Chapter 2
Technology and Development

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1 Introduction

Two major challenges face humanity in the coming century. The first is to generate the innovations and productivity improvements that will keep people on a path to higher standards of living. The second is to ensure that expanding human activity does not generate negative environmental externalities that block this path to progress.[1] In short, our future is about balancing the need for growth with the externalities that arise from that growth.

[1] Both these challenges are enshrined in the sustainable development goals (SDGs): SDG1 – "End poverty in all its forms everywhere"; SDG2 – "End hunger, achieve food security and improved nutrition, and promote sustainable agriculture"; SDG3 – "Ensure healthy lives and promote well-being for all at all ages"; SDG4 – "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all"; SDG6 – "Ensure availability and sustainable management of water and sanitation for all"; SDG7 – "Ensure access to affordable, reliable, sustainable and modern energy for all"; SDG8 – "Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all", SDG9 – "Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation"; SDG12 – "Ensure sustainable consumption and production patterns"; SDG13 – "Take urgent action to combat climate change and its impacts"; SDG14 – "Conserve and sustainably use the oceans, seas and marine resources for sustainable development."

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How both these challenges play out will be determined in large part by what happens in developing countries. It is here that the need to banish poverty is greatest. Indeed, 196 countries have signed up to the goal of eliminating extreme poverty by 2030. It is also in developing countries that environmental externalities from growth are increasing at the most rapid rate and where populations stand to be most affected.

These challenges are both complex and multifaceted and so require not just the development of new innovations but also their careful adaption to developing country contexts. Ensuring that new technologies work when deployed at scale in this way will require the coming together of engineers, technologists, economists, and policymakers. It is this collaborative approach to addressing development challenges which is at the core of development engineering.

This chapter provides an overview of some of the research areas where technology and development can be brought together in a fruitful manner. As with any nascent field, this is a preliminary and incomplete set of topics which is intended to foster and encourage further research in this exciting and important area of work.

We begin with the role of technology in shaping productivity and economic growth. A focus on productivity and growth is inescapable when one is considering poor populations and poor countries. This makes it natural for us to devote considerable attention to the role of technology in the production side of the economy. Hence, we consider how technological innovations can make firms in agriculture, manufacturing, and services more productive. Here, it will be made clear that information and communication technologies (ICTs) such as mobile phones have a critical role to play. The chapter also examines how trade can be made to flow more freely, both internally within countries and externally between countries, and the development benefits that follow from this. Furthermore, we explore how investments in communication and transportation infrastructures can improve the functioning of markets and accelerate structural change and the movement of people from less productive to more productive jobs.

Structural change is ultimately what drives poverty downwards as workers become more productive.[2] For most poor people in the world, labor is their only asset. This means that much of development is about getting people into better jobs, with people's incomes largely being determined by the returns on their labor. We therefore consider how technology can be harnessed in this vital process, both in improving the efficiency of job search and matching and in expanding the size of the markets within which people can sell their labor. We also comment on how the automation of labor market activities brings both challenges and opportunities as the nature of work changes across the world. Finally, this section will summarize evidence on how technology can be used in schools to widen access to quality education.

Also central to production, particularly for populations with little capital, is access to financial technologies such as mobile money. These are beginning to

[2] Structural change in the economy is a process involving the movement of people from less productive jobs (e.g., subsistence agriculture) to more productive jobs.

transform the landscape of financial services in the developing world by bringing the ability to borrow and save to populations who have traditionally been excluded from formal financial institutions, thus allowing them to fund new productive activities. These financial technologies may also expedite the movement of money and make households more resilient when hit with different types of shocks. Finally, digital payment technologies are increasingly being used by governments and firms to reduce leakages in payment systems, whether this be payments for workers or welfare transfers to poor populations. Together, these can bring improvements in efficiency and changes in household financial behavior that stand to have long-run implications for development.

It is clear that different inputs are needed for people and firms to take on the modern production activities that drive structural change. One key input is electricity. Our chapter will outline how innovations in renewables such as solar are being combined with technological improvements in national grids to universalize access to electricity. This is revolutionizing the choice of electricity source for firms and households across the developing world, many of whom have been entirely without access to electricity until now. Given that the bulk of greenhouse gas emissions come from the combustion of fossil fuels, one major issue that needs to be confronted in the energy space is how electricity is generated and how the associated environmental externalities are reflected in policies and pricing. Equally critical is the removal of electricity theft and subsidies which are often regressive but are endemic to public utilities in several developing countries. Improvements in generation technologies, energy efficiency, and technologies for monitoring consumption can all be harnessed to ensure that rapid growth in electricity demand in developing countries will be met in a manner that is as sustainable as possible.

This concern with sustainability extends beyond the issue of energy generation and is discussed throughout the chapter. Both growth and the externalities from growth are now deemed central to the study of development economics, which was not the case a decade ago. As such, we will consider how human activity will affect the environment and how technology can be used to minimize the negative environmental externalities that emanate from this activity in a range of different areas, including agriculture and transport. This will involve considering what type of growth is occurring, including the kinds of firms involved and the types of work people engage in but also how technology can be harnessed to counter processes like climate change.

Strong state capacity is required to steer a path towards sustainable growth and development. Here, there is increasing recognition that technology can play an important role, both in the form of platforms that promote political engagement and in applications that serve to increase the accessibility, monitoring, and integrity of elections. Together, these serve to improve the accountability of governments to citizens and help close the gap between the design of policy and its implementation that often exists in developing countries. Closing this gap can lead to improvements in the functioning of the state, for example, in ensuring that populations have access to a higher quality of public services.

In the final part of the chapter, we consider how technology can play a role in development by shaping access to healthcare. Exciting new work is documenting how, in doing so, technology can help to bridge the gap in health between developing and developed countries. This also loops back into what types of work people can do, the returns to their labor, and how well firms function.

The complexity of the development challenges that humanity is facing in each of these areas demands that technological innovations and ideas be brought to bear on them. This is what makes the study of development engineering so important. It is really about bringing in frontier thinking from technology into development, to guide interventions and policy decisions. Only in doing so will we have a chance at achieving the difficult balance between ending extreme poverty by 2030 and doing so in a way that does not block the path of prosperity for future generations.

2 Firms, Trade, and Infrastructure

The relationship between technology and productivity is at the core of many economic models, with theories that stress the importance of technological innovations for sustained growth making up a significant share of the growth economics literature (e.g., Solow, 1957; Aghion & Howitt, 1992; Romer, 1990). In this section, we review the existing literature on two channels linking technology to development, an area of research that remains comparatively small. First, technology can improve productivity in firms and agriculture. Second, technology can facilitate trade, enhancing the integration of markets both within and across countries (Donaldson, 2015). These in turn have the propensity to accelerate the structural change process which underpins economic development.

2.1 Boosting Productivity in Firms and Agriculture

2.1.1 Agriculture

To date, agricultural productivity remains relatively low in the world's poorest regions, with subsistence farming still the most widespread occupation in many developing countries (Lowder et al., 2016). An important body of research in development economics has been dedicated to understanding the role technology can play in rectifying these vast disparities in productivity across countries. This may take the form of agricultural biotechnologies, including improved seeds and fertilizers promising higher yields, or ICTs used to receive and share agriculture-relevant information. The hope is that resulting shifts in productivity can eventually enable developing countries to jumpstart their structural change processes, facilitating the flow of labor from agriculture into the manufacturing and service sectors.

The adoption of agricultural biotechnologies such as improved fertilizers and seeds has been a hallmark of production in many developed countries, given their proven impact on yields and cost (Brookes & Barfoot, 2018). Many have studied how these benefits have been extended to developing countries, who in 2018 accounted for 54% of global biotech crop area (ISAA, 2018). For example, in a study in Kenya, Duflo et al. (2008) estimated annualized rates of return of 70% to the use of chemical fertilizer. Similarly, Bustos et al. (2016) study the introduction of genetically engineered soybean seeds in Brazil and its positive impact on agricultural productivity. They show that such technologies can in turn trigger industrial growth, releasing labor from agriculture and allowing it to shift towards industry and services.

ICTs represent another avenue for boosting agricultural productivity in developing countries. This encompasses the use of mobile phones, Internet, television, and radio to receive and share information on prices, weather, and farming techniques, both within private networks and as part of government initiatives. By improving information circulation and connectivity, ICTs stand to help farmers optimize production decisions. Rosenzweig and Udry (2019) shed further light on this in their study of weather forecasts in India. They argue that accurate forecasts increase profits by allowing farmers to allocate resources to exploit rainfall conditions. For example, in areas where forecasts are accurate, they show that a pessimistic forecast lowers planting-stage investment and use of rainfall-sensitive crops. In settings such as India (Jensen, 2007) and Niger (Aker, 2010), the use of mobile phones for sharing price information was furthermore shown to promote arbitrage in fish and grain markets.

ICTs can also reduce the cost of agricultural extension services, particularly in low population density regions. Fabregas et al. (2019) discuss how this may be vital for increasing exposure to science-based agriculture advice. They furthermore note that GPS-enabled devices may facilitate the tailoring of information, for example, notifying farmers of local pest outbreaks, as well as two-way communication, where farmers are able to ask specific questions. Digital Green is one development organization harnessing ICTs in this way. It connects farmers with experts and disseminates information via video. In India, it was shown to increase adoption of certain practices sevenfold relative to traditional training and visit-based extension approaches and to be 10 times more effective per dollar spent (Ghandi et al., 2009). Overall, in sub-Saharan Africa and India, meta-analyses indicate that information transmission via mobiles has increased yields by 4% and the likelihood of adopting recommended agrochemical inputs by as much as 22% (Fabregas et al., 2019).

Despite significant enthusiasm for biotech crops, development initiatives have sometimes been confronted with poor adoption rates, presenting an important puzzle for economists and policymakers. Where returns have proven heterogeneous across farmers, this may simply reflect optimal decision-making. For example, in rural Kenya, Suri (2011) showed that at least some farmers are better off not adopting technologies such as hybrid maze. In other cases, however, returns to a technology have been shown to significantly exceed the cost of the investment, implying other constraints might be at play (Duflo et al., 2011).

