DIRECTIONS IN DEVELOPMENT
Communication and Information Technologies

The Jobs of Tomorrow

Technology, Productivity, and Prosperity in Latin America and the Caribbean

Mark A. Dutz, Rita K. Almeida, and Truman G. Packard

WORLD BANK GROUP

The Jobs of Tomorrow

DIRECTIONS IN DEVELOPMENT
Communication and Information Technologies

The Jobs of Tomorrow

Technology, Productivity, and Prosperity in Latin America and the Caribbean

Mark A. Dutz, Rita K. Almeida, and Truman G. Packard

WORLD BANK GROUP

1818 H Street NW, Washington, DC 20433
Telephone: 202-473-1000; Internet: www.worldbank.org

1 2 3 4 21 20 19 18

ISBN (paper): 978-1-4648-1222-4
ISBN (electronic): 978-1-4648-1223-1
DOI: 10.1596/978-1-4648-1222-4

Cover photos: ©istockphoto.com. Photographers (left to right): Cyano66, danchooalex, Zapp2Photo, skynesher, Leonid Eremeychuk, and Vertigo3d.
Cover image design: Florencia Micheltorena
Cover design: Debra Naylor / Naylor Design Inc.

Library of Congress Cataloging-in-Publication Data has been requested.

Contents

Boxes

Figures

Maps

Tables

Foreword

In the first decade of the 21st century, the Latin America and the Caribbean region achieved strong growth with greater shared prosperity. Between 2000 and 2014, the region reduced poverty from 43 to 23 percent. For the first time, more people were in the middle class than those living in poverty. Now, all countries face the challenge of sustainably expanding these social achievements based on productivity growth. That's why increasing productivity needs to become a top priority by adopting new-to-the-firm technologies in ways that both improve the job prospects of lower-skilled workers and increase the incomes of the poorest.

To design development policies, we need an understanding of the impact of new technology adoption on inclusive growth—growth that improves the job prospects of lower-skilled workers. This is even more important given the new wave of digitalization and automation that is rapidly altering many economies around the world. One of the key findings presented here is that lower-skilled workers can, and often do, benefit from adoption of productivity-enhancing technologies biased toward skilled workers. Concerns that lower-skilled workers will be replaced by new technologies are often misplaced in practice. With a supportive business environment and procompetitive enabling policies and institutions, higher firm output based on increased productivity can expand sufficiently to increase jobs across all tasks and skill types within adopting firms—as long as low-skill occupations are not predominantly automated and displaced by the new technologies. Cross-country studies highlight additional ways that digital technology adoption can fuel inclusive growth, including lowering the fixed costs of exporting through online trading platforms, reducing mobility costs for workers in poorer countries, and increasing labor market efficiency through Internet-enabled worker-firm job matches.

This research highlights the critical role of three types of policies supporting growth and jobs from technology adoption. First, technology diffusion policies should ensure that all businesses have access to the latest global technologies at competitive prices. Second, product market policies should ensure that adopting businesses have the incentives and opportunities to grow. Third, education, skill, and labor market policies should ensure that workers are equipped with the right skills and that businesses can flexibly deploy workers to meet changing business needs. Implementation of these policies will help ensure that technology adoption has a positive impact on both productivity and workers in this new technological age.

Jorge Familiar
Vice President
Latin America and the Caribbean Region
The World Bank

Acknowledgments

This book was prepared by Mark A. Dutz, Lead Economist, Macroeconomics, Trade and Investment Global Practice (task team leader [TTL]); Rita K. Almeida, Senior Economist, Education Global Practice (co-TTL); and Truman G. Packard, Lead Economist, Social Protection and Jobs Global Practice (co-TTL) of the World Bank Group. Robert D. Willig (Professor Emeritus, Princeton University) helped immensely in the formulation of the ideas underlying the regional study proposal, this book, and the associated background studies. Solid research assistance was provided by Jon Mallek.

The work was conducted under the general guidance of Carlos Vegh, Chief Economist of the Latin America and the Caribbean Region of the World Bank Group, and Daniel Lederman, Deputy Chief Economist. It benefited from funding from the World Bank's Latin America and the Caribbean Chief Economist's Office, under the regional study, "Digital Technology Adoption, Skills, Productivity, and Jobs in Latin America."

The book builds on an extensive set of background research studies prepared for this regional study (see appendix A). The team is grateful for helpful comments from Marialisa Motta, Margaret Grosh, and Reema Nayar, Practice Managers of the Finance, Competitiveness, and Innovation; the Social Protection and Jobs; and the Education Global Practices, respectively, as well as from the authors of all the background papers, who provided useful comments throughout the book's preparation process. Special thanks go to Omar Arias, Paulo Bastos, and Mary Hallward-Driemeier, who provided useful guidance and advice for the book. The team also thanks Erhan Artuç, Miriam Bruhn, Kumud Ghimire, Siddhartha Raja, Rita Ramalho, Indhira Santos, Marc Schiffbauer, and Joana Silva. We also thank participants in the World Bank Group's authors' workshop in Washington in October 2016; the American Economic Association's invited session in January 2017; and the Latin American and Caribbean Economic Association's invited session in October 2017 for their comments and suggestions.

About the Authors

Mark A. Dutz is Lead Economist in the Macroeconomics, Trade, and Investment Global Practice of the World Bank. He is responsible for work on productivity growth and its interaction with poverty reduction and shared prosperity. He has authored policy papers on innovation, productivity, knowledge-based investment, biotechnology, information communication technologies, climate change, competition, investment, and trade policies, and their linkages with growth and inclusion. He is co-editor of *Making Innovation Policy Work: Learning from Experimentation* (2014) and *Promoting Inclusive Growth: Challenges and Policies* (2012), and he is lead author of *Jobs and Growth: Brazil's Productivity Agenda* (2018) and *Unleashing India's Innovation: Toward Sustainable and Inclusive Growth* (2007). Dutz has worked at the World Bank since 1990, and has experience in all regions and in the Office of the Chief Economist. He has also worked with Compass Lexecon, Inc., the Turkish State Minister of Economic Affairs and Treasury, and the European Bank for Reconstruction and Development. In addition, he has been a consultant for the Organisation for Economic Co-operation and Development, the World Trade Organization, the World Intellectual Property Organization, and Canada's Networks of Centres of Excellence. He has taught at Princeton University and has published articles in journals and monographs on applied microeconomics, including on international trade, competition and innovation, and public policy toward network industries. Dutz holds a doctorate in economics from Princeton University and a master's in public affairs from Princeton's Woodrow Wilson School of Public and International Affairs.

