes. For instance, the intensive margin index varies from 1.56 for inventory to 2.12 for advertising, suggesting a large gap to the frontier, and only slight variance across business functions (see Figure 13). For customer service, 66 percent of firms provide customer service usually atthe store, while 34 percent often use the phone. Even though 4 percent of businesses have adopted online modes of customer service, less than 1 percent are frequently using it. The gap concerning the frontier is also significant for pricing strategies. Few establishments use more advanced methods such as automated promotions (0.34 percent) or personalized pricing driven by predictive analytics (0.01 percent). Manual pricing is the most used method for 66 percent of companies in the sector, followed by automated markup using Excel or other similar software (34 percent).

Figure 13: Wholesale and Retail

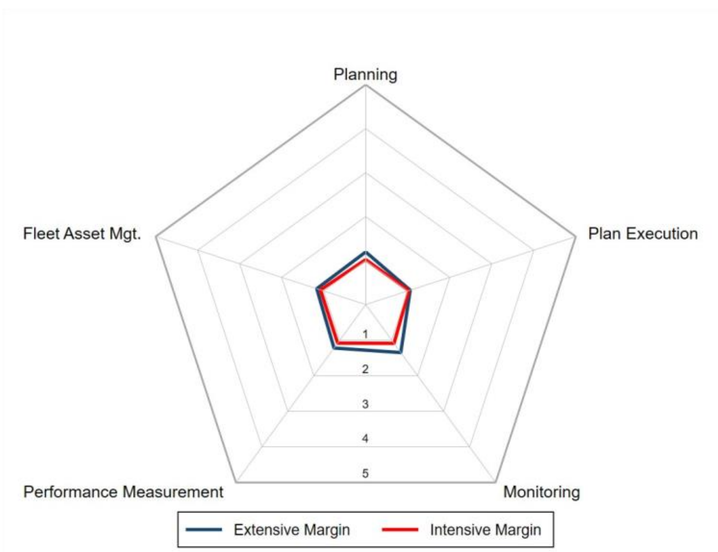

We observe similar results for merchandising strategy and inventory: 64% percent of businesses rely on manual selection as the most used technology for merchandising, while 36 percent use category management tools. Only 0.52 percent intensively apply specialized software that considers the firm's turnover, inventory, and space. As for inventory, about 92 percent of the establishments areusing either handwritten record-keeping (67 percent) or computer databases with manual updates(25 percent) as the most frequently used methods. In addition, an important share of firms, about 34 percent, are using social media as advertisement channels. Yet, only 15 percent use it as the most often used method. In the intensive margin, 60 percent rely on paper-based communication, 6 percent use traditional methods such as radio, billboards, and TV, and 20 percent use email or mobile phones.

Differences between small and large firms are only significant at the extensive margin. There we observe a marked association between the adoption of technology and firm size. For instance, there is a gap between large and small companies in the adoption of more sophisticated methods of inventory (1.14) and pricing (1.05). However, the intensive use of these technologies is much more similar across sizes with minimal variation across business functions, indicating that even large firms are considerably far from the frontier.

#### 7.2.5 Transportation

Lastly, in land transportation in Ethiopia, most firms still rely predominantly on manual technologies and paper documentation (Figure 14). For plan execution, 98 percent of firms use manual processes with the support of fax, text, or phone calls, and 0.79 percent use manual processeswith the support of digital platforms or mobile apps as the most frequently used technologies. As for monitoring, 95 percent of firms rely on event-driven method at predetermined intervals with thesupport of fax, text, or phone calls. As for transportation performance management, the vast majority of firms still rely on the two most basic technologies, namely manually monitoring and reporting (93 percent), and computers with nonspecialized software (6 percent). Lastly, for fleet asset management and maintenance, the use of paper- driven systems (94 percent) is also high. Such a low level of technological sophistication in this sector is mainly driven by the large numberof small firms that rely on rudimentary technologies. Technology adoption in this sector is also positively associated with firm size, and large firms use more sophisticated technologies. In addition, this limited use of more digitally integrated technologies that can help the management and optimization of the fleet also reduce the ability of the sector to reduce carbon emissions.

Figure 14: Transportation

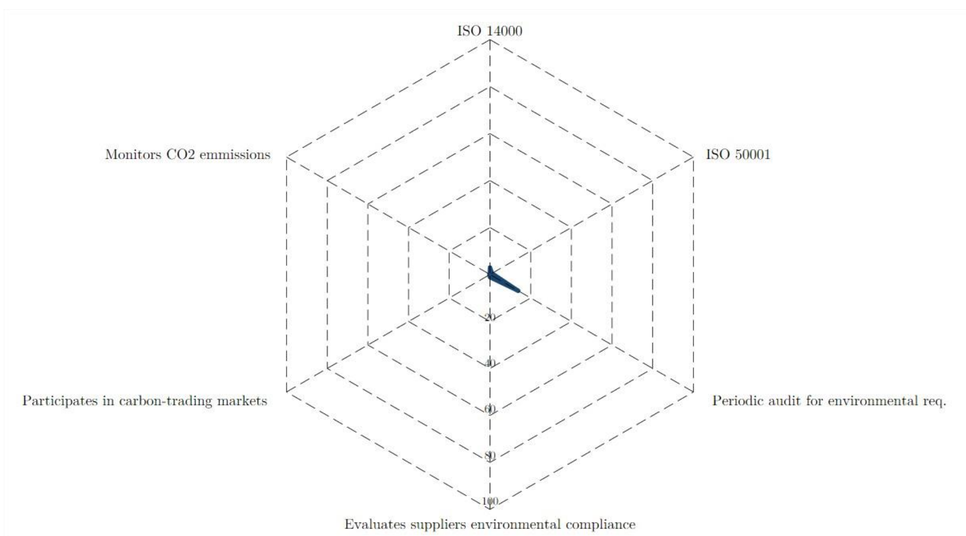



## 8 Adoption of Green Technologies

The FAT survey in Ethiopia also examined a set of questions on green management practices, energy consumption, and the adoption of “green” technologies. This green module has been implemented in four other countries: Brazil, Cambodia, Chile, and Georgia. The granular information collected allows analysis of the adoption of green technologies, green management practices, and their relationship with other technologies. This can provide insights into how to incentivize greening the production sector.

The use of green practices and technologies in Ethiopia is almost nonexistent. In terms of the transition to cleaner energy sources, the use of onsite renewable sources, such as solar, wind, biomass, or geothermal energy is negligible (only 1 percent of firms). The adoption of green practices is quite low among firms in Ethiopia and concentrated in periods of audits for compliance with environmental regulatory requirements. Close to 15 percent of firms report having periodic audits by a third party for compliance. Only 3 percent of businesses in Ethiopia have ISO 14001 certification (or at least certification in one of the ISO 14000 family), whichis the standard for environmental management system. Other practices inquired about in the survey—for example, ISO 50001 certification; evaluation of suppliers' environmental compliance;participation in carbon-trading markets; and monitoring of CO2 emissions—were negligible. While this pattern holds even when firms are disaggregated by size, the likelihood of adopting green practices does increase with firm size. Close to 20 percent of large firms report having periodic audits, and 13 percent have some type of ISO 14001 certification. This is likely the result of exporting requirements.