Here, one important strand of the literature has emphasized the role of market inefficiencies, including poor infrastructure, insecure land rights, and missing markets, particularly in the area of financial services (Jack, 2011). For example, where agriculture is rain-fed and farmers lack access to formal insurance, incentives to invest in inputs and technologies may be diminished. This has been tested experimentally in Ghana by Karlan et al. (2014), who find that when provided with insurance against the primary risks they face, farmers could find the resources to increase expenditures on their farms. Similarly, even where the benefits of ICTs are well known, farmers may be unable to access or act on information due to lack of telecommunications, electricity, and transportation infrastructure or illiteracy.

Behavioral factors can also inhibit the diffusion of agricultural technologies. In the case of ICTs, for example, information disseminated via these interfaces may not be afforded the same level of trust as that shared via social networks and traditional extension services. Here, some have pointed to the role of social learning and network effects in the diffusion of agricultural technologies. Studies such as Foster and Rosenzweig (1995), Conley and Udry (2010), Bandiera and Rasul (2006), and Duflo et al. (2010) suggest that their adoption might pose less of a risk for poor farmers when the cost of experimentation is shared with others.

Interlinked with the desire to increase agricultural efficiency are sustainability concerns. It has been estimated that the global population will reach 9 billion by 2050, which will demand a 60% increase in agricultural production (Alexandratos & Bruinsma 2012). However, this intensification risks accelerating climate change through its contribution to greenhouse gas emissions and resource degradation. Moreover, our ability to meet the growing global demand is in itself threatened by climate change and the damaging impact of changing weather patterns on yields, increasing the risk of food insecurity in developing regions (Ignaciuk & Mason-D'Croz, 2014). As such, it is imperative that agricultural technologies enable farmers' adaptation to a changing climate while minimizing any further environmental degradation. Evidence suggests that biotechnologies have contributed significantly to agriculture's sustainability, for example, by reducing the need for pesticide spray and facilitating cuts in fuel use and tillage changes (Brookes & Barfoot, 2018). There has also been much enthusiasm surrounding conservation agriculture (CA) practices. Centered on diversified crop rotation, minimum soil tillage, and maintenance of permanent soil cover, these intend to prevent soil erosion and degradation and enhance biodiversity whilst improving yields (FAO, 2001).

One notable application of CA is the Kenya Cereal Enhancement Program – Climate Resilience Agricultural Livelihoods Window (KCEP-CRALW), co-funded by the European Union and the International Fund for Agricultural Development (IFAD). This provides smallholders with access to training, improved inputs, and CA services through an electronic voucher system, hoping to reduce poverty and promote food security in Kenya's vast arid lands (IFAD, 2015). IFAD reports that the initiative has already reached 83,000 famers and is currently being scaled up throughout Kenya (IFAD, 2020). However, evidence regarding the success of CA in practice has been mixed. For example, in a study of rural Zimbabwe, Michler et al. (2019) find that CA produces no yield gains and sometimes yield losses in years of average rainfall, but does mitigate the negative impacts of deviations in rainfall. Other studies have shown that yield gains are heavily context-dependent and may only be observable after several years (Stevenson et al., 2014). Ultimately, rigorous evidence on the effectiveness of these technologies and the potential trade-offs involved in their uptake remains limited, as are adoption rates. As such, this must be an important focus for research in coming years.

Overall, much remains unknown as to the constraints to technology adoption in agriculture. Solutions might lie in packaged interventions that relax multiple constraints simultaneously, for example, making complementary infrastructure investments. Another area worthy of further investigation is the unequal adoption of biotech crops across the developing world. While adoption of biotech crops has reached over 90% in countries such as Brazil, Argentina, and India, other regions have been lagging behind (ISAAA, 2018). This links to persisting political opposition to genetically modified crops in certain regions, which must be met with dialogue between plant scientists, economists, and policymakers across countries (Elliott & Keller, 2016). Simultaneously, research must continue to seek paths to achieve sustainable intensification of our agricultural production.

2.1.2 Firms

Another fundamental link between technology and development relates to its ability to improve the productivity of firms in manufacturing and services. Neoclassical economic theory has long accepted technological change as the sole driver of long-term growth since the seminal work of Solow (1957). This prompted a vast body of research aimed at understanding the drivers of productivity (Syverson, 2011; Bloom & Van Reenen, 2010) and testing the impact of technological innovations.

In the context of developed countries, various studies have documented a positive impact of new technologies on industry-wide productivity. One notable example is the minimill's introduction to the US steel manufacturing sector, to which Collard-Wexler and De Loecker (2015) attribute a significant increase in productivity in the second half of the twentieth century. Here, they identify a reallocation of output among incumbents, where the least productive firms that failed to adopt the new technology were driven out of the industry. Other evidence has robustly linked the 1990s acceleration in US productivity to the development of ICTs.[3] For example, focusing on the valve manufacturing industry, Bartel et al. (2007) find that new IT investments improved the efficiency of all stages of the production process and increased the skill requirements of machine operators.

There also exists a small but growing literature on technology's role in firm and sector productivity in the developing world. Exploiting firm-level survey data, Commander et al. (2011) find evidence of a large, positive productivity effect of ICT

[3] See Draca, Sadun, and Van Reenen (2007) for a review of the literature on ICTs and firm productivity.

adoption in both Brazil and India. In Brazil, this effect was largest for firms simultaneously investing in flattening organizational structures and, in India, in areas with better infrastructure. Moreover, ICT capital intensity was negatively correlated with poor infrastructure and pro-worker labor regulation. A more recent study by Atkin et al. (2017a) investigates the introduction of a new cutting technology in Pakistan's soccer-ball industry. While this was found to reduce waste and increase technical efficiency for nearly all firms in the sector, adoption rates were low when the technology was offered free of charge to a random subset of these. The authors attribute this to misaligned incentives in piece-rate contracts, where employees were initially slowed by the new technology and faced no private incentive to reduce waste, resulting in resistance to adoption. Indeed, when employees were offered financial incentives conditional on demonstrating competence in using the technology, adoption increased significantly.

Ultimately, the literature on technology's impact on firm productivity in developing countries remains in its nascent stages. However, the examples above provide an important cautionary tale for policymakers – though new technologies can be highly effective at raising productivity in firms, we must not lose sight of the conditions that encourage adoption and high returns. This should involve consideration of infrastructure investments and the regulatory environment.

2.2 *Facilitating Trade*

Firms and households in developing countries face relatively restricted access to markets. Whether a result of policy barriers (e.g., regulations) or poor transportation infrastructure, this prevents firms from engaging in trade and inhibits the transfer of technology. This also stops households from accessing cheaper goods and seeking more productive work opportunities which are key drivers of growth and development. As such, many experts have argued for measures to facilitate trade, such as investments in transportation infrastructure. The use of ICTs can also help to overcome transport costs and facilitate arbitrage, improving market efficiency and firm performance and reducing waste.

A small but growing empirical literature emphasizes the positive welfare effects of trade for both producers and consumers in developing countries. For example, Atkin et al. (2017b) randomize access to export markets for small carpet-making firms in Egypt. They find evidence of "learning by exporting," where exporting firms witnessed improvements in technical efficiency, resulting in higher output quality and profits. On the consumer side, Atkin et al. (2018) study retail FDI (foreign supermarkets' entry into the local retail sector) in Mexico. They detect large welfare gains for the average household, primarily driven by lower living costs. Finally, Redding and Sturm (2008) offer rigorous evidence on the importance of market access for economic development using Germany's division and reunification as a natural experiment.

One important factor that inhibits trade and its associated welfare benefits is high transportation costs. In recent years, a number of studies have demonstrated how combatting this via infrastructure investments can accelerate economic development. For example, railroads – a major technological advancement of the nineteenth century – were shown to facilitate internal trade and market access and produce lasting growth and welfare effects in settings such as colonial India (Donaldson, 2018) and nineteenth-century US (Donaldson & Hornbeck, 2016). Similarly, focusing on 15 countries in sub-Saharan Africa who have a port as their largest city, Storeygard (2016) finds that incomes in secondary cities are highly sensitive to the cost of transport to the largest city.

By reducing transport costs, transportation infrastructure investments also allow households to access external work opportunities, which may improve the allocation of human capital. For example, Morten and Olivera (2018) study the road networks connecting Brasilia and Brazil's state capitals. These are shown to have decreased both trade and migration costs, resulting in important welfare gains. Adukia et al. (2020) focus instead on transport networks to rural areas in their study of India's $40 billion program to construct all-weather roads to nearly 200,000 villages. They detect a positive impact on adolescent schooling outcomes, particularly in areas where the relative return to high-skill work increased the most. This is consistent with market access having raised the return to human capital investment, suggesting the potential for long-run gains to infrastructure investments. In a later study of the same intervention, Asher and Novosad (2020) detect a large reallocation of workers out of agriculture. This is reinforced by a model developed by Gollin and Rogerson (2014) in which reducing transportation costs generates agricultural productivity gains, in turn decreasing the fraction of people working in subsistence farming.

On the other hand, another strand of the literature has cautioned that gains from infrastructure and trade may be unevenly distributed. This may be the case where certain regions are disadvantaged in ways that prevent them from realizing the benefits of improved market access and instead are confronted with issues such as capital flight. Faber (2014) explores this question in his study of China's National Trunk Highway system, as a by-product of which many peripheral counties were connected to major production centers. He argues that declining trade costs produced adverse growth effects for peripheral regions as economic activity and employment were displaced to urban regions. In another study of China's transportation networks, Banerjee et al. (2020a) detect only a small positive effect on sectoral GDP per capita and no effect on growth. Tsivanidis (2018) sheds further light on the distribution of infrastructure gains, focusing on urban public transport. He studies the construction of the world's largest bus rapid transit system in Bogotá, estimating large aggregate output and welfare gains. However, he finds that these were accrued slightly more by high-skilled workers, despite this being a service relied upon more by the low skilled. His model points to knock-on effects on commuting costs, commuting decisions, and wages. Together, these studies underline the emphasis that must be placed on general equilibrium effects in the study of transportation infrastructure and provide a cautionary note to policymakers attempting to use such investments as means of targeting certain groups or regions.