Rita K. Almeida has worked for the World Bank since 2002, where she has been leading policy dialogue in Latin America and the Caribbean, Eastern Europe, and the Middle East and North Africa. Before joining the Bank's Education Global Practice, she worked on the Global Knowledge team of the Social Protection and Jobs Global Practice, and she was Research Economist in the Development Economics Department. Almeida's main areas of expertise include education and skills development policies, labor-market analysis, activation and graduation policies for the most vulnerable, labor market regulations and social protection for workers, firm productivity and innovation policies, public expenditure reviews, and the evaluation of social programs. Rita has served as lead on several World Bank publications, including *The Right Skills for the Job? Rethinking*

Training Policies for Workers and *Toward More Efficient and Effective Public Social Spending in Central America*. Her work has been covered in the news media, featured in leading world economic reports, and published in top general interest and specialized economic journals, including *The Economic Journal*, *American Economic Journal: Applied Economics*, *Journal of International Economics*, *Journal of Development Economics* and *Labour Economics*. Almeida earned her doctorate in economics from the Universitat Pompeu Fabra in Barcelona. Prior to joining the Bank, she worked in an investment bank and taught at the Portuguese Catholic University. She has been a Fellow of the Institute for the Study of Labor since 2003.

Truman G. Packard is a Lead Economist in the World Bank's Social Protection and Jobs Global Practice. He has worked at the World Bank since 1997, providing advisory assistance to governments in emerging markets on how to improve labor regulation and social security to create jobs. Packard has worked with countries in Latin America, Central Europe, and East Asia; he currently focuses mainly on Brazil and Indonesia. Trained as a labor economist, he holds a doctorate from the University of Oxford in the United Kingdom. His published work focuses on how labor law and social insurance programs—retirement benefits, unemployment insurance, and health coverage—affect peoples' incentives to work and save.

Executive Summary

Over the past decade, many countries in the Latin America and the Caribbean (LAC) region have achieved strong growth and poverty reduction—but in an unsustainable manner, through a commodity boom. Now that the commodity tailwinds have receded, Latin American countries face the challenge of securing and expanding their needed social achievements sustainably, through productivity growth enabled by new technologies.

Although the adoption of new technologies enhances long-term growth and average per capita incomes, its impact on lower-skilled workers is more complex and merits clarification. Concerns abound that new machines and other forms of advanced technologies developed in high-income countries would, if adopted by firms in the LAC region, inexorably lead to job losses for lower-skilled, less-well-off workers and exacerbate poverty. Conversely, there are countervailing concerns that policies intended to protect jobs from technology advancement would themselves stultify progress and depress productivity.

This book squarely addresses both sets of concerns with new research showing that adoption of information and communication technologies (ICT) offers a pathway to more inclusive growth by increasing adopting firms' output, with the jobs-enhancing impact of technology adoption assisted by growth-enhancing policies that foster sizable output expansion. "Inclusive growth" in this book is growth that improves the job prospects of lower-skilled workers. The research reported here uses economic theory and multicountry LAC data to demonstrate that lower-skilled workers can, and do, benefit from adoption of productivity-enhancing technologies biased toward skilled workers, such as ICT. The use of the Internet allows firms to benefit by increasing productivity in areas ranging from supplier and customer relations to recruiting and training, while use of production, client management, and other software further supports production planning and processes, product pricing, and related business tasks; and as information becomes more available across the firm, workers can become more sophisticated and make better decisions.

The inclusive jobs outcomes arise when the effects of increased productivity and expanding output overcome the substitution of technology for workers. The impacts on lower-skilled workers occur through both substitution and output effects. Although the substitution effect replaces some lower-skilled workers with new technology and more highly skilled labor, the output effect can lead to an increase in the total number of jobs for less-skilled workers. After all, as the adopted technology increases the firm's productivity, it enables reductions in variable costs and product prices that generate an expansionary output effect. Critically, output can increase sufficiently to increase jobs across all tasks and skill types within adopting firms, including jobs for lower-skilled workers, as long as lower-skill task content remains complementary to new technologies and related occupations are not predominantly automated and replaced by machines. It is this channel for inclusive growth that underlies the power of procompetitive enabling policies and institutions—such as regulations encouraging firms to compete, policies supporting the development of skills that technology augments rather than replaces, and institutions that are capable and accountable—to ensure that the positive impact of technology adoption on productivity and lower-skilled workers is realized.

The size of the output expansion effect from the use of better technologies and its impact on lower-skill jobs depend on the competitive market environment in affected industries. Firms producing tradable output with effective distribution channels and flexible input supplies predictably will expand vigorously in response to the rise in productivity attributable to technology adoption. Firms in competitive markets will be further impelled to reduce prices as their costs decrease through the use of more productive technologies, thereby stimulating additional demand and output. Firms operating in countries with education systems that produce more abundant and easily accessible skills complementary to technology will also adapt and expand faster. These output expansion effects are more apt to lead to greater demand for less-skilled workers if the production and distribution tasks required for output expansion are not largely fixed costs, so that the output expansion requires the performance of tasks and generates demand for more workers. Positive economy-wide inclusive effects are also more likely, to the extent that less-well-off workers can acquire throughout their lives skills that are complementary to the adopted technologies. The inclusive effects are also more likely to occur where expanding firms can flexibly hire and reallocate workers in response to market opportunities, so that workers displaced within exiting or contracting firms are able to move and find similar or better employment opportunities in expanding firms within their existing or other industries.