Figure 15: Percentage of Firms Adopting Green Practices

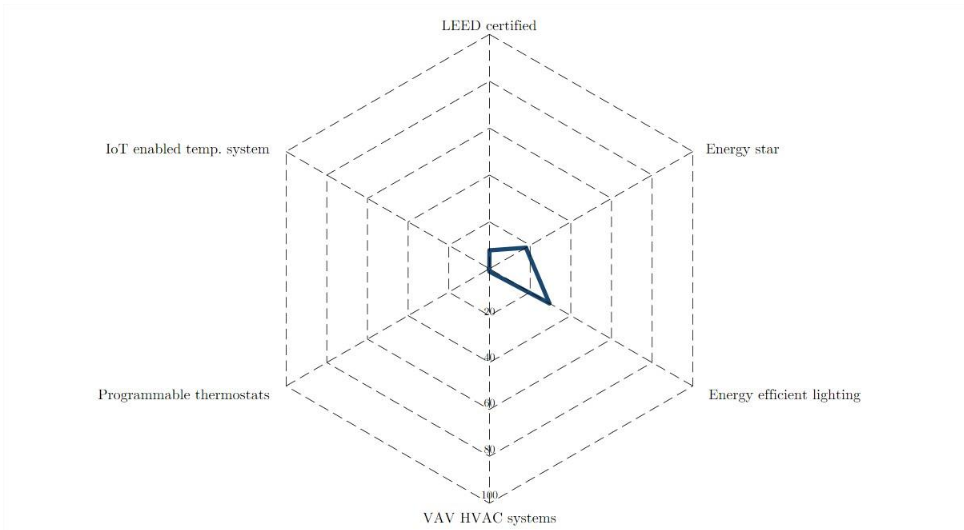



Close to 30 percent of firms have energy-efficient lighting, and 18 percent have energy-efficient rated equipment, with small firms being less likely than medium and large ones to have these things. Adoption of LEED certification[8] is still relatively low in Ethiopia (8 percent

[8] LEED is one of the most widely used certification programs, based on a framework for healthy, efficient, carbon and cost-saving green buildings. It considers both embodied and operational emissions. (Embodied emissions are those that associated with the life cycles of materials used in construction.)

of firms), with smaller firms being much less likely to be certified (5percent) than larger ones (18 percent). The use of technologies such as VAV (variable air volume) and HVAC systems; programmable thermostats, timers, robots and motion sensors; and internet of things (IoT) enabled systems to control the temperature of the premises, lighting systems, or refrigeration units is almost negligible.

Figure 16: Building-Related Green Technologies, Standards, and Certification

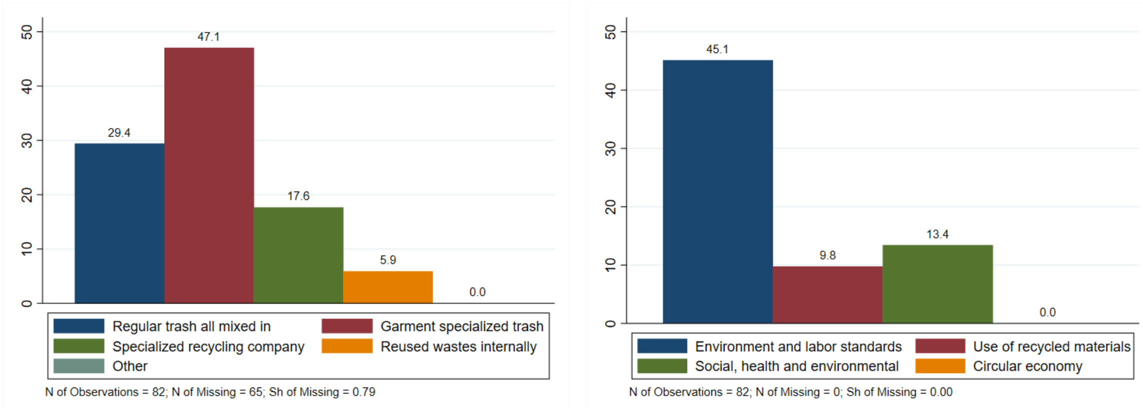



Another important dimension in the green footprint of firms is related to pollution, for example water contamination. Close to one fourth of large firms havewastewater treatment, while only 3 percent of medium firms and 1 percent of small firms do. Among the large firms that do treat their wastewater, 61 percent use both primary and secondary treatment, while only 17 percent also carry out tertiary treatment.

The FAT survey also collects sector-specific green technologies and practices in some sectors. In the wearing apparel industry, close to half of the surveyed firms reported mostly disposing of their fabric, threads, labels, and other materials all mixed together through a specialized garment trash company. About 30 percent of firms mostly disposed of their waste materials mixed in with regular trash. A small share (18 percent) sorted it internally and disposed of it through a specialized recycling company for each material, and an even smaller share (6 percent) sorted and reused their waste materials internally – with larger companies being more likely to do so.

Close to half of the companies reported having environmental and labor standards such as OEKO, the Made in Green label, and Fair Wear, with large firms being more likely to meet such standards. Thirteen percent of firms reported having social, health, and environmental certification such as B Corporation or Bluesign, and 10 percent reported having certification related to the use of recycled materials, like the Recycled Claim Standard (RCS), with small and large companies being more likely to be certified than medium ones. No company reported having a circular economy certification such as Cradle to Cradle.

Figure 17: Green Practices and Standards in the Wearing Apparel Industry




(a) Method used most oftento dispose of waste material

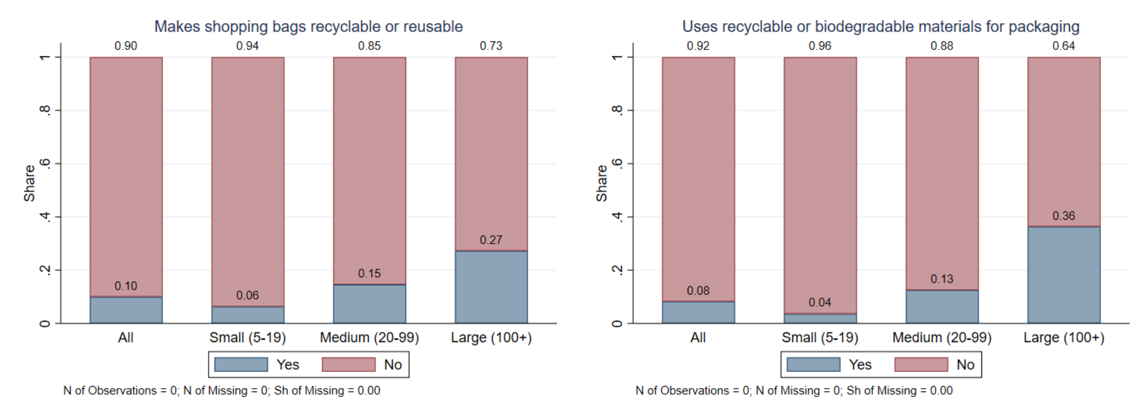
(b) Percentage of firms with certifications

Note: Panel a refers to the intensive margin; Panel b refers to the extensive margin.

In the wholesale and retail sector, sustainable packaging is quite rare. About 10 percent of firms use recyclable or reusable shopping bags, and 8 percent use recyclable or biodegradable materialfor packaging (Figure 18). Only 2 percent of businesses in the wholesale and retail sector use recycled packaging from shipments. Large firms are more likely than medium and small firms to adhere to these practices, except in terms of recycling packaging from shipping. However, about a quarter of the surveyed retail firms reported that they considered sustainability standards when selecting sourcing or distribution vendors. As expected, such considerations are higher among medium and large firms.

In the land transportation industry, which is in relative terms a heavy carbon emitter, carbon emissions control by authorities and monitoring by companies are not veryprevalent. Nearly 70 percent of firms reported that there are *no* regulations in carbon emission control, and about 25 percent responded to some nonbinding guidelines. In addition, only 8 percent of the firmsoperating in the transportation sector reported that they have targets for carbon emissions andthat they monitor them. There is a huge heterogeneity in the targeting or monitoring of carbon emissions across firm sizes. Compared to small or medium firms, large firms are significantly more likely to monitor and have targets for carbon emissions (33 percent). This lack of regulation of emissions and the limited use of technologies to maximize and manage the fleet suggest that there is large scope for reducing emissions in this sector.