Another consideration which must factor importantly into infrastructure investments relates to environmental concerns. For example, Balboni (2019) documents the high coastal concentration of populations and infrastructure and demonstrates the negative impact of rising sea levels on the profitability of this allocation. She argues that, under a central sea-level rise scenario, 72% higher welfare gains could have been achieved by a foresighted allocation avoiding the most vulnerable regions. Others have cautioned that improved transportation infrastructure risks deforestation and biodiversity loss (Damania & Wheeler, 2015; Dasgupta & Wheeler, 2016). These highlight the importance of accounting for future environmental change when making contemporary infrastructure investment decisions. Sustainability considerations must also steer the nature of the transportation investments being made and how these are powered. Here, an encouraging example is India's Dedicated Freight Corridor, a major infrastructure investment which stands to increase India's share of rail in freight transportation and generate significant reductions to CO_2 emissions (Pangotra & Shukla, 2012).

Alongside transportation infrastructure, another force which may act to facilitate trade is the improved circulation of market information. The fast expansion of ICTs, in particular mobile phones, has been shown to generate major efficiency gains. For example, Jensen (2007) documents how the 1997–2000 expansion of mobile phone coverage along India's Keralan coast allowed fishermen to call sellers at different markets in search of the best price for their output. This resulted in a dramatic fall in price variation across local markets, higher profits, and the elimination of waste, generating welfare gains for producers and consumers alike. Similarly, Aker (2010) finds that the 2000–2006 introduction of mobile phones in Niger reduced price dispersion by 10–16% and increased profits, which she attributes to reduced search costs for farmers.

3 Labor Markets and Structural Change

Development is all about structural change, that is the movement of people from less productive to more productive jobs. In many cases, this involves movement across geography, for example, from the countryside to cities or from poor to rich countries. How technology can encourage this process of development is an area of significant interest in which research in economics is beginning to make some inroads. These technologies, however, also imply that the nature of work is changing, with the enormous expansion of platform-type employment as well as the disruption arising from the mechanization of many occupations. Technology thus has the ability to create new employment opportunities as well as to destroy them. Navigating the path to understanding how technology influences labor markets will require careful investigation into how precisely occupational structures are being affected, rather than assuming that technology will be either a good or a bad thing for employment.

3.1 Bridging the Employer-Employee Information Gap

Research has shown labor market frictions to be an important impediment to firm growth (Greenwald, 1986; Gibbons & Katz, 1991; Abebe et al., 2017a, 2017b), suggesting that improving the efficiency of the job-matching process could be crucial for developing countries. This may be especially the case given their large youth populations, with over ten million Africans entering the labor force annually (Mohammed, 2015), coupled with the high youth unemployment rates characterizing many poorer regions (McKenzie, 2017). Here, technology offers immense opportunities, particularly in labor markets where information may be scarce and for workers considering migration.

In their seminal paper, Bryan et al. (2014) show that encouraging workers to seasonally migrate to cities improves the welfare of rural households in Bangladesh. This is predicated on workers being able to find jobs. Technologies which allow them to do so and indeed allow employers to contract workers for specific tasks are becoming ever more prevalent across the developing world. For example, many of India's migrant workers are contracted online by recruitment companies to fill positions carrying out a huge range of services in Indian cities. Babajob is the country's largest marketplace for informal and entry-level formal jobs, having registered 6.1 million jobseekers and over 370,000 employers across India as of 2018. To promote its accessibility, the platform offers a range of online and offline access options, including Internet, text messaging, and interactive voice response (GIE, 2018).

The availability of contracting online has also meant that large numbers of workers from low- and middle-income countries can secure employment across international borders before migrating to these jobs. Some obvious examples of this are the huge numbers of workers who move from India, Pakistan, and Bangladesh to the Gulf countries to work in construction and other activities.[4] But online contracting is also central to the movement of health workers and domestic maids, for example, from the Philippines to a whole range of countries (Calenda, 2016). The advent of these technologies implies that labor markets have become much broader, in effect expanding job opportunities from the national to the international.

While the benefits in theory could be large, existing research on technology's impact on the efficiency of the job-matching process is extremely limited. Dammert et al. (2013) provide the first experimental evidence in a study of a public labor market intermediation service (LMI) in Peru, randomly assigning registered job seekers to be contacted via SMS or traditional methods (in person or by phone). They detect a positive impact on employment which was larger for SMS intermediation, though not statistically significantly so. Moreover, the employment effect dissipated after 3 months and was not accompanied by an effect on matching efficiency. They furthermore note that those with less labor market experience

[4] See, for example, the Musaned electronic platform used in Saudi Arabia to hire Bangaldeshi domestic workers.

seemed to benefit less from the service and were less likely to search for jobs through digital means. Ultimately, digitization of the intermediation service proved both viable and cost-effective but was not in any way transformative.

Overall, the body of research on these technologies is too small to reach a conclusion regarding their impact on job search behavior, migration, unemployment duration, the quality of matches, and labor market efficiency in developing countries. Moving forward, attention should also be paid to their inclusionary potential, for example, the effectiveness of Babajob's use of different access options in combatting potential barriers such as illiteracy. Ultimately, it is also clear that technologies that facilitate job search will be restricted to regions with sufficient telecommunications and electricity infrastructures. Complementary investments in these will be vital to ensure the success of any such platforms. However, it is clear that by increasing the size of the markets over which workers can search and by improving matches between employers and workers, these technologies undoubtedly hold promise.

3.2 Transforming the World of Work

Technological advances prompt questions about the future of work, with automation and digitization threatening the existence of jobs that can be carried out by robots. Prominent examples include assembly-line work and clerical jobs involving "routine tasks" (Autor et al. 2003). Indeed, various studies have attributed declines in employment in these positions in the US across the twentieth century to automation and digitization (Autor et al., 2003; Autor, 2015; Levy & Murnane, 2004). Conversely, others have emphasized complementarities between automation and human labor, painting a more optimistic picture for the future of work. This relates to a conjecture by Autor (2014) that some tasks may be inherently "uncodifiable." In this way, automation may enhance the value of labor that humans can uniquely supply and protect certain occupations from substitution altogether. This is consistent with the phenomenon of job polarization that has been well-documented in developed countries, i.e., the simultaneous growth of high-skill, high-wage and low-skill, low-wage occupations.[5]

What can these debates, which have largely revolved around developed countries, tell us about what lies in store for countries at earlier stages in the structural change process? On the one hand, the "alarmist" view argues that larger employment shares in low-skill work in developing countries imply that more of their jobs could feasibly be taken over by technological change that is skill-biased. Indeed, the World Bank (2016) estimates that two-thirds of all jobs in developing countries are susceptible to automation. Others have furthermore warned of potential "reshoring,"

[5] See Goos & Manning 2007; Goos et al., 2014; Autor & Dorn 2013; Autor et al., 2015; Autor et al., 2006, 2008; Autor 2014; Michaels et al., 2014; Graetz & Michaels 2015.

where labor in poorer countries gradually loses its cost advantage to robots in richer ones, ceasing the outsourcing of manufacturing that has hitherto been an important source of growth (Schlogl & Sumner, 2018; Maloney & Molina, 2016). For these reasons, Schlogl and Sumner (2018) project that, in developing countries, automation will cause wage stagnation and "premature deindustrialization," as proposed by Rodrik (2016). On the other hand, by breaking existing barriers to entry and efficiency, Maloney and Molina (2016) argue that technology may support new ICT-intensive industries. For example, Kenya's M-PESA mobile money program works with nearly 400,000 agents across the Democratic Republic of Congo, Egypt, Ghana, Kenya, Lesotho, Mozambique, and Tanzania (Vodafone, 2020), and India's IT sector created 200,000 new jobs in 2019 alone (Bhattacharya, 2020). Further dampening concerns surrounding automation, others have pointed out that technologies typically diffuse at an altogether slower rate in developing countries. Indeed, many of the jobs being carried out by humans in poorer regions have long-since been automated in developed countries (World Bank, 2016).

Several notable attempts have been made to quantify technology's impact on labor markets in developing countries to date. Maloney and Molina (2016) use census data to test for job polarization in the developing world, of which they find no strong evidence. However, they point to a relative decline in employment in the "plant and machine operators and assemblers" category in Indonesia, Brazil, and Mexico since around 2000 as potential evidence of incipient deindustrialization. In another study, Hjort and Poulsen (2019) provide the first direct evidence on the causal relationship between ICTs and labor markets in a developing country context, exploiting the gradual arrival of fast Internet in a range of African countries. They detect a large increase in employment rates and argue that this is driven by job creation in higher-skill occupations. For example, they find evidence of firm entry in South Africa, primarily in ICT-intensive sectors such as finance, and increased productivity of existing firms in Ethiopia. Moreover, the authors show that, after obtaining a fast Internet connection, firms in Ghana, Kenya, Mauritania, Nigeria, Senegal, and Tanzania seemed to engage in more exporting, online communication with clients and training. These benefits appear to have also extended to workers with lower skill levels. In particular, the increase in the probability of employment that the authors observe is of comparable magnitude for those with primary, secondary, and tertiary education. Together, these results paint a different picture to that described by the more alarmist view of technological change's labor market impact.

Overall, we are yet to find rigorous evidence of labor market polarization and displacement in developing countries of the kind experienced in developed countries to date. However, this is an understudied area far from the point of consensus. Additional uncertainty for workers in developed and developing countries alike is introduced by future technological advances that will inevitably extend the range of automatable jobs. Here, machine learning and artificial intelligence have raised particular concerns, given their potential to master "nonroutine" tasks (Autor, 2015; Webb, 2019).