Country studies on Argentina, Chile, Colombia, and Mexico find inclusive growth due to the increased productivity impact of adoption of ICT and the resulting positive output effects on lower-skilled jobs. In Argentina, manufacturing firms that invested in ICT capital witnessed larger job increases for low-skilled as well as high-skilled workers in high-growth firms through strong output expansion effects that drive inclusive growth. In Colombia, manufacturing firms' use of high-speed broadband directly increases demand for laborers and lower-skilled production workers, as well as higher-skilled professional workers. In Mexico, a greater share of labor in manufacturing firms using the Internet results in an increased number of blue-collar workers, even though the increase is larger for white-collar workers. In Chile, the use of complex (production, client management, and other business) software increases the number of low-skilled production workers, while no significant change is observed for skilled production workers and managers. These studies are partial equilibrium analyses at the firm level and do not address the impact on total employment of possible job losses or exits among less-efficient nonadopting firms. However, the Brazil studies on staggered Internet rollouts, examining effects at the municipal level, do reflect general equilibrium effects within municipalities, including firm downsizing and exits and their economy-wide feedback effects on employment in each directly affected municipality. The sectoral impacts study with both contemporaneous and lagged effects finds no positive economy-wide net effect on the total number of formal jobs in the directly affected municipality, while the tasks and labor policies impact study finds an overall negative impact on employment in the short term, with a larger negative impact for routine, manual tasks. This is to be expected in a country such as Brazil, where opportunities for efficient global output expansion have been more limited in light of its policy distortions, including high trade and other product market expansion barriers. Importantly, the sectoral impacts study with lagged effects finds that aggregate employment shifts from sectors with limited expansion opportunities (wholesale and retail trade, public administration, and publicly owned utilities, which jointly made up almost half of the formal workforce in 2010) to sectors with more output expansion opportunities (such as manufacturing, transport, and finance and insurance). In Brazil's manufacturing sector, Internet access with lagged effects induces positive job and wage effects, not only for high-skill occupations but also for medium-skill jobs. And in Mexico, the positive effects from technology adoption on jobs in manufacturing are much larger than the effects in the less-tradable commerce sector. The country studies are able to show causal effects rather than correlations by focusing on drivers that are exogenous to output and the demand for jobs, skills, and labor earnings. The effects of technology adoption on productivity and job-related outcomes are identified in a number of the studies from plausibly exogenous changes in the availability of ICT or in its quality over time and space. These exogenous variations are exploited as instruments for the otherwise possibly endogenous firm-level use of ICT.

Cross-country studies highlight two additional channels from ICT adoption to inclusive growth: a market access effect that works in favor of smaller firms, and a worker mobility effect that reduces the cost of information about job opportunities. With respect to market access, an increase in the share of online exports across countries is found to be associated with a decline in the wage skill premium, thereby reducing wage inequality. This effect is driven by a decrease in the fixed costs of exporting due to online trading platforms that level the playing field between small and large firms for access to international markets. International transactions over the Internet disproportionately benefit smaller firms that also tend to hire relatively more lower-skilled workers, allowing them to reach new consumers across the world and reap the accompanying productivity gains. With respect to mobility, workers face higher mobility costs in poorer countries. Access to the Internet is associated with lowering workers' costs to move across sectors and regions, increasing labor market efficiency by allowing better employer-employee matches.

Policies that enable technology diffusion and product market competition are critical to ensuring that the positive impact of technology adoption on inclusive growth is realized. The first priority for firms in the LAC region are policies to facilitate technology diffusion, adoption, and use, including policies to support the rollout of faster Internet service at more affordable prices and reduce the high tariffs and taxes on digital technology business tools to enable digital technologies generally. Current adoption of digital technologies across the LAC region is highly heterogeneous and lags behind comparators in the Organisation for Economic Co-operation and Development, showing that there is still much potential for additional adoption in LAC and for the accompanying benefits of productivity and inclusive growth. Second, product market policies should enhance opportunities and sharpen incentives for output expansion in response to the productivity increases that technology adoption yields. Enabling product market policies include boosting the intensity of local market competition, further opening external trade, improving access to finance, and supporting management quality upgrading.

In addition, education, skills, and labor market policies should ensure that the skills provided through the formal schooling system, and those acquired throughout life in the labor market, are supporting the adoption and use of digital technologies and are available to firms when they need them. The Brazil tasks and labor policies impact study shows that more-technology-intensive industries reduce their relative reliance on employment to conduct more routine tasks, thereby shifting the skills composition of the jobs they create toward nonroutine and more cognitive and analytical tasks. Among the set of nonroutine tasks, communication and interpersonal skills are in particularly high demand. After the adoption of complex software by firms in Chile, firms also increase their investment in training of ICT-specific technical skills.

Evidence also shows that the stringency of labor market regulations matters for the skills demanded in the labor market. Evidence from Brazil suggests that more stringent enforcement of labor market regulations, contrary to policy intentions, disproportionately benefits more-skilled workers—because firms react to labor policies by substituting technologies and occupations with higher-level cognitive and nonroutine tasks for occupations that previously performed mostly routine tasks. A cross-country study for this book finds that a higher statutory minimum wage is positively associated with higher digital technology use by firms. This study also finds that business use of digital technologies is lower in countries that require firms to follow more burdensome procedures to dismiss workers.

Importantly, procompetitive technology diffusion, product-market, skills, and labor policies that are often lacking in the LAC region also help create a business environment in which firms have stronger incentives and capabilities for investing in technology adoption. Firms invest in productivity upgrading through technology adoption when faced with the market discipline, profit rewards, and capabilities with which to do so. The same business environment characteristics that support sizable output expansion and more inclusive growth—including sufficient competition in investment in and delivery of ICT services to adopt these technologies; product and input market competition; alignment of higher education offerings with labor market needs; and high-quality management skills—also provide incentives for and enable firms to invest in technology adoption. Finally, while the output expansion effect—collectively enabled by technology adoption, product market, skills, and labor policies—is clearly a desirable pathway for making productivity gains inclusive, redistributive fiscal policies to support displaced workers and those unable to find new jobs are a complementary pathway to inclusion facilitated by the overall efficiency benefits of technology adoption.