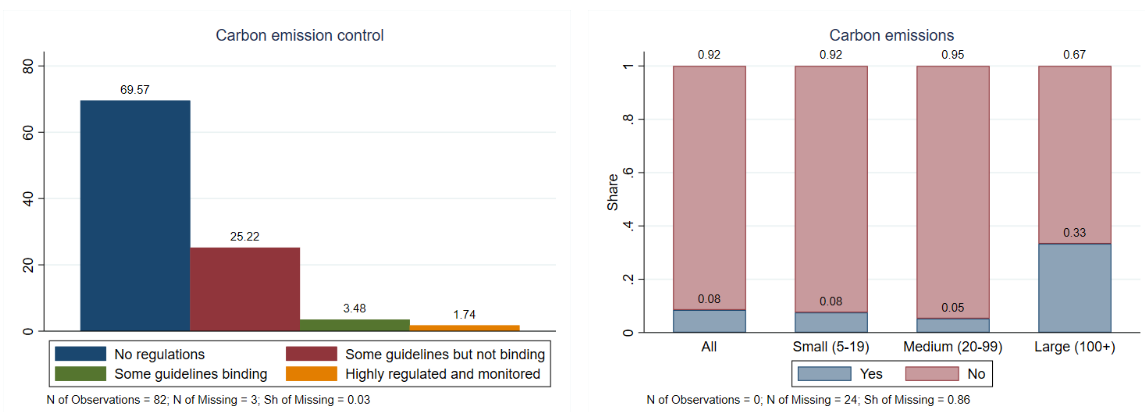
Figure 18: Green Practices in the Retail Sector




(a) Use recyclable or reusable shopping bags

(b) Use recyclable or biodegradable material for packaging

Figure 19: Green Standards and Practices in the Land Transportation Sector

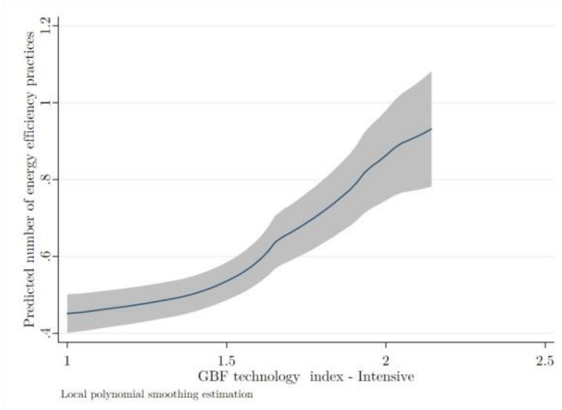



(a) Firms' assessment of carbon emission control by authorities in their region

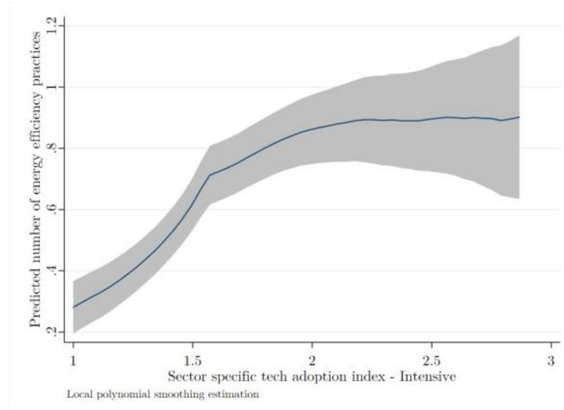
(b) Percentage of firms that monitor and have targets for carbon emissions

One final important element is the relationship between green and "brown" technologies. Figure 20 shows the correlation between the predicted number of energy-efficient practices and the technology indexes for general and sector-specific business functions. Both subfigures show that the adoption of energy-efficient practices is positively associated with the overall technological level of firms. This highlights the fact that there are large commonalities in the barriers and drivers of both green and "brown" technologies.

Figure 20: Energy-Efficient Practices and Technology Adoption




(a) General Business Function Technology Adoption: Intensive Margin




(b) Sector-Specific Technology Adoption: Intensive Margin

Note: The technology indexes used in Panels a and b refer to the intensive margin, which captures the **most widely used** technology across business functions. The y-axis measures the **number** of energy-efficient technologies and practices used by the firm.

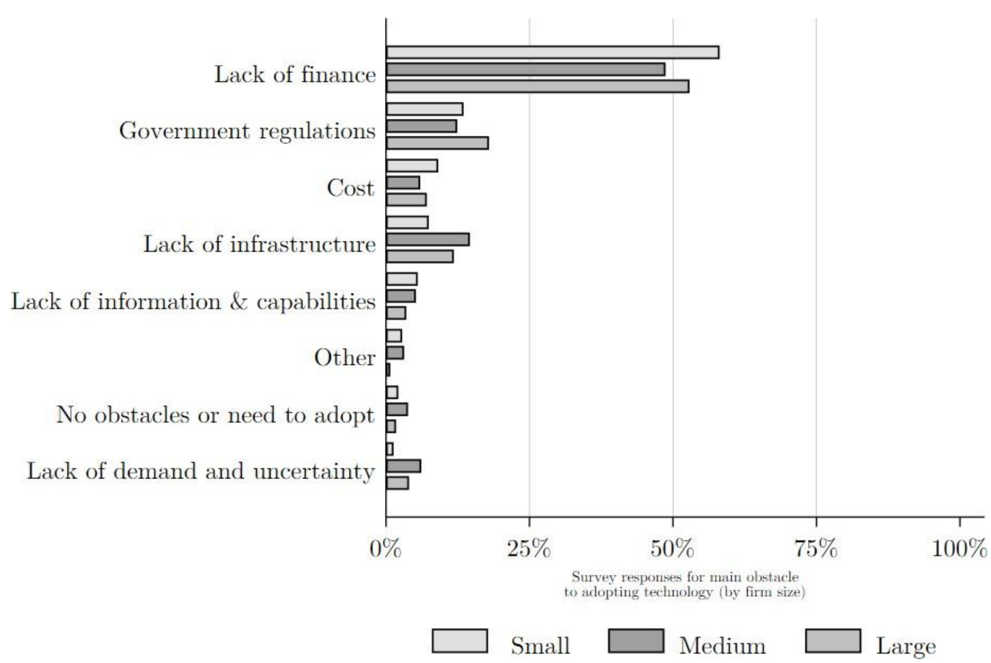
# 9 Barriers to the Adoption of Technology

As the previous sections show, the adoption of technology in Ethiopia is low across the board. This section will help us to better understand the barriers that firms face in adopting more advanced technologies. In addition to studying the perceived barriers, we will also explore the role of other factors, including access to finance and to government support, and firm capabilities.

## 9.1 Perceived Barriers

The survey asks respondents to indicate the main barrier to their adopting new technologies, from six main categories: lack of information, knowledge, or technical capacity; lack of demand or uncertainty; cost; lack of finance; government regulations; or lack of infrastructure. Figure 21 presents the share of firms, by size, that report that a given obstacle is a key obstacle for their firm. As can be seen, across all firm sizes, lackof finance is seen to be the main constraint perceived by managers, with over 50 percent reporting it as the key obstacle they face. Government regulations, costs, and poor infrastructure are also seen to be major barriers, with 10 to 20 percent of firms reporting that they face regulations, costs, or infrastructural constraints (including roads, electricity, etc.), but these constraints are perceived as relatively lower constraints compared to lack of finance by businesses. In what follows we will explore some of these perceived barriers in more detail.