With vast uncertainty ahead, countries must enact forward-looking policy change to equip their workforces as best possible for skill biased technology change. One option is to focus on education investment. Encouragingly, the World Bank (2019) report that, between 2000 and 2014, the share of employment in high-skill occupations increased by 8 percentage points in Bolivia and 13 percentage points in Ethiopia. However, Schlogl and Sumner (2018) caution that education is no panacea. Indeed, even developed countries with far higher average skill levels are struggling to insulate their labor forces from competition with new technologies. Rather, the authors underline the likely future importance of a social safety net. How exactly developing countries might fund this remains an extremely pressing open question.

3.3 Widening Access to Quality Education

Education represents a critical input to labor markets and development, and it is the focus of SDG 4 to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" (UN, 2020). As described above, educational investments may also help equip the labor force for future skill-biased technological change. It is estimated that there were 750 million illiterate adults in 2016, largely concentrated in South Asia and sub-Saharan Africa, and 262 million children aged 6–17 out of school in 2017 (UN, 2019). However, measures to increase enrolment will do little to improve attainment unless the education provided in schools is of high quality (Banerjee et al., 2008). Whether technological applications can help guarantee this has been the focus of an increasing number of studies.

One important strand of the literature has focused on computer-assisted learning (CAL). This consists of educational software programs which often adjust to students' achievement levels. Optimists have highlighted how these can target some of the issues endemic to education provision in developing countries, such as underqualified teachers and large classrooms with significant heterogeneity in student learning levels. Indeed, in their review of the literature on education and technology, Bulman and Fairlie (2016) note that effects are generally stronger in developing country contexts, perhaps due to lower levels of human capital. However, this overall positive result masks some important nuances.

In particular, Banerjee et al. (2008) conduct a randomized evaluation of a CAL program in Vadodara, India. Here, grade 2 students were given weekly access to a computer for playing math games which tailored themselves to students' achievement levels. The authors detect substantial test score gains, though these dissipated over time. In another study of India, Muralidharan et al. (2019) evaluate the "Mindspark" CAL program for after-school instruction of middle-school students, which also offers customized content. They find significant improvements in test scores which were particularly large for weaker students, implying the program effectively catered to a wide range of learning levels.

On the other hand, in a randomized evaluation in Gujarat, Linden (2008) found that CAL caused students to learn significantly less when computers were used as a substitute for the normal curriculum. However, when used as a complement, i.e., as an out-of-school program, CAL had a positive effect on learning, especially for weaker students. This the author attributes to the program's design, which reviewed material in the existing curriculum. Outside of India, Carrillo et al. (2010) evaluate a mathematics and language CAL program for primary school students in Ecuador. They detect positive impacts on mathematics test scores and an insignificant (negative) effect on language test scores. Together, these results suggest that CAL is able to promote learning for students of a wide range of abilities but also reinforce the importance of careful format design and considerations of the context into which CAL is being implemented.

In contrast to generally positive results in evaluations of CAL, programs focused on improving access to computers have shown limited success. Such was the case for Beuermann et al. (2015), who analyze an experiment in Peru in which students were given a laptop for home use and fail to detect an impact on academic achievement. In another study, Barrera-Osorio and Linden (2009) evaluate a national program in Colombia to install computers in public schools, also training teachers on how to use them in specific subjects. Here again, the authors detect no impact on student outcomes, which they attribute to their limited incorporation into classroom teaching. These results underline the potential ineffectiveness of interventions that do not tailor technologies to a specific need.

Throughout this chapter, we have documented how successful applications of mobile technologies can have a vital impact on living standards and economic development. In addition to their use in school instruction, these encompass digital agricultural extension programs, mobile money, online job portals, social media, and simple SMS communication. However, the persistent problem of illiteracy in developing countries serves as an important barrier to their use, preventing people from accessing the associated benefits. While development initiatives have taken measures to help overcome this, for example, harnessing interactive voice response technologies, another solution is to tackle the problems of illiteracy and digital illiteracy head-on via targeted initiatives. Research has also shown that this can in turn enhance learning outcomes in other areas.

In particular, Aker et al. (2012) evaluate the experimental incorporation of mobile phone instruction into a standard adult education program in Niger. This was found to substantially increase writing and math test scores compared to the original model, with a relative improvement in math scores still visible after 7 months. The authors attribute this to improved motivation and effort in the classroom, which links to their conjecture that being able to use mobile phones for other services increases the returns to education. Treated students also used mobile phones more actively beyond the classroom, which may have served as means for them to practice their skills. In a later study of the same program, Aker and Ksoll (2020) document that immediate gains in reading scores persisted after 2 years and also reveal a wide range of other socioeconomic effects. In particular, individuals who received additional mobile phone instruction had more diverse income-generating activities, improved food security and asset ownership, were more likely to sell a cash crop, and were more likely to save. The authors were unable to disentangle whether these effects are due to improved learning outcomes or use of the mobile technology itself, an important question for future research.

Overall, the limited success of programs focusing on the distribution of hardware suggests that access to technology may not be the binding constraint to its successful use in education (Bulman & Fairlie, 2016; Escueta et al., 2017). Rather, this seems to depend on the careful design of the CAL programs that students use them for and their thoughtful integration into existing curriculums. In these cases, it has been proven that technology may enhance the learning of students across the achievement spectrum. Moreover, it appears that equipping students with digital literacy can improve learning outcomes in traditional areas of academic study and generate further welfare and economic benefits. However, the success of technology-enabled education broadly rests on the quality of telecommunications and electricity infrastructure, which remains dire in many developing contexts. In sub-Saharan Africa in particular, under 50% of all primary and lower-secondary schools have access to electricity, the Internet, computers, and basic drinking water (UN, 2019). Investing in these crucial amenities must be a first order priority for education initiatives.

It is also vital that we do not understate the importance of human capital in the education workforce. Improvements in educational outcomes will hinge on the skill, motivation, and efforts of teachers in the delivery of both ICT-enhanced and more traditional lessons. Indeed, Aker et al. (2012) note that teachers in their sample with higher education were "better able to harness mobile phones to improve students' educational experiences." Here, technology can also play its own role, for example, in enabling the monitoring of teacher attendance. In an experiment in India, Duflo et al. (2012) show that such initiatives can provoke substantial increases in attendance with positive knock-on effects on student outcomes.

There is also hope that technology can be exploited to educate children in settings where teachers are unavailable altogether. This has become particularly salient in light of the COVID-19 pandemic. For example, the Vodafone foundation reports that over 1.1 million young people in Africa are accessing educational materials online via their e-school programs (Vodafone, 2020). Here, future research must also consider whether and how technology can be used to tackle the gender gaps in educational attainment that remain in developing countries.

4 Financial Technologies

Throughout this chapter, we have documented the range of new opportunities for communication and service provision that have accompanied mobile technology's fast expansion throughout the developing world. One such case is financial technologies, namely, mobile money. This generally refers to the application of mobile phones for sending and receiving money. Transfers take place via SMS for a small fee, and do not require ownership of a formal bank account. Deposits and withdrawals are made by visiting a mobile money agent, a process akin to exchanging cash with “e-money.” In this way, mobile money is far removed from the mobile banking applications used by many in developed countries.

Demirgüç-Kunt et al. (2020) estimate that there are 1.7 billion unbanked adults globally, 1.1 billion of whom have a mobile phone. This has sparked enthusiasm surrounding mobile money as a way of bringing formal financial institutions to populations hitherto reliant exclusively on cash. In doing so, it has the propensity to significantly reduce transaction costs and facilitate saving, with important implications for welfare and development. For firms and governments harnessing mobile money for the transfer of wages and welfare payments, there is also scope for significant efficiency gains and reduced leakage. However, whether this technology actually constitutes a development “leapfrog” for low-income countries, whereby mobile banking facilitates universal financial inclusion while bypassing the formal banking sector, remains unclear. This may crucially depend on countries’ regulatory frameworks, among other important factors. These issues are discussed in this section.

4.1 Increasing Financial Resilience

In the absence of access to financial services, households revert to inefficient, risky, and costly methods for making transfers to friends and relatives. These include informal practices, such as asking friends or bus drivers to pass on cash, and use of money transfer services, such as Western Union (Aker, 2018). Mobile money stands to significantly facilitate these processes – senders can transfer funds through a simple SMS, requiring only that both parties own a mobile phone and the payment of a transaction fee. A new body of research is beginning to show that, in doing so, mobile money is having an important impact on household financial behavior and welfare.

This question is examined by Jack and Suri (2014) in their seminal study of M-PESA, the developing world’s most renowned mobile money success story. The authors document that users experience a significant reduction in the transaction costs associated with sending remittances, which in turn facilitated inter-household risk sharing. In particular, following a negative income shock, M-PESA users received more remittances and from a wider range of sources, allowing them to avoid cutting their consumption. In another study of the same program, the authors reveal that improved smoothing also extended to negative health shocks (Suri et al., 2012). Batista and Vicente (2018) confirm that these effects are not limited to Kenya’s M-PESA, offering some of the first experimental evidence in a study of rural Mozambique. Here again, they detect evidence of improved smoothing and reductions in hunger episodes, which they attribute to increased receipt of remittances. These studies speak to mobile money’s ability to bolster the financial resilience of poor households in the face of shocks that would have otherwise cut into their consumption and education spending, suggesting significant welfare gains.

Beyond facilitating consumption smoothing, there is evidence of wider socioeconomic effects following mobile money's introduction. For example, in rural Mozambique, Batista and Vicente (2018) detect a fall in agricultural activity in treatment areas as well as an increase in out-migration, which can be a route out of poverty (Bryan et al., 2014). Similarly, in a long-run evaluation of M-PESA's economic impacts, Jack and Suri (2014) estimate that access to mobile money lifted almost 194,000 households, equivalent to 2% of Kenyan households overall, out of extreme poverty, which they attribute to improved financial resilience and higher savings. They also document a shift of women out of subsistence agriculture and into business and retail occupations. Together, these studies indicate a causal link between mobile money and development via improvements to the economic lives of the poor.