Abbreviations

AI	artificial intelligence
ATM	automated teller machine
DAI	Digital Adoption Index
ICT	information and communication technology
IT	information technology
LAC	Latin America and the Caribbean
OECD	Organisation for Economic Co-operation and Development
PISA	Programme for International Student Assessment
PPP	purchasing power parity
SBTC	skill-biased technological change
TFP	total factor productivity

CHAPTER 1

Introduction

Policy makers throughout Latin America and the Caribbean (LAC) would like to understand how best to leverage recent and ongoing global, business-relevant technologies to support productivity upgrading with inclusion. During the first decade of the twenty-first century, growth and poverty reduction in most LAC countries have been driven by an unsustainable commodity boom rather than by sustainable productivity increases. Recently rising levels of unemployment and poverty in a number of countries raise the issue of whether more inclusive growth can be promoted more sustainably through productivity upgrading. A number of important questions need to be answered. Under what conditions do firms have an incentive to adopt better technologies, and what are the overall impacts of technology adoption on productivity, the number of jobs, the types of skills demanded, and the wages offered to workers? Are the level and pace of technological change having a significant impact on the jobs available to the workforce and the types of skills demanded by businesses in LAC? Do labor market regulations and social protection institutions help or constrain technology adoption in the region?

This book discusses technology adoption and its impact on inclusive growth through productivity, jobs, types of skills, and wages in Latin America. Although it investigates impacts across all four of these outcomes, the book focuses particularly on two dimensions of inclusive economic growth: overall job growth, and how less-skilled, less well-off workers can also benefit from technology adoption. Although employment opportunities for less-skilled workers, supported by on-the-job training and continuous education, are clearly a desirable pathway for making technological gains inclusive, complementary pathways—such as redistributive fiscal policy to support displaced workers and those unable to find a job, given that the overall efficiency benefits are positive—should also be explored.

The penetration of digital technologies during recent years in several middle-income LAC countries has created a learning opportunity that yields valuable policy insights into how technology adoption can create a pathway to inclusive growth. By "inclusive growth," this book means growth that improves the job prospects of lower-skilled workers.[1] The book and background technical studies that form its analytical foundations are focused on the production side of the economy. The impacts on job creation that the studies explore are *additional* to positive impacts of technology adoption on consumer welfare through lower prices and greater variety of product choices.[2] Digital technologies in this book encompass different types of information and communication technologies (ICT) used by businesses, from basic Internet and high-speed broadband Internet to the use of production, client management, and other business software packages and the use of "big data" to better understand consumer tastes and better tailor goods and services to identified needs. Mechanisms through which increasing use of ICT raises firm-level productivity include, among others, lowering costs and adding value to process and production design, to relations with suppliers and customers, to recruiting and training, and to the integrated management of core business processes. The book's focus on five middle-income countries—Argentina, Brazil, Chile, Colombia, and Mexico—is dictated both by the availability of high-quality data and by the differentially paced penetration of digital technologies in the LAC region.

The evidence and conclusions presented in this book are relevant for lower-income countries in the LAC region and for helping to understand the impacts of the adoption of other types of technologies beyond ICT that reduce costs and expand firms' sales opportunities. The conceptual framework underpinning the analysis models the impact of the adoption of ICT at the firm level—with ICT representing any technology that, in combination with higher-skilled workers, raises firm productivity and reduces variable costs of production. The assumption that technology in combination with more skilled workers increases firm productivity is known as "skill-biased technological change." It is related to the fact that skilled labor is relatively more abundant in developed than in emerging economies, given that most technologies are still generated in developed economies. The adoption of technology also requires firms to incur fixed costs to install the technology, train their workers in its use, and realign the skill mix of their workforces. An important conclusion of this conceptual framework is that the impacts that technology adoption will have on the demand for workers and types of skills firms seek are largely empirical matters that can be informed by the framework of economic theory.

Channels Linking Technology to More Inclusive Growth

This book investigates three channels linking technology adoption with more inclusive growth: a sufficiently large firm-level output expansion effect, a market access effect that increases smaller firms' relative demand for lower-skilled workers, and a worker mobility effect that lowers cross-sectoral and cross-regional worker mobility costs through better Internet access.

The hypotheses about the effect of technology adoption on firm productivity and on the jobs and wages of lower-skilled workers associated with output expansion are the most general because they are not restricted to the use of ICT.

They apply to all technologies that raise business productivity and reduce variable costs, including a range of applications of robots and artificial intelligence, 3D printing (additive manufacturing), nanotechnologies and biotechnologies, and new material technologies—as long as lower-skill task content remains complementary to new technologies and related occupations are not completely automated and replaced by machines. All the country-specific studies explore these hypotheses based on available data on ICT. The hypotheses about the effect of technology on market access by firms that favors smaller firms that tend to hire relatively more low-skilled workers and on worker mobility costs are dependent on the adoption of ICT. They are respectively explored in only one cross-country study each. All the studies jointly provide new empirical findings on the extent to which these three channels can create a pathway to more inclusive growth. These findings are important because they debunk the frequent presumption that technology adoption necessarily kills jobs. Box 1.1 summarizes the recurring concern about the impact of firms' technology adoption

Box 1.1 Déjà vu—Preoccupations of and Responses to Perennial Luddites

Radical and rapid change can be uncomfortable. It challenges norms and disrupts routines. Fears that new technologies will replace workers and destroy jobs are no different. Throughout recent history, technological change has been met with pessimism and even catastrophizing. Periods defined by rapid advances in technology tend to stoke fears of "technological unemployment." From the early advances of the Industrial Revolution to the advent of driverless cars today, the idea that new technologies will put people out of work is as recurring as it is controversial (Mokyr, Vickers, and Ziebarth 2015). Despite successive warnings of mass unemployment in the wake of technological change, however, the dire predictions have yet to come about. Nonetheless, each new wave of technological advances is met with similarly dire predictions, insistent that "this time is different."

One of the original and perhaps most dramatic responses to spurts of technological change came during the first Industrial Revolution. Led by Ned Ludd, English weavers stormed factories and destroyed industrial textile machines they were sure would lead to the extinction of work and society's downfall. While those very machines did change industrial manufacturing forever, they did not result in mass layoffs and high levels of long-term unemployment as feared (Vivarelli 2014). Although 98 percent of the labor required to weave cloth was automated, the number of weaving jobs actually increased because demand for the lower-priced cloth more than offset the labor-saving automation (Bessen 2015). Deloitte (2015) finds that technology, in fact, has created more jobs than it has displaced in England and Wales since the mid-nineteenth century. And Alexopoulos and Cohen (2016) find that commercialization of new technologies raised productivity and employment and lowered unemployment between 1909 and 1949 in the United States.