Figure 21: Perceived Obstacles to Adopting Technology by Firm Size



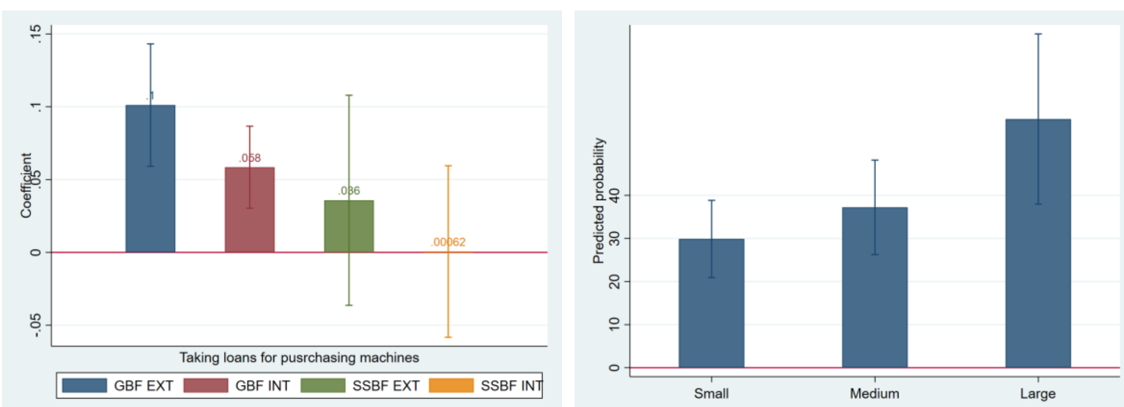
Note: Small = 5 to 19 employees, Medium = 20 to 99 employees, Large = 100+ employees.

## 9.2 Financial Constraints

This section further studies the association between financial constraints and the adoption of technology, taking into consideration the characteristics of firms. Figure 22a presents the predicted relationship between financial access (as measured by whether firms took out loans to purchase machines or software) and technology adoption (as measured by the four indexesdescribed previously). The results suggest that financial access is positively associated with adopting more advanced technologies linked with General Business Functions, both on theextensive and the intensive margins. On the other hand, financial access is not significantlyassociated with the adoption of SBF technology, either at the extensive or intensive margin.

Figure 22b presents the predicted probability of firms taking loans to purchase machines or software, by firm size. The results show that there is a positive relationship between firm size and the predicted probability of borrowing, and the magnitude of the coefficient is higher as firm size increases. Large firms are over four times more likely to have taken loansto purchase software or machines as compared to small firms.

Figure 22: Loans for Purchasing Machines/Software




(a) Technology Adoption on Loans (b) Loans by Firm Size

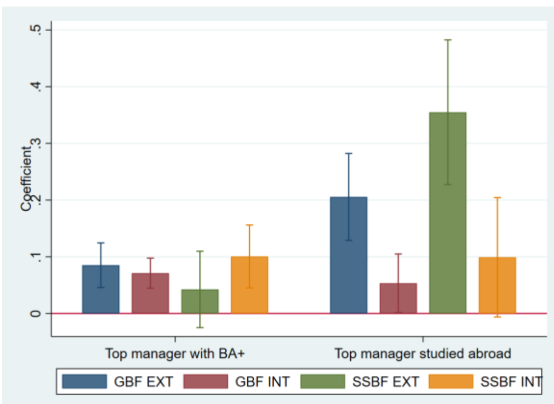
Note: Panel (a) provides coefficients and 95 percent confidence intervals from regressions. Each technology measure is regressed on a dummy for taking out loans to purchase machines or software, *while controlling for sector, size, regions, and other baseline characteristics*. Panel (b) shows the predicted probability of getting loans by firm size and confidence intervals from the Probit regression *controlling for sector, size, regions, and other baseline characteristics*. All estimates are weighted by sampling weights.

## 9.3 Firm Capabilities

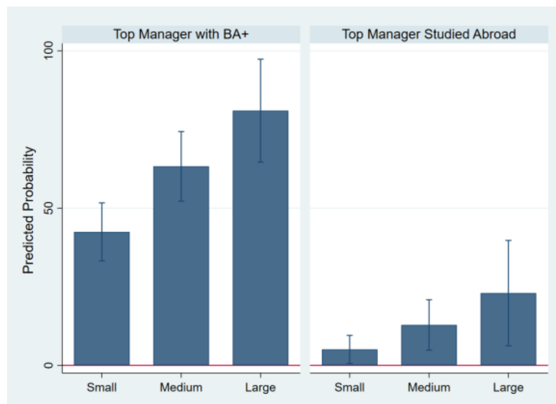
### 8.3.1 Management quality and skills

The largest share of firms in the survey cited the lack of capabilities as the main obstacle they faced when it came to the adoption of technology, including the lack of knowledge about acquiring new technology, and the lack of skills required to use it properly. This section further explores the relationship between human capital, both workers and managers, and the adoption of technology. These capabilities and skills are measured using educational level and training as the measure. Figures 23a and 23c present the coefficients of linear regression models of the various technology indexes according to the human capital of managers and workers. Having a top manager with a college degree is positively associated with the adoption of general business functions (GBF) technology (at both the extensive and intensive margins) and with sector-specific business functions (SBF) technology (at the extensive margin). Having a top manager who studied abroad is also positively associated with the adoption of technology, as measured by all four indexes.

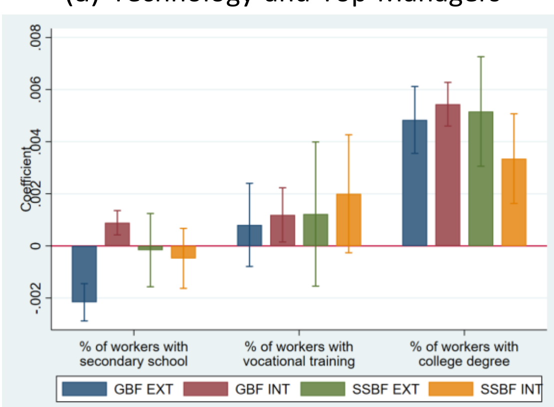
Figure 23: Human Capital



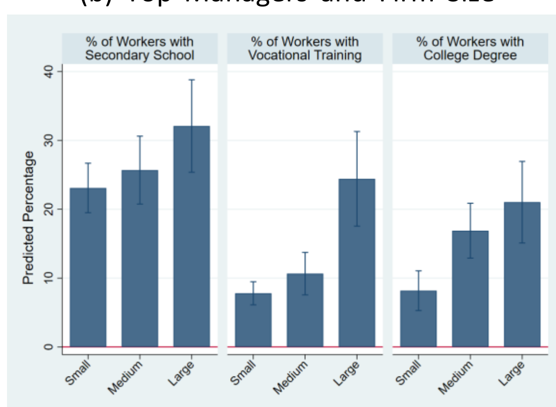

(a) Technology and Top Managers




(b) Top Managers and Firm Size




(c) Technology and Workers




(d) Workers and Firm Size

Note: Panels (a) and (c) provide the coefficients and 95 percent confidence intervals from regressions. Each technology measure is regressed on a dummy for top managers' education (for example, BA+ and study abroad) and the percentage of workers with various educational levels (secondary school, vocational training, college degree), while controlling for sector and size. Panel (b) shows the predicted probability of having top managers with a BA+ or study abroad by firm size, with confidence intervals from the Probit regressions controlling for other baseline characteristics. Panel (d) presents the predicted percentage of workers with various levels of education by firm size from the linear regressions controlling for other baseline characteristics. All estimates are weighted by sampling and country weights.

The share of workers with a college degree is positively associated with adoption of GBF technology (at both the extensive and intensive margins), but there is no significant association for SBF technology on either margin. Similarly, the share of workers with a secondary school education is positively correlated with the adoption of GBF technology on both margins, but negatively correlated with the adoption of SBF technology on both margins. Finally, the results are similar for the share of workers with vocational training. A higher share of vocationally trained workers is positively associated with adoption of GBF technology (at both the extensive and intensive margins), but negatively associated with the adoption of SBF technology on both margins.

Figure 23b and Figure 23d present the predicted probability of the measures of human capital on firm size. Having a top manager with a college degree is positively associated with firm size, while there is no such relationship in the case of a top manager having studied abroad. There is a positive association between workers' educational characteristics (secondary schooling, vocational training, college degree) with firm size.