Recent years have seen mobile money extending beyond simple transfer and savings facilities to include other traditional financial services, such as loans. For example, Safaricom's M-Shwari enables consumers to open a bank account and make deposits and withdrawals via M-PESA. They can also request a loan, the decision for which is based on financial history data (Suri, 2017). In their evaluation, Bharadwaj et al. (2019) document that M-Shwari had high take-up and effectively improved access to credit and resilience to income shocks. However, the potential for transformative socioeconomic impacts was limited by the small and short-term nature of the loans. In another study of Indonesia, Harigaya (2016) evaluates the experimental digitization of a group microfinance program via mobile money, which meant deposits and withdrawals were more convenient and could be carried out in the absence of peers. The author detects a decline in savings, which he attributes to a weakening of the peer effects that underline the motivation for group banking, as well as sensitivity to fees, which, though small, appeared to increase the salience of transaction costs. Blumenstock et al. (2016) study a separate mobile money innovation in which this was used for wage payments in an Afghan firm, and half of employees were experimentally assigned a 5% default savings contribution. This was found to significantly increase savings, which the authors attribute to the overcoming of behavioral barriers. Together, these studies highlight the potential for innovative applications of mobile money but caution that behavioral factors can work to both their advantage and disadvantage.

4.2 Facilitating Firm and Government Transactions

In recent years, applications of mobile money have been extending from person-to-person payments to also include person-to-business and government-to-person (or NGO-to-person) payments (Suri, 2017). This can include the payment of wages, as described above, as well as the transfer of welfare payments to households, transactions which would otherwise have to take place via cash. In this way, mobile money may produce important efficiency gains for firms, governments, and NGOs. This question is evaluated by Blumenstock et al. (2015) in another

RCT in Afghanistan wherein a subset of employees was transitioned from cash to mobile money payments. They detect significant benefits to the organization, which included significant savings in salary disbursement activities. In an experiment in Niger, Aker et al. (2016) study an NGO application of mobile money to send emergency cash transfers to households following a drought, of which women were the primary beneficiaries. Here, households in which women received electronic rather than cash payments had improved diet diversity and their children consumed one third of an extra meal per day. In addition to time savings in obtaining the transfer, the authors present evidence of improved female bargaining power to explain their results. Overall, these studies show that the efficiency gains enabled by mobile money can benefit both firms and households.

Applications of mobile money are also coming to form an important part of the COVID-19 response, partly to prevent disease transmission via cash exchanges. For example, telecommunication operators across Africa, including M-PESA, have removed fees on small mobile money transactions (Flood, 2020). Others have lowered the barriers to opening accounts, such as by waiving additional documentation requirements (Peyton, 2020). In a move to support struggling small businesses, M-PESA has also raised daily transaction limits (Finextra Research, 2020). Similarly, governments have been using mobile money to scale up emergency welfare programs. For example, Togolese informal workers have been able to register for and receive a state grant via their mobile phones (Financial Times, 2020). The UNHCR has also been distributing mobile phones and SIM cards to displaced families and making assistance payments into these (Faivre, 2020). This positive shock to the use of mobile money stands to kick-start its diffusion in areas where adoption has been hitherto limited.

Dampening enthusiasm surrounding mobile money are concerns surrounding its inclusionary potential, i.e., whether mobile money can effectively extend access to financial services throughout the developing world. This relates to the finding that initial adopters of mobile money may be positively selected in terms of education and income (Batista & Vicente, 2020; Suri et al., 2012). Here, researchers have pointed to potential barriers such as lack of trust, illiteracy, affordability, and possession of official documents required to sign up for accounts, issues which may disproportionately affect women. Indeed, the GSM Association (2019) report that women in low- and middle-income countries are 10% less likely to own a mobile phone and 23% less likely to use mobile Internet in the first place. This ownership gap extends to 28% in South Asia. These figures underline the need for more research into what drives female adoption of mobile phones and mobile money in particular.

Another important barrier to the widespread diffusion of mobile money is the strength of the agent infrastructure, to which Suri (2017) attributes M-PESA's success relative to other mobile money initiatives. For example, in her study of Niger, Aker (2018) discusses how, in one region, households lived an average of 15 km away from the nearest agent. In such contexts, adoption of mobile money was low, despite high costs of alternative methods for sending remittances and high ownership of mobile phones.

Overall, it is clear that mobile money is already beginning to transform the landscape of financial services in the developing world. Its use has been proven to facilitate transactions for individuals, firms, governments, and NGOs, translating to improvements in efficiency and changes in household financial behavior that stand to have long-run implications for development. Recent years have also seen mobile money technology applied to a range of other financial services characteristic of more traditional bank accounts. However, whether these can have the transformative impact that appears to accompany mobile money's basic transfer and savings functions is yet unknown. There are also many remaining questions surrounding the factors that impact the widespread diffusion of mobile money, including behavioral biases, the agent infrastructure, illiteracy, and affordability. Moving forward, there is high demand for further rigorous economic evidence to inform these debates.

5 Energy and Environment

To this day, nearly 1 billion people remain without an electricity connection, and many others receive only partial and intermittent supply (IEA, 2019). Lack of access to this vital technology constrains the set of productive activities households can engage in and inhibits firm performance. The desire to scale energy generation to close this gap has inspired investments into both national grid capacity and alternative off-grid technologies. However, as with any other form of technology, availability may not be the binding constraint to its successful use. Rather, barriers such as electricity theft and poorly functioning utilities continue to inhibit the uninterrupted flow of power to households and firms and its associated benefits for growth and development. Simultaneously, it is vital that growing energy demand in developing countries is met with sustainable sources. These challenges can only be met by harnessing technological innovation.

5.1 Scaling Energy Access

It has been well-documented that reliable energy access is an essential ingredient to economic development (Moneke, 2019; Lipscomb et al., 2013), with many emphasizing an important firm performance channel. For example, both Kassem (2020) and Rud (2012) detect positive impacts of electrification on the entry and performance of manufacturing firms in their respective studies of Indonesia and India. In their evaluation of the Indian textiles industry, Allcott et al. (2016) furthermore document that electricity shortages reduced average output by about 5–10%, underlining the importance of the grid's reliability.

Another dimension of electrification's promise lies in its potential to generate behavioral change, namely, by allowing households prolonged access to light and powering time-saving appliances such as fridges and microwaves. These extend the time available for studying and productive tasks, which may in turn generate longer-run economic benefits to further motivate electrification efforts. Several studies have attempted to capture these effects. Most notably, Dinkelman (2011) studies South Africa's mass rollout of the grid to rural households. She finds that electrification significantly boosted female employment by releasing women from home production and fostering micro-entrepreneurship. This positive impact on female employment is also detected by Grogan (2018) in his study of rural, indigenous households in Guatemala. Interestingly, Fujii and Shonchoy (2020) furthermore find evidence of a negative impact of electrification on fertility. Ultimately, effects of this nature are harder to study, and so much remains unknown as to the longer-run social and economic impact of electrification. However, it is vital that these remain an important focus of research, lest we understate the benefits of and therefore underinvest in electricity.

In line with the well-documented benefits of electrification, infrastructure investments to scale up national energy generation and transmission have become a mainstay of development policy. Here, many African countries are turning to hydropower, exploiting the abundant water supply provided by their rivers. A landmark example is the Grand Ethiopian Renaissance Dam, set to become Africa's largest hydropower project with a 6000 MW capacity (Power Technology, 2020). Overall, hydropower is set to provide 90% of Ethiopia's electricity and also constitutes a promising avenue for growth as it intends to export surplus to neighboring countries (IHA, 2017). In South America, Brazil houses the continent's largest installed hydropower capacity (IHA, 2018), which accounts for around 80% of domestic electricity generation (IEA, 2020). Solar has become another important avenue for scaling national energy generation. 2016 saw the completion of Rwanda's Rwamagana Solar Power Plant, whose 8.5 MW capacity made it East Africa's first utility-scale solar power plant (Mininfra, 2020). Another standout case is Kenya, quickly approaching 100% renewable energy generation thanks to investment in geothermal, wind, and hydropower sources. In 2019, it opened the Lake Turkana Wind Power farm, the largest in Africa with 365 turbines and a 310 MW capacity (Dahir, 2019).

In spite of the aforementioned investments in national energy capacity, a significant share of the developing world is expected to remain off-grid due to the high cost of extensions to remote, rural areas. In particular, of the 315 million set to gain access to electricity in Africa's rural regions by 2040, it is estimated that only 30% will be connected to national grids (African Progress Panel, 2017). Instead, many are anticipated to be electrified via off-grid and micro-grid technologies. These can consist of systems powering individual households or larger-scale ones serving several at a time. They are able to reach remote regions at relatively low cost and can be powered by renewable sources. Smaller devices are insufficient for powering large appliances such as fans, fridges, and TVs, instead primarily intended for phone charging and lighting. These technologies have been met with much enthusiasm and are inspiring a generation of tech entrepreneurs. For example, in Côte d'Ivoire, Evariste Akoumian's Solarpak makes backpacks with built-in solar panels that collect energy while children walk to school (Capron, 2016). These absorb enough energy during the day to power a lamp for 4 to 5 h – enough to allow children to do their homework at night.

In practice, however, evidence from India suggests that the theoretical benefits of microgrids have not always manifested. In a study targeting non-electrified households in Uttar Pradesh, Aklin et al. (2015) installed solar microgrids in 81 randomly selected villages that were previously reliant on kerosene lamps to light their homes. They document an increase in electricity supply, as indicated by reduced kerosene expenditure, but detect no broader socioeconomic impacts. The authors suggest that the power supply supported by the microgrids had been insufficient to encourage business activities or the accumulation of social and human capital.