In the United States in the 1950s and 1960s, fears of job displacement in the wake of new technological advances arose again. An investigative piece called "The Automation Jobless"

box continues next page

Box 1.1 Déjà vu—Preoccupations of and Responses to Perennial Luddites *(continued)*

detailed the fear of increasing unemployment, claiming that automation was the second most important worry among Americans, surpassed only by the desire for peace. The fear at the time was not so much that technology would eliminate jobs but rather that technological innovations would not create any new employment (*Time* 1961). These fears grew to such a fevered pitch that President Lyndon Johnson created a task force assigned to seek solutions to the apparently looming crisis. After long and careful deliberation, the National Commission on Technology, Automation, and Economic Progress found that automation, in fact, did not threaten employment. It ultimately concluded that although new technologies might destroy particular jobs, they would not eliminate the need for human work.

In most recent instances of technology adoption, more jobs have been created than were expected. The impact of the automated teller machine (ATM) on the demand for bank tellers is instructive. Even though the ATM replaced cash-handling tasks, the number of full-time-equivalent bank tellers has grown substantially faster than the entire labor force since 2000. Because ATMs allow banks to operate branch offices at lower cost, they have been prompted to open many more branches, creating more jobs: there are more bank teller jobs in the United States now than when the ATM was introduced. Similarly, the number of cashiers has grown since barcode scanners were widely deployed during the 1980s, and the number of paralegals has grown robustly since the introduction of electronic document discovery software for legal proceedings in the late 1990s (Bessen 2015, 2016). More broadly, the employment-to-population ratio in the United States increased remarkably in the second half of the twentieth century, even as women joined the workforce en masse (Autor 2015).

Researching "automation" today—using a machine vilified in the 1961 *Time* article (a computer) to operate an online search engine (Google) that employs tens of thousands of workers in jobs that did not exist two decades ago—yields ominous, yet familiar, results: "Robots will eliminate 6% of all US jobs by 2021, report says" (Solon 2016), and "Technology could kill 5 million jobs by 2020" (Kottasova 2016). The parallels to past periods of rapid technological advancement are uncanny. At least no one is storming Google's headquarters and destroying its servers—yet.

on people's labor market opportunities, and just how polarizing the ensuing debates have been.

The first and most important channel from technology adoption to more inclusive growth is through the additional jobs for less-skilled workers generated by a sufficiently large output expansion effect. Conceptually, the impacts on workers of firms' ICT investments, and any other investments in technologies that reduce variable costs in a skill-biased manner, happen through both substitution and output effects. The substitution effects often work against low-skilled workers. This is what underlies the thinking of the "perennial Luddites" (box 1.1). The most visible immediate effect of the introduction of a skill-biased technology is the replacement of lower-skilled workers in those tasks that are substituted for by the newly adopted technology. However, according to the predictions of the conceptual framework that are tested in the country studies for this book, this replacement does not have to be the case. First, the substitution effect depends on the type of technology adopted and whether it complements skilled or low-skilled labor. Second, the hypothesis underlying the adoption of technologies is that they increase the firm's productivity, enabling a reduction in variable costs and product prices, which—combined with possible increases in product quality, the introduction of new products, and marketing outreach efforts—can generate strong output expansion effects. These output effects can lead to an increase in the total number of jobs created. Critically, output can increase to such an extent that jobs are increased across all tasks and skill types within adopting firms, including not only the highest-skill but also lower-skill jobs. The size of this effect and its impact on lower-skill jobs will depend on the sector and on its business environment, including the extent of competition in the product market. Firms in the tradable sectors are hypothesized to exhibit the greatest output expansion effect on employment in response to the reduction in prices enabled by adopted technologies. This effect occurs because these firms benefit from higher demand in markets made possible by greater regional and international export possibilities. And firms facing greater product market competition are hypothesized to reduce prices more in response to variable cost reductions, also increasing the output expansion effect. These theoretical predictions are the hypotheses that are tested in the country studies.

The country studies underpinning this book show that job growth can be inclusive in the wake of digital technology adoption when supported by procompetitive technology diffusion, product market, skills, and labor policies that jointly create a business environment in which firms have strong incentives and capabilities to expand output. Both productivity and lower-skill jobs increased following digital technology adoption at the firm level in Argentina, Chile, Colombia, and Mexico.[3] The two studies on Brazil and separate studies on Colombia and Mexico explore the impact of new or greater use by businesses of the Internet or high-speed Internet. In Mexico, a greater share of labor using the Internet in manufacturing and services results in an increased number of blue-collar workers.[4] In Colombia, manufacturing firms' use of high-speed broadband directly increases demand for laborers and lower-skilled production workers as well as higher-skilled professional workers. The Argentina study finds that manufacturing firms that invest in ICT capital witness larger job increases for low-skilled as well as skilled workers in high-growth firms, supporting the importance of strong output expansion effects in driving inclusive growth. The Chile study focuses on the impact on workers of firms' use of complex software, specifically production, client management, and other business software, which is quite different from the Internet. It finds that over a six-year horizon this technology increases the number of low-skilled production workers, with no significant change in the number of skilled production workers and managers. The adoption of more complex software in Chile increases the use of routine and manual tasks while decreasing the use of abstract tasks. Importantly, the Brazil studies provide insights at the economy-wide level: while increased Internet access has no net effect on aggregate employment, employment shifts from sectors with more limited expansion opportunities (wholesale and retail trade, public administration, and largely publicly owned utilities, which jointly made up almost half of the formal workforce in 2010) to sectors with more output expansion opportunities (such as manufacturing, transportation, and finance and insurance). In the Brazil study of sectoral impacts, jobs increase for middle-skilled workers only in the manufacturing sector, not in other nontradable sectors such as wholesale and retail trade, where middle-skilled workers lose jobs. And in Mexico, much larger positive effects on jobs are seen in manufacturing than in the less-tradable commerce sector.