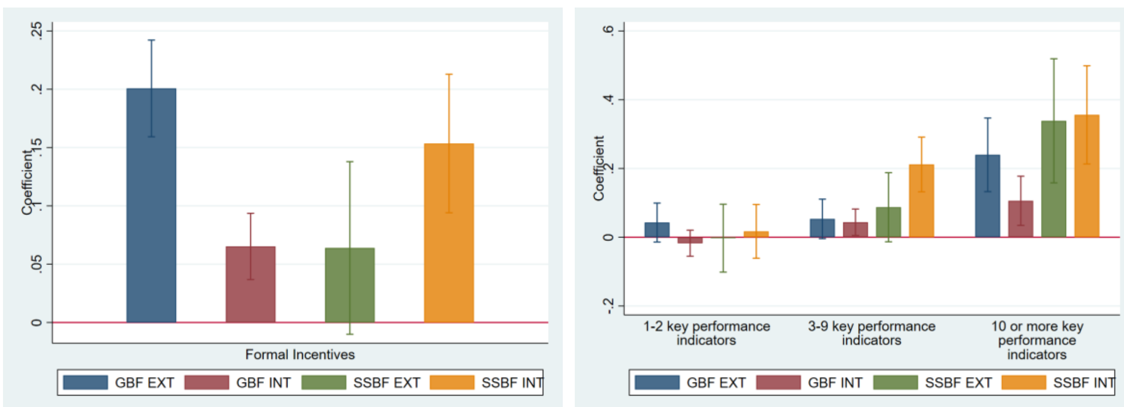
Recent literature also highlights the key role of management capabilities in driving productivity differences across firms and countries (Bloom and Van Reenen 2010). The FAT survey furthers our understanding of how management capabilities are linked with the adoption of technology, using the data collected to study how incentives and performance indicators matter in this respect. For example, it collects information on whether establishments provide formal incentives for workers, as well as on the number of key performance indicators (KPIs) monitored within the establishment.

Figure 24 presents the results from studying the relationship between incentives and performance monitoring, and the adoption of technology in greater detail. Figure 24a shows that there is a significant positive association between the provision of formal incentives and the adoption of technology across all four measures of adoption. Figure 24b suggests that there is a significant positive relationship between the number of performance indicators used and the adoption of GBF technology, at both the extensive and intensive margins. On the other hand, the relationship between the number of performance indicators used and the adoption of SBF technology is much more varied. Having one or two KPIs showed no association with the adoption or intensive use of SBF technology. This was also true for having three to nine KPIs, and the intensive use of SBFs. On the other hand, having ten or more KPIs is significantly positively associated with the adoption and use of SBF technology.

### 8.3.2 Awareness, information, and overconfidence

In addition to skills, capabilities also refer to issues of information asymmetry that may be faced by firms, including a lack of knowledge about existing technologies, or flawed beliefs that might result in managers believing that they already use the most advanced technologies available. The literature suggests that interaction withother firms, especially multinational companies, or having managers with previous experience working in large firms, facilitates knowledge spillovers (Aliprant et al. 2015). Data collected in the FAT survey can help us test this relationship.

Figure 24: Management Capabilities and Technology Adoption



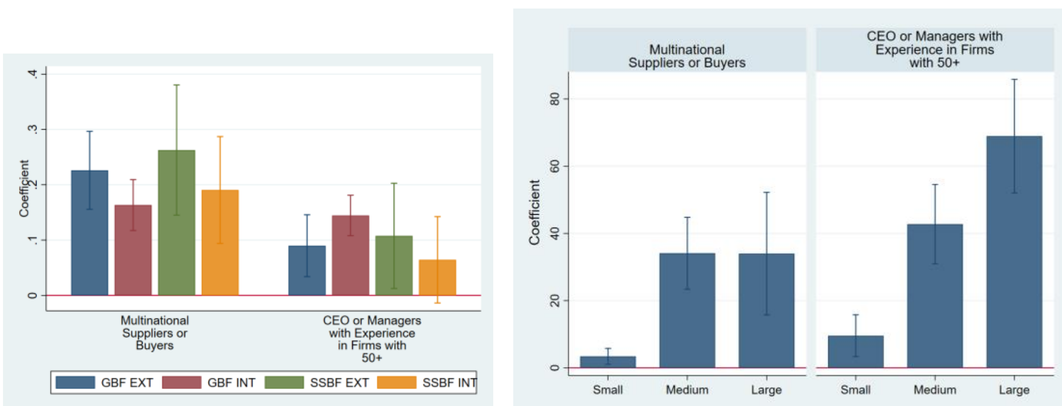

(a) Technology and Formal Incentives (b) Technology and Performance Monitoring

Note: Panel (a) and (b) provide the coefficients and 95percent confidence intervals from regressions. Each technology measure is regressed on a dummy for providing formal incentives and performance indicators, respectively, while *controlling for sector and firm size*. All estimates are weighted by sampling and country weights.

Figure 25a shows that having multinational suppliers or buyers is significantly positively associated with the adoption of technology across all four dimensions. Similarly, having a CEO or manager with experience in a large firm is significantly positively associated with it, except in the case of the extensive margin of SBF technology (where the relationship is not significantly different from zero). Figure 25b shows that there is no significant relationship between awareness and information and firm size when it comes to having multinational suppliers or buyers, but that there *is* a positive relationship when considering whether the firm has a CEO or manager with experience in a large firm.

The survey also allows us to look at the extent to which firms are over- or under-confident about their level of technological sophistication. Before the questions about the adoption and use of technologies, the survey asks how the firm has positioned itself (from1 to 10) relative to other firms in the country, and the most advanced firms in the world. We then rescale the firm's self-assessment from 1 to 5 and compare their responses to their actual technology indexes. Figures 26a and 26b plot this comparison to other local companies for both the GBF and SBF intensive margin indexes respectively, whereas Figures 26c and 26d plot the comparison with the most advanced firms in the world. Figure 26a suggests that almost all Ethiopian firms are overconfident about adopting more advanced technology compared to local peers, while Figure 26b suggests that the patterns are more mixed when it comes to the use of advanced technology. Firms at the bottom of the distribution are overconfident and firms at the top are under-confident. On the other hand, ***all*** firms are under-confident when it comes to the adoption and use of advanced technology in relation to the most advanced firms in the world (Figures 26c and 26d). These results suggest that firms may be overconfident about the level of technological sophistication they have adopted compared to other firms, especially in firms where the overall level of technology is low. This implies a reluctance or lack of incentive to upgrade their technologies precisely in those firms where this may be most needed.

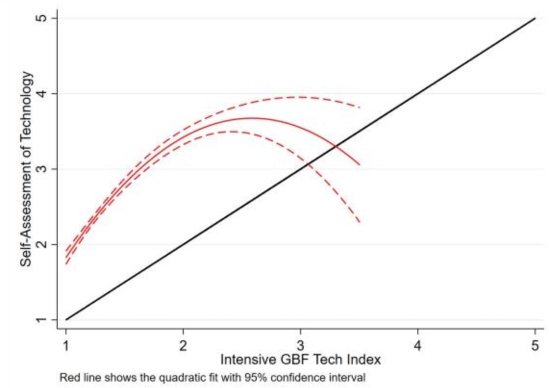
Figure 25: Awareness and Information



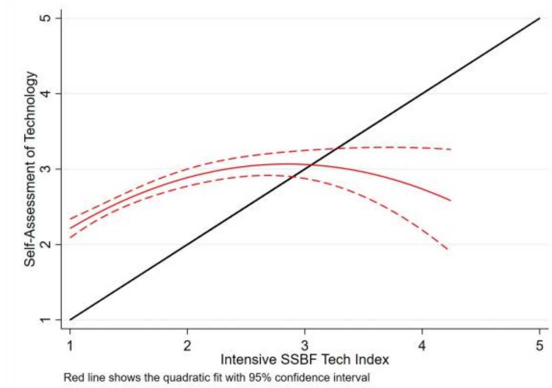

(a) Technology and Information (b) Information and Firm Size

Note: Panel (a) provides the coefficients and 95 percent confidence intervals from regressions. Each technology measure is regressed on a dummy for providing formal incentives and performance indicators respectively, while *controlling for sector and size*. Panel (b) shows the predicted probability of each awareness variable on firm size from the Probit regressions with *controlling for other baseline characteristics*. All estimates are weighted by sampling and country weights.