Others have assessed the microgrid's viability in contexts where it is available alongside the grid. In a study of Bihar, Burgess et al. (2020a) conduct an experiment in which microgrids were offered to a sample of villages at different prices. In this setting, households were also faced with the choices of individual household solar panels (own solar), diesel generators, and the grid, which was being rolled out over the course of the study. They found that, at market price, just 6% of households purchased microgrids, increasing to 19% under a 50% subsidy. Moreover, they saw microgrid demand collapse following grid extensions and improvements in own solar quality. Overall, they argue that richer households have a strong preference for the grid's higher capacity and predict that future income growth will drive electrification primarily via the grid. Simultaneously, off-grid solar will play a key role for poorer households in more remote areas. In this sense, off-grid solar, though highly valuable in situations where the grid alternative is not available, may ultimately be supplanted by the grid. Interestingly, however, the grid itself may increasingly be powered by renewables, including solar. In another study in India, Fowlie et al. (2019) document one company's experience deploying microgrids in Rajasthan. These are also met with low demand, eventually forcing the company to cease its operations. Here, the authors point to competition with the grid, with politicians' promises of imminent local extensions potentially deterring microgrid purchases.

Ultimately, in the face of large government subsidies for grid connections, microgrids may find it impossible to compete. In India in particular, the government has several schemes offering free grid connections to households below the poverty line. Here, Fowlie et al. (2019) argue for transparency in state expansion schedules and measures to ensure microgrids can be technologically integrated into the grid if and when this does arrive. Demand for microgrids also seems to be constrained by their relatively low capacity, which in turn may inhibit the socioeconomic benefits of electrification from manifesting. In this regard, there is certainly room for tech professionals to provide valuable improvements to these energy provision systems.

A natural conclusion of the above discussion on the development benefits of the grid, combined with the proven limitations of off-grid alternatives, would be to pursue rapid universal grid extension. However, a number of recent studies have documented that such efforts may too be alone insufficient to secure the economic benefits of reliable access. In particular, in a study of Western Kenya, Lee et al. (2016) reveal that, despite high population density and extensive grid coverage, electrification rates remain at 5% on average for rural households and 22% for rural businesses. Moreover, half of unconnected households are "under grid," meaning they could be connected to a low-voltage line at a relatively low cost. In another study, Lee et al. (2020) experimentally offer households in this setting the opportunity to connect to the grid at different subsidized prices. They detect surprisingly low demand even at high subsidy rates, which, combined with costs of supplying connections, imply rural electrification may even have reduced welfare.

Researchers have proposed different explanations for the advent of low-grid demand. Lee et al. (2020) point to credit constraints and the overall low quality of grid provision, with evidence of excess costs from leakage during construction, bureaucratic red tape, low grid reliability, and unaccounted for spillovers. For example, in addition to short-term blackouts lasting minutes or hours, households in rural Kenya face long-term blackouts which can extend for months. Others have argued that issues of grid quality are themselves a function of poor enforcement of payments and informal connections, i.e., individuals illegally connecting for free, a pervasive problem in developing countries. This is documented by Burgess et al. (2020b) in their study of Bihar, whose state electricity utility recovers just 34% of its costs. They argue that this is overwhelmingly the result of electricity having been treated as a right regardless of payment, producing tolerance for subsidies, theft, and nonpayment. The end result is an insolvent utility dependent on government bailouts and tightly rationed supply. McRae (2015) studies a similar paradox in Colombia. He demonstrates that quality upgrades are unprofitable for utility firms, as the state subsidizes their losses and low-income households prefer to receive a low-quality service for which they do not pay.

Ultimately, many developing countries are stuck in a low-quality electricity equilibrium in which households pay little for poor supply and governments battle the competing objectives of sustaining utility companies and retaining the political support of low-income households. More research must focus on finding paths to enhancing the reliability of grid supply and improving the organizational performance and financial sustainability of utilities. Without doing so, it may be impossible to generate the level of demand for and supply of reliable electricity to achieve the development benefits of electrification.

5.2 Guaranteeing Sustainability

World energy demand is on the rise, with the majority of growth set to stem from low-income countries (Wolfram et al., 2012). While this has the potential to spur welcome growth and development, higher energy consumption will also increase levels of pollution and other externalities. Though some national grid investment projects involve large-scale exploitation of renewable energies, others raise sustainability concerns. For example, the China-Pakistan Economic Corridor consists of $60 billion worth of infrastructure projects, including $35 billion for the scaling-up of Pakistan's energy supply (Stacey, 2018). Almost 75% of the new generation capacity will be coal-fired, contributing to an expected rise in the coal share of Pakistan's energy mix from 3% in 2017 to 20% in 2025 (Downs, 2019). Efficiency issues also arise on the consumer-end, with nontechnical losses such as electricity theft prevalent across the developing world, as discussed above. In sub-Saharan Africa in particular, Kojima and Trimble (2016) estimate the total annual value of uncollected electricity bills at 0.17% of national GDP on average. In this section, we discuss the potential for technological innovations to promote both sustainability and the efficient production and consumption of energy.

Electronic meters represent one such technology hailed as a potential solution to energy losses. One variety is the smart meter, which records electricity consumption and communicates this to the distribution company. These were a feature of the microgrids deployed by Fowlie et al. (2019) in Rajasthan, India. Here, however, the authors found that interpersonal relations and inter-caste dynamics rendered operators unwilling to enforce penalties in practice, making cost recovery impossible and the scheme ultimately unviable. Moreover, in his study of Colombia, McRae (2015) argues that grid upgrades involving the installation of meters are unprofitable for utilities, given that many households would be unwilling to pay a nonzero marginal cost even for a higher quality supply and that their existing losses were covered by state subsidies.

Perhaps a more promising technological solution is that of prepaid metering, which has grown in popularity across both the developed and developing world. Here, consumers must credit their accounts in order to access electricity, thus transferring the enforcement burden away from the utility. Jack and Smith (2020) evaluate the viability of this technology in a study of Cape Town, South Africa, in collaboration with the local utility. They detect a 14% decrease in consumption but a net increase in revenue thanks to improved cost recovery, mostly driven by a subset of poor customers who were delinquent on bills. The authors argue that the prevalence of this group in other developing countries suggests the technology could be effective in other settings. However, they caution that they are unable to assess the effect of the prepaid meters on theft, a large increase in which could undo positive revenue effects.

Another category of technologies that may encourage sustainability are energy-saving appliances, such as LED lighting. Evidence suggests that this can also have positive productivity co-benefits, as was recently shown in a study of Indian factories by Adhvaryu and Nyshadham (2020). The authors found that LED lighting, which emits approximately seven times less heat, reduced factory floor temperatures by several degrees, in turn leading to increased productivity. Another notable example is that of cooking appliances. An estimated 3 billion people across low- and middle-income countries continue to rely on traditional stoves and solid fuels such as firewood, biomass, or charcoal for heating and cooking (CCA, 2020). These contribute to deforestation and household air pollution, the death rates for which are highly concentrated in developing countries (Landrigan et al., 2018).

Various initiatives have attempted to encourage transitions away from these harmful methods, with varying success. Kar et al. (2019) evaluate one such program in Karnataka, India, which uses loans and subsidies to promote the use of liquefied petroleum gas. Despite increases in enrolment, they detect no impact on fuel sales, suggesting beneficiaries were not fully transitioning away from solid fuels. This underlines the potential barriers governments may face in encouraging households to replace traditional appliances with cleaner ones, especially in cases where individual gains are only felt once widespread adoption has been achieved.

Another major question facing developed and developing countries alike in their attempts to shift towards renewables relates to energy storage. This is especially the case for wind and solar as variable renewable energy (VRE) sources. For instance, wind generation can be high at night, generating power at a time where demand is low. Similarly, extra energy from peak sunlight generation cannot be easily stored for use at a later period. Even more concerning is the prospect of increasingly unpredictable weather patterns, which are only likely to heighten these issues. Existing scientific efforts to overcome these challenges are primarily taking place in developed countries. As such, solutions proposed are unlikely to be well-attuned to the electricity infrastructures characterizing developing countries, which for example often suffer from insufficient capacity (De Sisternes et al., 2020). In recognition of this disparity, the World Bank has committed $1 billion to a new program focused on accelerating investments in battery storage designed for developing and middle-income countries (World Bank, 2018d).

The extent of the challenge facing developing countries must not be understated. In order to guarantee growth and development, it is necessary that they find paths to scale up energy generation in a way that is sustainable for the planet and financially viable. Off-grid alternatives have thus far seen limited success and, without further technological adaptations, are unlikely to be able to meet the growing energy needs of populations in developing countries. However, without improvements to their organizational performance, national grids will also fail in this respect. There is thus a vital need for the economics and engineering communities to convene to design energy policies and programs that are suited to the needs and constraints of developing countries.

6 State Capacity and Public Sector Delivery

The growth of low-income countries may be constrained by limited state capacity, lack of transparency and accountability, and poor public service delivery. Technology can help address the agency problem in governments, both inside layers of government, by improving government transparency, public service monitoring and state effectiveness, and between government and citizens, by improving accountability and expanding political participation.

6.1 Bolstering State Effectiveness and Accountability

An important theme throughout this chapter has been the importance of infrastructure for growth and development. In addition to transport, telecommunications, and energy infrastructures, this extends to the administrative and fiscal infrastructures used by the government to raise and spend tax revenue. These are critical for the effective provision of the welfare programs and public goods that firms and households rely upon. However, these infrastructures tend to be much weaker in developing countries. Here, tax shares in GDP resemble those of now developed countries from 100 years ago (Besley & Persson, 2013) and administrations are grappling with corruption, evasion, and leakage (World Bank, 2003; Olken, 2006; Olken & Pande, 2012). This prevents the secure flow of funds and services to intended beneficiaries and disproportionately hurts the most vulnerable (World Bank, 2018a).