The second channel from digital technology adoption to inclusive growth is through a market access effect, working in favor of smaller firms—with lower-skilled workers benefiting disproportionately as a result of online platforms that facilitate smaller firms' access to world markets. The lower fixed entry costs into more distant national and foreign markets that digital technologies enable—brought about, for example, by online trading platforms—allow all adopting firms to benefit from lower trade connectivity costs. Critically, this technology adoption allows smaller firms, which tend to hire relatively more low-skilled workers, to disproportionately benefit from the reductions in fixed costs and thereby access larger markets and reap the accompanying productivity gains. The ability to increase revenues from existing inputs allows these firms to increase wages relative to more skill-intensive firms, thereby reducing the wage skill premium. A cross-country study for this book finds that a 1 percent increase in the share of online exports leads to a 0.01 percent decline in the wage skill premium, reducing wage inequality—with this relationship driven by countries that have a large share of employment in small firms.

The third channel from digital technology adoption to inclusive growth is through a cross-sectoral and cross-regional worker mobility effect, resulting in increased labor market efficiency. Adoption by workers of digital technologies such as better Internet access can reduce labor market frictions by reducing workers' mobility costs across sectors and subnational regions, allowing better employer-employee matches and reducing frictional unemployment. A cross-country study for this book finds that mobility costs are kept high by information asymmetries: the average costs for workers to move across both sectors and subnational regions are about 1.8 times the average annual wage, and are higher in lower-income countries. Countries with higher mobility costs also have higher wage inequality. If workers have better access to the Internet, these costs can be lowered across sectors and sector-regions.

Policies to Enable the Positive Impacts of Technology

Enabling policies are critical to ensuring that the potential positive impact of technology adoption on inclusive growth is realized. The empirical studies underpinning this book clarify how the channels that can, in principle, link technology adoption to inclusive growth in fact play out. Importantly, the studies carried out for this book provide insights into the proactive role policies should play for technology adoption to actually yield more inclusive growth. Three main types of supportive policies, each linked to the business environment, are jointly needed to increase firms' incentives and capabilities to expand output in ways that also improve the job prospects of lower-skilled workers.

First are policies to support technology diffusion, adoption, and use—including digital technology policies to support high-quality and competitively priced Internet rollouts. The Internet is the platform on which digital technologies thrive. Countries can do much more to support low-cost, high-speed Internet access, including procompetitive support of higher-speed broadband rollout regimes. They also should consider reducing the high tariffs and taxes on digital technology business tools to enable digital technologies generally. Current adoption of ICT across the LAC region is highly heterogeneous and lags behind comparators in the Organisation for Economic Co-operation and Development, demonstrating that there is still much potential for significant additional adoption in LAC, and for the expected accompanying productivity gains.

Second, product market policies should enhance opportunities and sharpen incentives for output expansion in response to the productivity increases that technology adoption yields. If total sales were more responsive to adopting firms' price decreases (quality increases and market outreach efforts) due to greater regional and international export possibilities, then output expansion would be even more likely. This output expansion could add significantly to the standard benefits of reducing logistics costs and other interregional and international trade barriers. Additional supportive product market policies include boosting the intensity of local market competition (including lowering entry and exit costs, supported by adequate bankruptcy protection to guard investors' interests if output retraction is necessary), improving access to finance (to purchase required inputs and fund promotion efforts), and upgrading management quality, along with other factors affecting firms' ability and know-how to enlarge production and distribution in response to lower variable costs.

Third, education, skills, and labor market policies are critical to ensuring that the available skills of individuals in the labor market support the adoption and use of digital technologies. The Brazil tasks and labor policies impact study shows that more technology-intensive industries with earlier access to the Internet, across all sectors of the economy, reduce their relative reliance on routine and manual tasks, thereby shifting the skill composition toward more cognitive and nonroutine tasks. Furthermore, among the set of cognitive tasks, technology-intensive industries also increase their use of communication and interpersonal skills in the aftermath of digital technology adoption. The Chile study also shows that the adoption of complex software is positively correlated with increased investment in digital ICT skills for managers. These findings have critical implications for the education and training systems in the region: in the future, as digital technologies further expand, the skills mix needed to succeed in the labor market will significantly change, but most of today's education and training systems are failing to keep up. In particular, the new research shows that workers will need solid higher-order cognitive, technical (ICT), and interpersonal skills. Furthermore, labor market policies also matter for inclusion. A cross-country study for this book looks at the relationship between digital technology adoption and de jure labor market regulations, which are typically more restrictive in the LAC region compared with low- and middle-income countries in other regions. It finds that a higher statutory minimum wage is positively associated with the extent of digital technology use by firms. Conversely, it finds that business use of digital technologies is lower in countries that require firms to follow more burdensome procedures to dismiss workers. The Brazil tasks and labor policies impact study has a related finding: stringent labor regulations particularly constrain the flexibility of firms in hiring lower-skilled workers who perform routine and manual tasks. Importantly, employment protection regulations in Brazil have adverse distributional consequences, with stringent enforcement of regulations affecting lower-skilled workers in routine and manual tasks more negatively. In contrast, appropriate policies should facilitate required cognitive and socio-emotional skill availability to meet the needs of business. They should facilitate firms' reallocation of workers across tasks in response to opportunities offered by technology adoption. They also should facilitate workers' mobility across firms and industries, particularly through support for job-search and business-relevant continuing education and training programs.

This book synthesizes policy-relevant analytical findings to inform an active debate across the LAC region about the impact of technology adoption on jobs and skills. The remainder of this book is organized around the following issues: Chapter 2 provides a succinct context underpinning the importance of fostering productivity with more inclusive growth through digital technology adoption. Chapter 3 lays out the core assumptions and implications of a conceptual framework for technology adoption that realistically assumes that both firms and workers are heterogeneous agents. The conceptual framework is preceded by a brief overview of the academic literature on the impacts of technology adoption for developed economies and the LAC region, with a more extensive survey in appendix B. Chapter 4 discusses new learning from the region on the impacts of technology adoption. The first section of chapter 4 focuses on impacts on productivity, business demand for jobs, types of skills, and wages. The second section of the chapter discusses the impacts on job dynamics and the role of complementary investments in skills. The third section discusses the role of labor market regulations on firms' decisions and jobs outcomes, while the fourth looks at the impacts of technology on firms and workers through trade and labor mobility. Chapter 5 discusses the main policy implications related to improving the broadly defined business environment, including technology diffusion support policies, product market policies, and education, skills, and labor market policies. Chapter 6 concludes by summarizing the main findings and outlining some questions for further research.