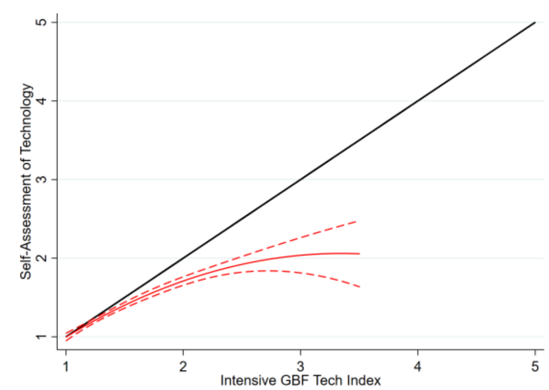
Figure 26: Association Between Self-Assessment and Technology Adoption



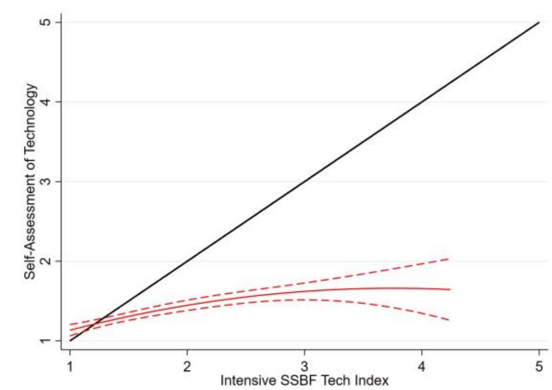

(a) In relation to other firms in the country




(b) In relation to other firms in the country




(c) In relation to the most advanced firms in the world



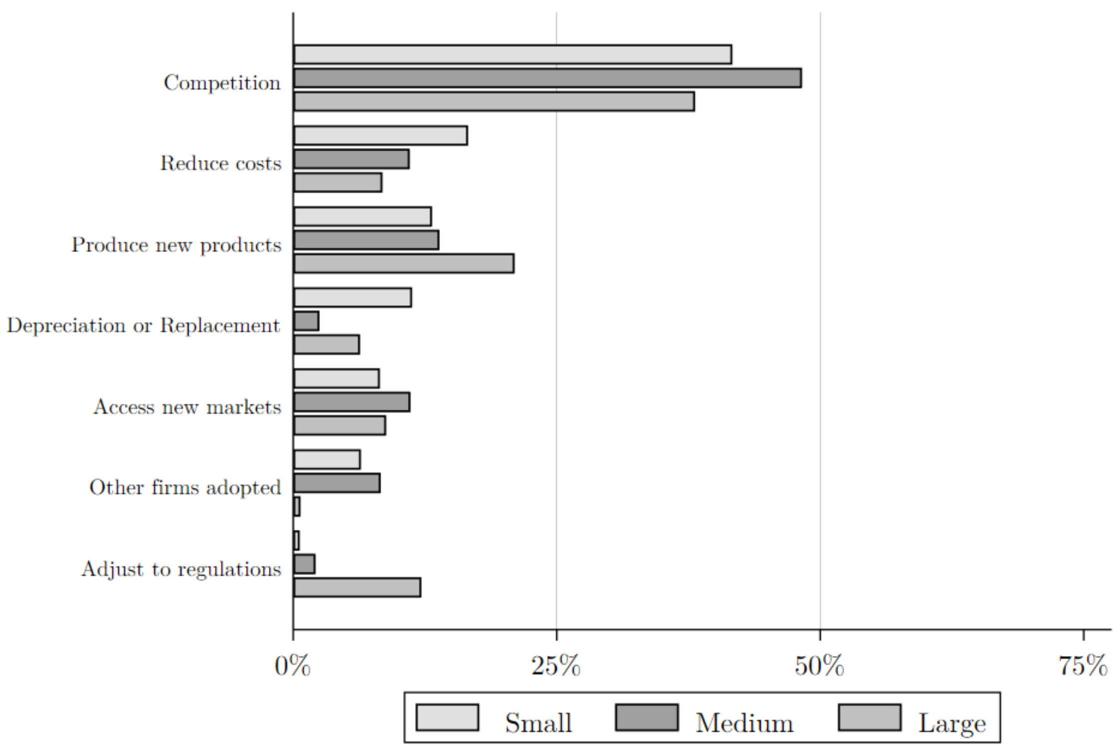

(d) In relation to the most advanced firms in the world

*Note*: The red line shows the quadratic fit with a 95 percent confidence interval. Each technology measure is regressed on the firm's self-assessment with respect to other firms in the country (Panels (a) and (b)) andthe most advanced firms in the world (Panels (c) and (d)), while *controlling for sector, size, and regions*.All estimates are weighted by sampling weights.

## 9.4 Access to International Markets and Competition

In addition to asking about barriers to the adoption of technology, the survey also asks about the reasons that prompted the firm to acquire new machines, software, or other equipment. Figure 27 presents the share of firms, by firm size, that cite a given reason for adopting technology. The most common reason given was competition, with 43 percent of firms mentioning this as a critical driver of the adoption of technology. This was followed by the role of other firms in the locality, or in other sectors, adopting technology (22 percent of all firms). For large firms, the production of new products was also an important reason. Other factors mentioned included the need for replacement due to depreciation, competition in the external market, technology adoption by other firms in the same sector, and the imperative to produce more efficiently.

Figure 27: Main Reason for Adopting New Technologies (by Firm Size)




To better understand the links between the domestic and international markets, we can look at how the adoption of technology varies by two key firm characteristics: whether the firm or company is (a) exporting and/or importing; and (b) domestically-owned or foreign-owned. Figure 28 shows that on the whole exporting firms have marginally higher sophistication in the use of GBF technologies as compared to importing firms or two-way trading firms, but only for a few business functions. This is consistent with the previous results mentioned above that show no large differences in technologies between small and large firms, and in export sectors. Nontrading firms have the lowest levels of adoption of GBF technology, as might be expected. On the intensive margin, any kind of trading firm is more technologically intensive compared to nontrading firms.

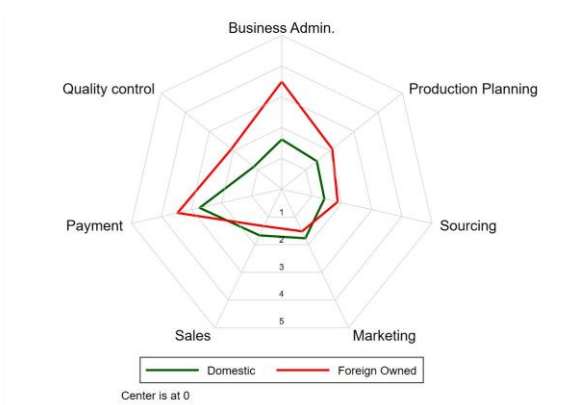
Figure 29 shows that foreign-owned firms (those with greater than 50 percent foreign ownership) are more likely to adopt technology than domestically owned firms, on both the extensive and intensive margins. This is the case for all of the GBFs, with the exception of marketing, where the two kinds of firms are similar.