The question of how to tackle these issues is a vital one for development. Here again, policymakers and economists have been hoping that at least part of the answer lies in technological innovation. In particular, government administrations are increasingly harnessing ICTs and other forms of technology, ranging from electronic procurement platforms to biometric authentication. These share the general benefits of limiting informal interactions between officials and households and firms and streamlining administrative processes. However, each can be faced with its own limitations. These are discussed in the following section.

One essential faculty of the state is the procurement of goods and services from firms, accounting for an estimated $820 billion of annual spending in developing countries alone (World Bank, 2018b). However, this process is often marred by corruption and collusion, for example, where contracts are restricted to select insiders and firms collude to raise prices. In the attempt to overcome this important barrier to effective provision, governments have been transitioning towards electronic procurement platforms (e-procurement) that provide a standardized online mechanism for advertising bids and awarding and pricing contracts. By increasing the transparency of the bidding process, reducing the cost of submitting a bid and restricting interaction between officials and firms, e-procurement intends to facilitate the entry of non-favored firms and those beyond the local area. This enhanced competition may in turn improve project costs and quality. On the other hand, a more sophisticated system risks excluding those without Internet access. Thus, whether e-procurement is ultimately to the benefit of competition or the quality of public provision is an empirical question.

Lewis-Faupel et al. (2016) provide some of the first rigorous evidence on e-procurement, exploiting its gradual roll-out for public works programs in India and Indonesia. This was found to improve project timeliness in Indonesia and road quality in India, which the authors contend was driven by entry of higher-quality firms beyond the home region. In another study, Abdallah (2015) documents preliminary evidence on a similar e-procurement scheme in Bangladesh. He detects a 12% decrease in the price-to-cost ratio of procurement packages, amounting to over $10 million in estimated savings for 2013 alone. He suggests this may have been driven by reduced political influence rather than by increased national competition. Conversely, using cross-country evidence, Kochanova et al. (2018) find that e-procurement is only associated with higher public procurement competitiveness in developed countries. Ultimately, despite a few promising results, much remains unknown about the success of these initiatives and what might drive the observed effects.

Another prerequisite for the efficient provision of public services is the effectiveness of civil servants. To this end, various studies have evaluated the application of ICTs to monitor employee performance and improve work incentives. One notable example is a study by Debnath and Sekhri (2017) of school meal provision in Bihar, in which intermediate officials had become a source of leakage. In the attempt to tackle this problem, the state rolled out an Interactive Voice Response System (IVRS) that made daily calls to schools to collect reliable data with which to hold officials accountable. This reform was found to improve the likelihood of lunch provision as well as the quality and quantity of meals, suggesting a significant reduction in leakage. Other applications have targeted absenteeism among frontline providers. For example, Duflo et al. (2012) conduct an experiment wherein tamper-proof cameras were used to record teacher attendance in India's NGO schools, data which was then used to determine wages. The authors detect an impressive 21 percentage point decrease in absenteeism, which furthermore translated into higher student test scores. In a similar experiment with nurses, Banerjee et al. (2008) also document an initial drastic improvement in attendance. However, this began to dissipate after just 6 months, at which point the health authority began to undermine the system through granting exemptions. Together, these studies underline both technology-enabled monitoring's potential for motivating service providers and the necessity of political will for guaranteeing successful implementation.

In developing countries, many households are acutely reliant on social safety nets to fund basic expenditures, programs on which 1.5% of GDP is spent on average by their governments (World Bank, 2018c). However, the effectiveness of these well-intentioned initiatives can be seriously inhibited by leakage and identity fraud, issues that another set of technology-enabled initiatives are attempting to target. These include transitioning from cash to electronic disbursal of benefits, with accounts linked to recipients' biometric information. The Indian government in particular has rested much hope on such technologies. Its Aadhaar program has become the world's largest biometric digital identification system, having registered over one billion users in just 6 years (Nilekani, 2018). Research in economics is beginning to respond with evaluations of these efforts.

Muralidharan et al. (2016) assess biometric authentication at scale, experimentally introducing biometric smartcards for the receipt of pension and workfare payments in collaboration with the Andhra Pradesh state government. They detect large, positive returns that far exceeded costs for both programs, including a reduction in leakages and "ghost beneficiaries," i.e., false benefit claims on behalf of other individuals, as well as improved public satisfaction. In another study, Barnwal (2019) examines the Indian government's deployment of biometric authentication for household receipt of subsidized fuel, attempting to stem its diversion to a black market for firms (who otherwise had to pay a higher, taxed price). He argues that biometric authentication was initially effective in curtailing this illegal activity. However, when the reform was unexpectedly reversed following political lobbying by local officials, black market supply was quickly re-established. Overall, these seem to suggest that programs utilizing biometric authentication can effectively prevent the leakage of vital transfers but may be susceptible to loss of political will.

A related technology that has been harnessed by the Indian government is e-invoicing, whose application to their flagship workfare program is evaluated by Banerjee et al. (2020a, 2020b). These digital platforms enable "just-in-time" financing, where funds are dispensed only in response to specific invoices, rather than in the form of advances to be justified down the line. Drawing upon an experiment in collaboration with the Bihar state government, the authors detect a fall in leakage in the form of fewer ghost workers and a decrease in local officials' wealth, culminating in a 24% fall in expenditure. However, this was accompanied by only a small increase in beneficiaries and no change in wages or projects completed, as well as longer delays in household payments, consistent with the higher administrative burden placed on local officials. Echoing the experience of Barnwal (2019), the Bihar experiment was unexpectedly ceased after a few months. However, a comparable scheme was subsequently rolled out across India, providing the authors with a longer-run quasi-experiment. Here, they find a similar, persistent fall in expenditure. Overall, e-invoicing seems to have yielded long-run fiscal savings without generating direct benefits to households of the kind witnessed by Mularidharan et al. (2016). This relates to the broader question of the potential co-existence of winners and losers to technological applications.

Many studies have documented significant savings following the deployment of technology-enabled initiatives by governments in developing countries, sometimes also translating into a higher quality of service for firms and households. However, these have unsurprisingly sometimes been met with efforts by local officials with vested interests to thwart their implementation. Overcoming these political barriers is a vital obstacle to progress. The success of these initiatives will also rely upon levels of technical proficiency and complementary infrastructure that may be hard to come by in poorer regions and demand significant investment to overcome inevitable logistical hurdles. Such was the experience of Muralidharan et al. (2016) in India, where after 2 years, only around 50% of subdistricts had been converted to smartcard payments. Furthermore, there remain many open questions surrounding general equilibrium effects, in particular whether these initiatives simply displace corruption to other areas.

Another area of increasing importance relates to the privacy concerns that accompany large-scale state data collection efforts, particularly regarding their potential use as part of wider state surveillance efforts (Drèze & Tiwari, 2016). These have become highly salient in light of the COVID-19 pandemic, which has seen several nations request the universal downloading of contact-tracing apps. In many cases, there is limited transparency as to who can access the data and how it might be used post-pandemic (O'Neill et al., 2020). Given the speed at which administrations in developing countries have been harnessing technologies, it is vital that research continues to respond with their rigorous evaluation.

6.2 Improving Political Participation and Electoral Integrity

Another channel through which technology stands to impact the functioning of government is by increasing political participation. This view, described by Diamond (2010) as the "liberation technology" argument, emphasizes that ICTs such as Internet, mobile phones, and social media can facilitate communication and information transmission and promote political mobilization. These technologies are also being harnessed to increase the accessibility and integrity of elections, namely, by helping to overcome illiteracy and prevent the tampering of vote counts. This is vital for the effective functioning of democracy and ensuring that people's preferences are reflected in policy, which too often fall short in developing countries. These have in turn been shown to have implications for the extent to which policies are efficient and support the needs of the most vulnerable (Becker, 1983; Besley & Burgess, 2002).

Following the rapid diffusion of ICTs across the developing world, the question of their impact on political mobilization has been the focus of an increasing number of studies. One notable example is a study by Manacorda and Tesei (2020) exploiting detailed georeferenced data on protest incidence and participation across the African continent. They estimate that mobile phone coverage does increase the probability of a protest but only during times of economic downturn – periods where grievances are high and the opportunity cost to participation is low. The authors also find evidence of "strategic complementarities" in protesting, whereby fellow community members' participation reduces the costs and increases the returns to one's own participation. These appear to be enhanced by mobile technology, which can easily publicize information on protest attendance.

Others have focused on the role of social media, a relatively new technology whose impact on democracy has been the subject of much debate, both in developed and developing countries. Here, Diamond (2010) cautions that technology is "open to both noble and nefarious purposes." For example, alongside potential reductions of communication costs and equalizing effects, there has been much concern surrounding their control by powerful actors and the proliferation of "fake news" (Allcott & Gentzkow, 2017). Here, existing evidence, especially in the context of developing countries, remains limited, though a number of studies are beginning to uncover social media's impact on political mobilization. For example, Enikolopov et al. (2020) study the effect of one popular social network on a wave of political protests in 2011 Russia, using quasi-random variation in the platform's penetration. They detect evidence of a positive causal impact on both the incidence and size of protests, which they argue is driven by reduction in the cost of collective action. In another study, Acemoglu et al. (2018) examine the impact of street protests in Egypt's Arab spring. They find that Twitter activity data is a predictor of protest incidence, suggesting a role for social media in facilitating coordination. Finally, in China, Qin et al. (2017) document a surprisingly large number of posts on China's Sina Weibo microblogging platform discussing politically sensitive topics and corruption allegations and find that the latter is predictive of future corruption charges of specific individuals. Building further on these initial results presents an important area for future research.

When citizens lack an effective mechanism for expressing their political preferences, governments face weakened incentives to deliver policies that will benefit them. This underlines the importance of both the accessibility and integrity of elections, an area to which ICTs have also been applied. For example, Fujiwara (2015) documents an important barrier to political participation that disproportionately affects the most vulnerable: illiteracy. In Brazil, he describes how this meant ballots were often erroneously completed and had to be discarded. As a result, when an electronic system offering guidance and visual aids was implemented in the late 1990s, the author reveals that millions of citizens, particularly those with lower levels of education, were de facto enfranchised. The implications for both political and health outcomes are striking: the vote-share of left-wing parties increased, which in turn translated into higher government expenditure on healthcare and improved service utilization and outcomes. More specifically, uneducated mothers received more prenatal visits, and there was a lower incidence of low-weight births.