Notes

1. The book's focus on the impact of technology adoption on workers, and especially lower-skilled (lower-income) workers rather than on all individuals in the lower part of the income distribution (for instance, all individuals in the bottom 40 percent of the income distribution, according to the World Bank Group's definition of shared prosperity), or on a specific measure of income inequality, is dictated by data availability.
2. For robust measures of the contribution of home broadband to consumer welfare through lower prices and greater variety of product choices during the early years of broadband adoption by U.S. households, see Dutz, Orszag, and Willig (2012). Consumer surplus from the Internet is found to concentrate in broadband services, with the net consumer benefits from home broadband in 2008 on the order of US$32 billion per year.
3. The result of an increase in lower-skill jobs holds across different types of digital technologies.
4. The increase is larger for white-collar workers in manufacturing, and for blue-collar workers in services. There is no evidence of reductions in the number of blue-collar workers in commerce, with the sector exhibiting very low and even nonsignificant coefficients in some of the econometric specifications.

References

Alexopoulos, Michelle, and Jon Cohen. 2016. "The Medium Is the Measure: Technical Change and Employment, 1909–1949." *Review of Economics and Statistics* 98 (4): 792–810.

Autor, D. H. 2015. "Why Are There Still So Many Jobs? The History and Future of Workplace Automation." *Journal of Economic Perspectives* 29 (3): 3–30.

Bessen, James. 2015. *Learning by Doing: The Real Connection between Innovation, Wages and Wealth*. New Haven, CT: Yale University Press.

———. 2016. "How Computer Automation Affects Occupations: Technology, Jobs and Skills." Boston University Law and Economics Working Paper No. 15-49, October, Boston University, Boston.

Deloitte. 2015. "From Brawn to Brains: The Effect of Technology on Jobs in the UK." Deloitte.

Dutz, Mark, Jonathan Orszag, and Robert Willig. 2012. "The Liftoff of Consumer Benefits from the Broadband Revolution." *Review of Network Economics* 11 (4).

Kottasova, I. 2016. "Technology Could Kill 5 Million Jobs by 2020." *CNN Money*, January 18.

Mokyr, Joel, Chris Vickers, and Nicholas L. Ziebarth. 2015. "The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different?" *Journal of Economic Perspectives* 29 (3): 31–50.

Solon, Olivia. 2016. "Robots Will Eliminate 6% of All US Jobs by 2021, Report Says." *The Guardian*, September 13.

Time. 1961. Business: "The Automation Jobless." February 24. http://content.time.com/time/subscriber/article/0,33009,828815-1,00.html.

Vivarelli, Marco. 2014. "Innovation, Employment and Skills in Advanced and Developing Countries: A Survey of Economic Literature." *Journal of Economic Issues* 48 (1): 123–54. https://doi.org/10.2753/JEI0021-3624480106.

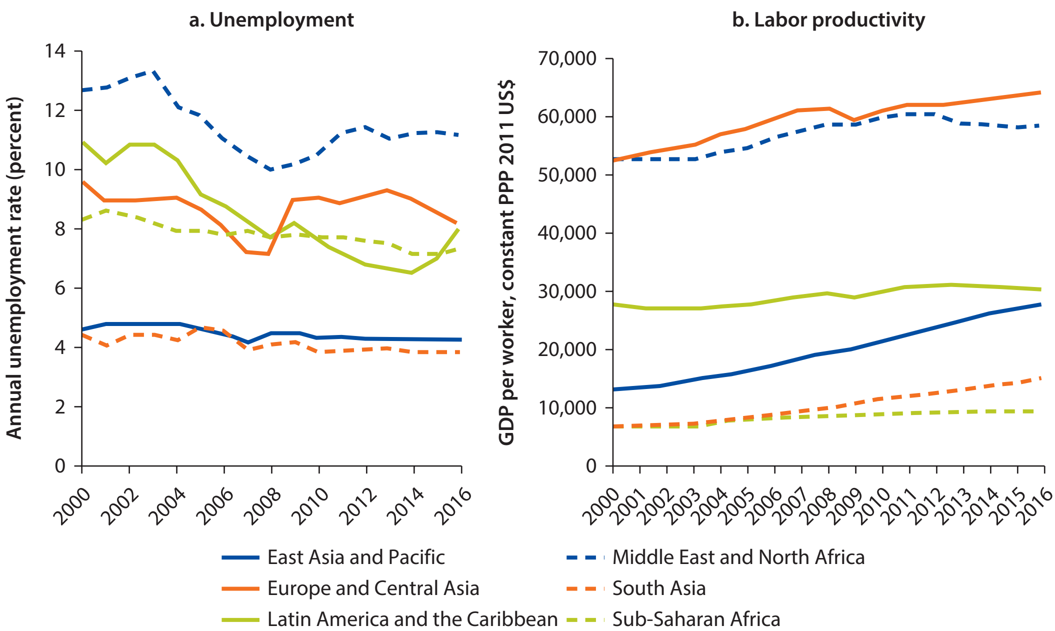
CHAPTER 2

The Need for Productivity-Enhancing Technology Adoption in Latin America and the Caribbean

Slower economic growth and rising unemployment in Latin America and the Caribbean (LAC) are giving new urgency to increases in productivity that create more jobs. Lackluster rates of productivity have long been a worry for policy makers in LAC (Perry et al. 2007; Pagés 2010). However, years of rapid growth fueled by the commodity "super cycle" provided a distraction from underlying structural issues that have long held countries in the region back from realizing their economic potential. The years of easy bounty are now over, pushing the need for productivity gains and job creation to the top of governments' lists of priorities once again (Lederman and Porto 2014; de la Torre et al. 2015). The rate of economic deceleration is by no means uniform across countries. Yet, as concerns about productivity and jobs grow, most governments in the region are facing a combination of monetary and fiscal policy constraints that could affect their capacity for policy maneuvering just as the risks of job losses and extended periods of unemployment are on the rise. It is also increasingly clear that unlike in the mid- and late 1990s, the current deceleration is not a transitory shock but a downward adjustment to a new, lower growth equilibrium absent structural microeconomic reforms. The average increase in unemployment in LAC and in selected study countries makes tapping new sources of productivity growth all the more important, as highlighted in figures 2.1 and 2.2.