Figure 28: Exporters and Importers


(a) Extensive Margin


(b) Intensive Margin

Figure 29: Domestic and Foreign-Owned Companies



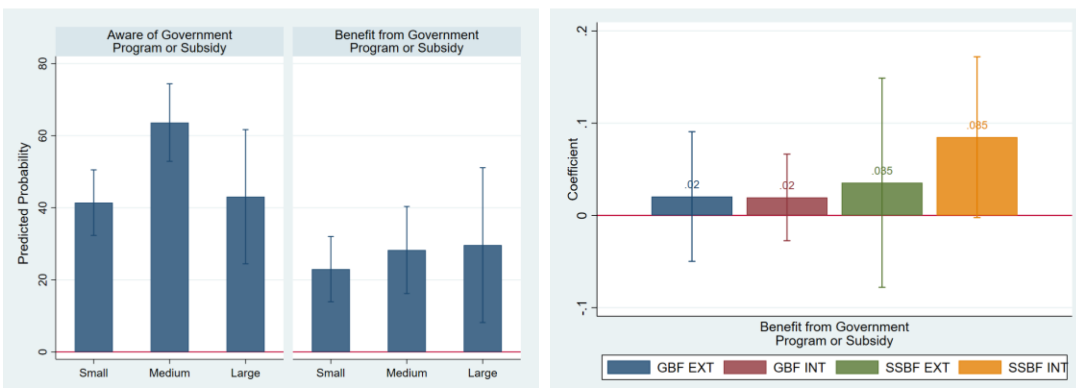

(a) Extensive Margin


(b) Intensive Margin

## 9.5 Access to Government Support

Government support can play an important role in addressing and overcoming some of the barriers highlighted above, especially those that relate to access to inputs such as capabilities, skills, or finance. Panel (a) of Figure 30 shows that in general firms are quite aware of government support programs for technology upgrading. Medium sized firms are the most likely to be aware of government subsidies; more than 60 percent of them are aware of such programs. Fewer firms, however, are likely to actually benefit from government programs or subsidies. On average, about 25 percent of firms benefitted from these programs. The propensity of receiving government support rises as firm size increases, but the difference is less between medium and large firms. More importantly, benefitting from a government program or subsidy for the adoption of new machines, equipment, or software seems to have a significant positive correlation in the technology indexes.

Figure 30: Awareness of Government Programs for Technology Upgrading




(a) Size (b) Predicted Probability

*Note*: Panel (a) presents the predicted percentage of firms that benefit from government programs or subsidies by size, from the Probit regressions controlling for sector, size, and location characteristics. Panel (b) shows the predicted probability of the awareness of government programs or subsidies with confidence intervals from the Probit regressions controlling for sector, size, and location characteristics. All estimates are weighted by sampling weights.

For those firms that receive support, the most common form of support reported was information (41 percent), followed **by technical assistance (41 percent), and loans (42 percent).** Tax incentives were less common (23 percent), and grants were rare (3 percent). Medium sized firms were the least likely to receive any type of support. The types of benefits received are quite different across firm sizes. For example, only 7 percent of small firms reported receiving tax incentives. Small firms are also significantly less likely to receive grants (19 percent) than large firms (56 percent), although they are more likely than medium firms to receive them (2 percent). These results may reflect differences in the eligibility for government programs, or the different needs for firms of different sizes. In order to improve the efficiency and effectiveness of such programs in supporting firms' adoption of technologies, it will be important to understand why there is such large heterogeneity across firm sizes.

# 10 Adoption of Technology and Performance

The literature finds evidence that the adoption of technology is a key driver of productivity differences across countries (Comin and Mestieri 2018). Following the literature, we examine the association between various technology indexes and firm-level productivity measured as the log of value added per worker in Figure 31. We find a positive and statistically significant relationship between technology indexes and productivity for both general business and sector-specific business functions.

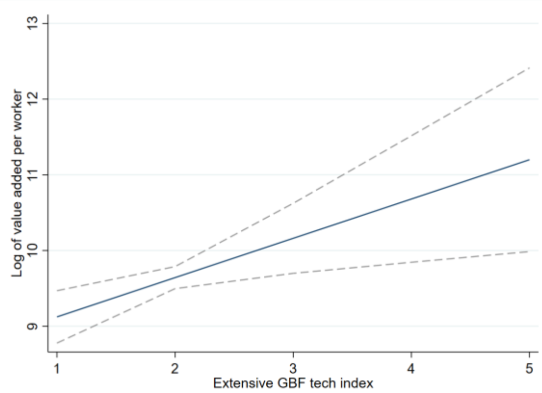
Table 5 shows the regressions for employment growth on technology adoption indexes while controlling for firm size in the base year 2019: for age of the firm, exporter or importer, multi-establishment, management quality index, management human capital index, innovation skill index, sectors, regions. The results show that employment growth is positively and significantly associatedwith technology indexes for both general and sector-specific business functions. But the magnitude of the coefficients is highest for the extensive margin of GBF technologies (0.16), which means that an increase in one unit—for example, transitioning from manual processes to computerization— is associated with about a 16 percent higher employment growth. The lowest magnitude was for the extensive margin of SBF technologies (0.08). Given that the employment growth is between before and after the COVID-19 pandemic, firms that adopted more advanced GBF technologies, such as digital technologies, might have benefitted from it to protect employment and grow during the pandemic, compared to those that did not. The magnitudes for SBF technologies may be lower because these are more focused on production-related technologies, many of which are less likely to be associated with digital technologies, except for very advanced ones. These results also suggest that the adoption of technologies is more labor-augmenting than labor-replacing.

Table 5: Employment Growth and Technologies

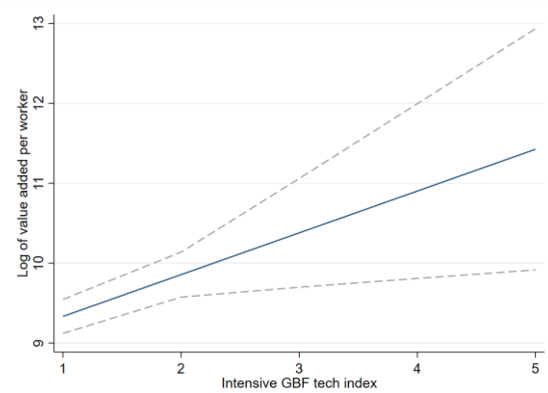
| VARIABLES | (1) Employment Growth | (2) Employment Growth | (3) Employment Growth | (4) Employment Growth |
|---|---|---|---|---|
| GBF EXT | 0.158** | | | |
| | (0.064) | | | |
| GBF INT | | 0.131* | | |
| | | (0.071) | | |
| SSBF EXT | | | 0.082** | |
| | | | (0.041) | |
| SSBF INT | | | | 0.112** |
| | | | | (0.049) |
| Ln(N of Employees in 2019) | -0.137*** | -0.128*** | -0.115*** | -0.114*** |
| | (0.028) | (0.025) | (0.026) | (0.028) |
| Firm Age 6 to 10 | 0.021 | 0.010 | 0.006 | 0.007 |
| | (0.048) | (0.052) | (0.061) | (0.064) |
| Firm Age 11 to 15 | -0.025 | -0.048 | -0.080 | -0.090 |
| | (0.053) | (0.061) | (0.070) | (0.073) |
| Firm Age 16 or More | -0.078 | -0.083 | -0.114* | -0.113* |
| | (0.055) | (0.057) | (0.064) | (0.068) |
| Exporter | 0.027 | 0.028 | 0.046 | 0.059 |
| | (0.072) | (0.074) | (0.081) | (0.075) |
| Multi-establishment | 0.003 | 0.029 | -0.030 | -0.035 |
| | (0.049) | (0.053) | (0.065) | (0.076) |
| Management Quality Index | -0.089 | -0.076 | -0.144 | -0.194** |
| | (0.082) | (0.082) | (0.093) | (0.098) |
| Management Human Capital Index | 0.320*** | 0.347*** | 0.457*** | 0.477*** |
| | (0.104) | (0.114) | (0.132) | (0.130) |
| Innovation Skill Index | -0.213 | -0.188 | -0.024 | -0.040 |
| | (0.160) | (0.168) | (0.180) | (0.190) |
| Observations | 1,270 | 1,270 | 769 | 618 |
| R-squared | 0.270 | 0.253 | 0.282 | 0.287 |
| Sector FE | YES | YES | YES | YES |
| Region FE | YES | YES | YES | YES |

Notes: Employment growth is regressed on each technology index (GBF EXT, GBF INT, SSBF EXT, and SSBF INT), controlling for firm size in the base year 2019: for firm age, exporter, multi-establishment, management quality index, management human capital index, innovation skill index, sectors, regions. Employment growth is constructed using the method developed in Davis, Haltiwanger and Schuh (1996): $(E_{2022} - E_{2019})/0.5(E_{2022} + E_{2019})$. Robust standard errors are in parentheses. Numbers are weighted by the sampling weight. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. GBF EXT = General Business Function Extensive Margin, GBF INT = General Business Function Intensive Margin, SSBF EXT = Sector-Specific Business Function Extensive Margin, and SSBF INT = Sector-Specific Business Function Intensive Margin.