In 2012, it was estimated that under 40% of elections in low- and middle-income countries were free and fair, a problem often attributed to lack of information (World Bank, 2016). Here, it has been shown that technology-enabled monitoring stands to make an important contribution. For example, Callen and Long (2015) study the issue of aggregation fraud, where votes are altered in the process of being added up across polling stations. In an Afghani election, they experimentally announce a "photo quick count," where provisional results posted at individual stations are photographed and compared to post-aggregation figures. This was found to provoke a 60% reduction in theft of election materials by candidate representatives and a 25% reduction in votes for politically powerful candidates. In Callen et al. (2016), the authors conduct an experiment to evaluate a similar photo technology in a Ugandan election. They detect similar evidence of reduced illegal practices and a fall in the vote share for the incumbent. Together, these studies make clear that photo quick counts can be a simple yet effective method of improving electoral integrity, which the authors furthermore emphasize are well-suited to being scaled via citizen-based implementation as mobile access expands. Relatedly, Aker et al. (2017) study the use of SMS messaging for the reporting of electoral irregularities in Mozambique, detecting a 5% increase in political participation as a result. These results underline the potential of ICTs to empower citizens in reinforcing the accountability of vital democratic processes.

Political participation and electoral integrity are the backbone of a functioning democracy. Research in economics has documented how these have often fallen short in developing countries, particularly in ways that disproportionately hurt the most vulnerable. The studies discussed above have highlighted some important successes in terms of how technologies have been harnessed to tackle these problems, which in the case of Fujiwara (2015) translated into tangible impacts on political outcomes and household welfare. However, we are left with a number of important unanswered questions, especially as regards their long-run effectiveness.

In particular, the use of ICTs to enhance political engagement and improve election monitoring will only be effective insofar as these cannot be subverted by powerful interests.

7 Health

In developing countries, access to healthcare is still a major problem faced by a large share of the poor, especially in rural areas. This constrains both living standards and productive capacity. Technology may offer solutions to both sides of the problem by expanding access to quality healthcare.

7.1 Improving the Quality and Delivery of Healthcare Services

For centuries, landmark innovations in health technology have generated drastic improvements in living standards and life expectancies, which in turn enhance the stock of human capital. In this way, they are vital to economic development. However, there remain vast global inequalities in health, with at least half the world's population still lacking access to essential health services (WHO, 2017). In developing countries, households experience worse access to immunization, professional birth attendants and contraception and suffer disproportionately from HIV, malaria, pollution-related diseases, and unsafe drinking water (Landrigan et al., 2018; UN, 2019). Overcoming these disparities is at the heart of Sustainable Development Goal (SDG) 3, to "ensure healthy lives and promote well-being for all at all ages", as well as SDG6, to "ensure availability and sustainable management of water and sanitation for all" (UN, 2020).

Health technologies targeting issues from which poor populations suffer disproportionately are vital in the fight against global health inequality. One such example is soil-transmitted helminth infections or worms, with a quarter of the world's population estimated to be at risk (Landrigan et al., 2018). In their landmark paper, Miguel & Kremer (2004) evaluate a program in which Kenyan primary school students were experimentally administered deworming drugs. They detect substantial health benefits and reductions in school absenteeism, effects which also spilled over to the non-treated. A decade later, Baird et al. (2016) estimate significant long-run impacts. In particular, men that had been treated as boys were found to work an additional 2.5 hours per week and spend more time in nonagricultural self-employment and were more likely to work in manufacturing. Similarly, women were more likely to have attended secondary school and worked more in nonagricultural self-employment and growing cash crops, rather than in traditional agriculture. Together, these studies indicate a link between healthcare technologies and the welfare improvements and transition out of agriculture that are intrinsic to our understanding of development.

Other studies have focused on health technologies for combatting malaria, a leading cause of death in the developing world that is both curable and preventable (WHO, 2019). For example, Bleakley (2010) studies anti-malaria campaigns in the United States in the early twentieth century and in Brazil, Colombia, and Mexico in the mid-twentieth century, made possible by critical scientific discoveries. These provoked significant declines in the incidence of the disease. Moreover, the author finds that cohorts more exposed to eradication efforts as children had higher literacy and incomes in their adult lives, which he attributes to a positive effect on labor productivity. Lucas (2010) also examines malaria eradication campaigns in his study of Paraguay and Sri Lanka, which effectively eliminated malaria in both countries. The author estimates that this in turn had a positive effect on educational attainment and literacy in both countries.

Despite many successful efforts to eradicate malaria and worms, these and other critical health problems remain endemic in certain parts of the world. In the case of malaria, 2018 saw an estimated 228 million cases worldwide, with almost 85% of the global burden concentrated in just 19 countries in sub-Saharan Africa and India (WHO, 2019). In order to generate further progress, it is clear that more investment in the dissemination of medications and insecticides, public health, and hygiene and health education will be required. What remains unclear, however, is whether applications of new technologies such as ICTs can support these vital functions.

Optimism regarding the application of ICTs to improve the efficiency and quality of health provision has been particularly strong in the case of rural areas, where existing services are most limited. For example, Lemay et al. (2012) study a small-scale intervention in which an SMS-based mobile network was established between community health workers (CHWs) in rural Malawi. They report improved information sharing between CHWs and district staff, for example, allowing them to report stockouts, ask medical questions, and manage emergency cases. In another study of rural Guatemala, Martinez et al. (2018) evaluate a smartphone application designed for supporting traditional birth attendants as they examined patients. These care providers are heavily relied upon by local communities but typically have limited support and linkage with public hospitals. The application was found to increase referral rates for pregnancy and childbirth complications. These positive initial results suggest that ICTs' proven benefits for enhancing connectivity and information in markets might be equally crucial for healthcare services.

The use of drones for the delivery of medical products, such as blood, vaccines, and insulin, represents another flagship example of technology's potential for improving healthcare provision. The company spearheading these efforts is Zipline, who in 2016 established the world's first and only national scale commercial medical drone delivery service in Rwanda, a country whose geography is notoriously hard to navigate (McCall, 2019). In 2019, Zipline delivered over 65% of Rwanda's blood supply outside of the capital (Robotics and Automation News, 2019).

Health technologies are also being used to deal with emerging challenges related to the COVID-19 outbreak. This includes the use of drones in the distribution of medical supplies, a service Zipline plans to offer (Zipline, 2020), as well as to broadcast social distancing regulations and monitor people's compliance, as has been carried out in Rwanda and India (Uwiringiyimana, 2020; Jamkhandikar, 2020). Furthermore, ICT applications are enabling virtual doctors' appointments and the dissemination of COVID-related information, for example, in mass government text messages (Flood, 2020). ICTs will also be vital in global efforts to track the virus's spread, echoing their use in Sierra Leone during the Ebola outbreak (O'Donovan & Bersin, 2015).

Overall, we have much to thank health technology for in terms of the life expectancies we enjoy today. Their harnessing to tackle the health problems suffered disproportionately in developing regions is also helping to slowly chip away at the vast inequalities in health outcomes that persist between countries. Research in economics has furthermore demonstrated the presence of knock-on effects these can have on education, incomes, and welfare. It is widely accepted that further progress will hinge on basic investments into public health and sanitation infrastructures and proven health technologies. However, much less is known about the potential contribution that applications of new technologies, such as ICTs, can make to these efforts. Indeed, Sundin et al. (2016) document that most of these initiatives fail to progress beyond the pilot stage but emphasize the importance of social and economic factors over technological ones. For example, they describe how health-related mobile phone applications have been limited by patients' inability to charge their phones. As such, they argue that health technologies must be supported by thorough knowledge of sociocultural dynamics and business practices in order to be able to effectively scale.

8 Conclusion

Development and growth are fundamentally about the spread of innovations and ideas. In this chapter, we reviewed a range of areas of work which can help to enhance this spread. A key insight that we have gleaned is that the same ingenuity that has driven human progress since time immemorial will also be required to tackle the externalities that have been engendered by that progress.

Development engineering is fundamentally about harnessing innovations and bringing them to bear on development challenges, but that is not where the subject stops. Indeed, much of the value of recent work is concerned with how alliances between technologists, engineers, economists, and policymakers can enable the design of interventions that work at scale in developing countries in particular. This is easier said than done as there is often a tougher and more complex set of constraints to overcome in scaling technological innovation in developing versus developed countries. These are not just related to the way markets work but also to some fundamental barriers associated with the design of regulations and the way that political and other institutions work. In this sense, development engineering is truly a field that bridges between science and social science.

The types of challenges faced by developing countries are not only large in magnitude, but also extremely urgent. There are close to a billion people in extreme poverty and close to a billion without electricity, with nearly all growth in energy demand over the next few decades expected to stem from developing countries (Wolfram et al., 2012). With extremely young populations, there is the challenge of how millions of young women and men will find meaningful work (Alfonsi et al. 2020). There also exists a wealth of unanswered questions regarding the relationship between growth and the environmental damages that accompany it, with evidence that these may be more acute in the world's poorer regions (Burgess et al., 2017; Greenstone & Jack, 2015). If we are serious about eliminating extreme poverty by 2030 and about shielding more vulnerable populations from the effects of climate change, and pollution, then we cannot sit on our hands.

This chapter has begun to point to some areas where technology can play a critical role in addressing the major development challenges which are enshrined in the SDGs, but it is still just a start. In many ways, it is more of a call to arms for a diverse set of actors from the private sector, civil society, academia, and government to come together to maximize the positive role that different technologies can play in the process of development. Only in this way can we generate the innovations and productivity improvements needed to keep humans on a trajectory to higher living standards while ensuring that negative externalities generated by this growth do not block the path to progress.

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