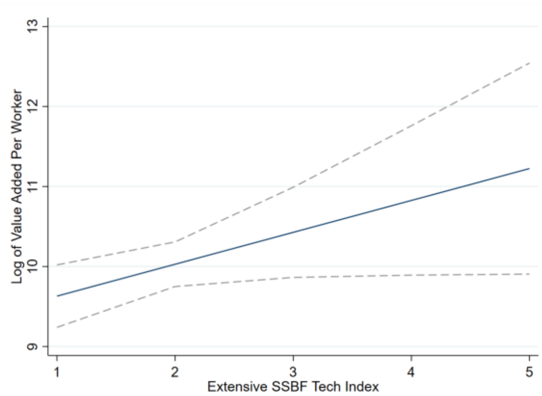
Figure 31: Firm-Level Technology Adoption Index and Value Added per Worker



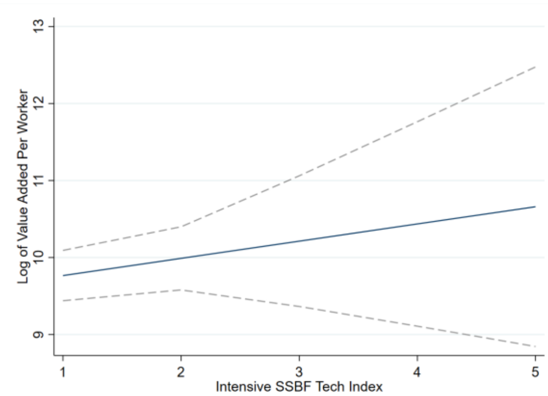

(a) Extensive GBF Tech Index




(b) Intensive GBF Tech Index




(c) Extensive SSBF Tech Index




(d) Intensive SSBF Tech Index

*Note*: Regressions control for sector, size, region, and other baseline characteristics. All estimates are weighted by sampling weights.

# 11 Concluding Remarks

Leveraging new firm-level data from a comprehensive survey carried out in four of Ethiopia's most populous regions in 2022, this study provides a granular view of the adoption and use of technology in the country. We show that the average Ethiopian firm is far from the technological frontier, and below the level of technological sophistication observed in other African countries such as Ghana or Kenya, as well as aspirational countries like Brazil and Vietnam. These technology gaps are on average similar across sectors. In agriculture, the largest employer in the country with 68 percent of the jobs, farms often rely on manually operated machines forcrop production, pest control, and packaging. The manufacturing sector also relies mainly on manual and basic computer-based technologies, although in this sector firms are more likely to enjoy access to electricity and own computers or smartphones, than in the agricultural sector. However, at 40 percent, access to the internet is remarkably low when compared to formal manufacturing firms in Africa and elsewhere. Similarly, digitization and use of the next generation of industry 4.0 technologies, both critical drivers of productivity, are virtually absent in production processes.

Three key factors emerge when comparing the results of the survey for Ethiopia with other peer countries. First, the high frequency of power outages can act as a disincentive to investing in technological upgrading, which in addition increases the carbon footprint of production when electricity from the grid is substituted by diesel fueled generators. Second, Ethiopia's limited access to the internet, among the lowest in the global data set, makes it difficult for firms to adopt integrated digital systems, cloud computing and other IoT-based technologies. Third, and most importantly, firms across sectors exhibit high variance both in the adoption of technologies and intensity of their use, implying the need to also focus on upgrading the top firms in Ethiopia.

The results of this study further our understanding of the productivity/employment puzzle in the context of African firms, which was highlighted by Diao et al. (2021). Panel data on manufacturing firms in Ethiopia and Tanzania show a dichotomy between large firms with high productivity and low employment growth, as contrasted with small firms that absorb labor but do not experience productivity growth. However, unlike Diao et al. (2021), we did not find evidence that the poor employment performance of large firms is necessarily related to the use of the capital-intensive techniques associated with more sophisticated technologies. The gap between technology adoption by the average firm and the top 20 percent of firms is relatively small in Ethiopia, unlike in countries like Ghana, India, and Kenya. These low levels of dispersion may be rather, a result of the overall relatively low levels of technology adoption in Ethiopia generally. Interestingly, the results from the survey show that the perceived constraints of the adoption of technology – lack of capabilities and skills, lack of demand, and uncertainty; and inadequate access to finance – are consistent across all firm size groups.

Finally, the study also finds a positive and statistically significant relationship between technology indexes and productivity (measured as the log of value added per worker) for both general and sector-specific business functions. Going forward, it would be useful to understand why this is the case and how it relates to the productivity/employment puzzle.[9]

Industrialization is the primary means by which Ethiopia hopes to realize its objective of reaching middle-income status by 2025. Indeed, the Government seeks to boost the growth of the manufacturing and agricultural sectors as important sources of employment and exports. The results in this paper show that the technology and digital gap is large also for large firms and exporters, even when compared with peer countries in Africa. Technology upgrading is a continuous process where leapfrogging is rare (Cirera et al, 2022), and the main findings here show that there is clear room for government policies to support the adoption of more basic technologies that can help accumulating technological capabilities. The focus of policy should not be on adopting more sophisticated Industry 4.0 technologies in the short run, and when there are no capabilities and skills to successfully do so, but in starting to adopt more basic digital technologies for management and production that can help to obtain important productivity gains. For example, adopting tools for management of processes, production planning or supply chain management, using specialized software or simple versions of ERP. In addition, these policies should also target exporting firms where there could be larger returns to digitalization, such as digital systems for traceability in food processing.

While the HGER already includes ambitious measures to mainstream the use of ICT and digitalization across priority sectors, complementary firm-level interventions are required to move Ethiopia towards the technological frontier. Raising awareness on the benefits of the digital transition, promoting knowledge transfer and capacity development for managers and employees alike on the use of digital tools, and making available financial instruments that will allow firms to acquire more sophisticated technologies should be contemplated in future industrial development programs.

The remarkably limited adoption of green practices among Ethiopian firms also calls for the development of mechanisms to promote environmental compliance, particularly in the construction and apparel industries, which are both major drivers of growth in Ethiopia. But any effort to promote sustainability standards needs to be matched with financing as well as adequate monitoring and enforcement. While the government of Ethiopia strongly upholds the concept of sustainable and carbon-neutral development across sectors, and companies

[9] [10]One caveat is that this analysis looks at adoption of technology along two margins: extensive (used or not used), and intensive (extent of use). In doing so, it differs from the measure of capital intensity that is used by (Diao et al., 2021), who measure the capital-to-labor ratio at the firm level.

are expected to comply with the standards and regulations set by the Ethiopian Environmental Protection Authority (EPA), the enforcement of compliance with existing regulations has been weak. Enhancing coordination among key actors, providing financial incentives for green innovation among existing firms, and enforcing environmental regulations should be better reflected in Ethiopia's industrial policy in keeping with the desire for low-carbon development and technological upgrading.

The findings of this research have implications for the way in which policies are designed in order to upgrade technologies and enhance firm capabilities across sectors. There are, however, some important knowledge gaps around the costs and quality of access to existing technologies. Such knowledge can help further the design of more effective technology upgrading programs.

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