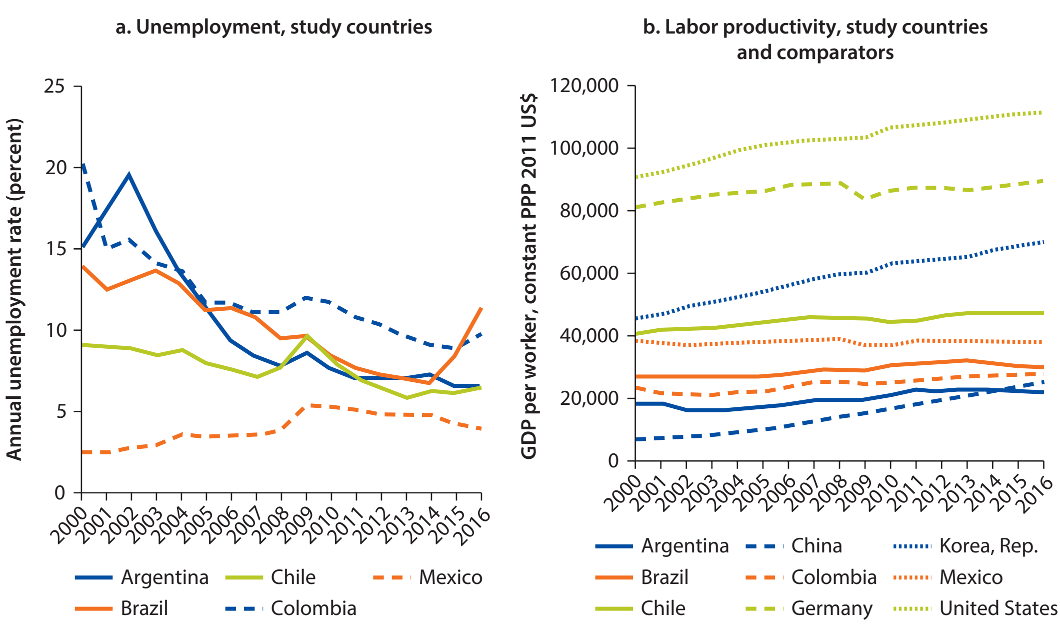
The speed of adoption and extent of Internet use varies enormously within the LAC region. Figure 2.3 shows the varying rates of Internet adoption by households across countries between 2000 and 2013, highlighting the large divergence with the Organisation for Economic Co-operation and Development (OECD) average. Figure 2.4 compares levels of Internet household penetration, together with mobile phone penetration as a comparator, ranking all countries in the region. Although the extent of mobile phone use is higher than 80 percent in most LAC countries, the extent of Internet use still varies greatly,

Figure 2.1 Unemployment and Productivity by Region



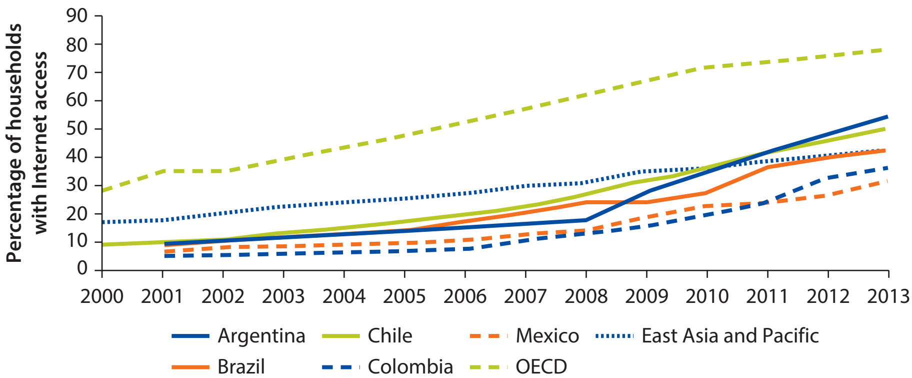
Source: World Bank World Development Indicators.
Note: PPP = purchasing power parity.

Figure 2.2 Unemployment and Productivity in Study Countries and Comparators



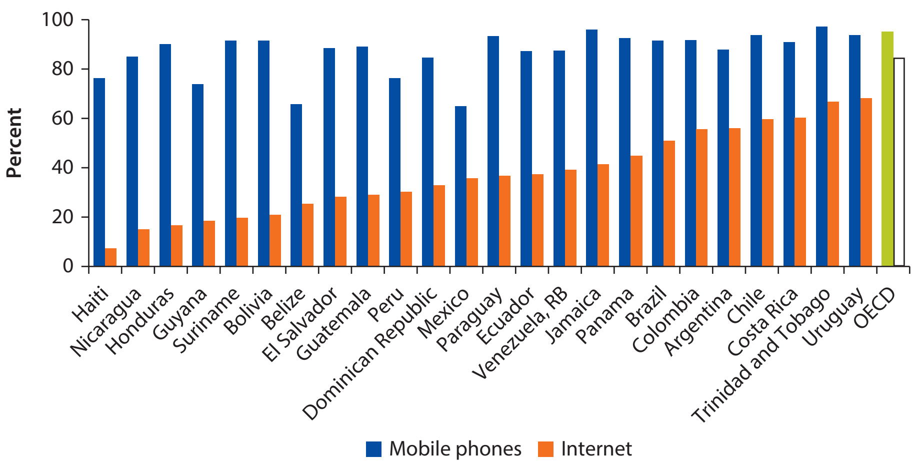
Source: World Bank World Development Indicators.
Note: PPP = purchasing power parity.

Figure 2.3 Rates of Adoption of the Internet across Study Countries



Source: International Telecommunication Union.
Note: OECD = Organisation for Economic Co-operation and Development.

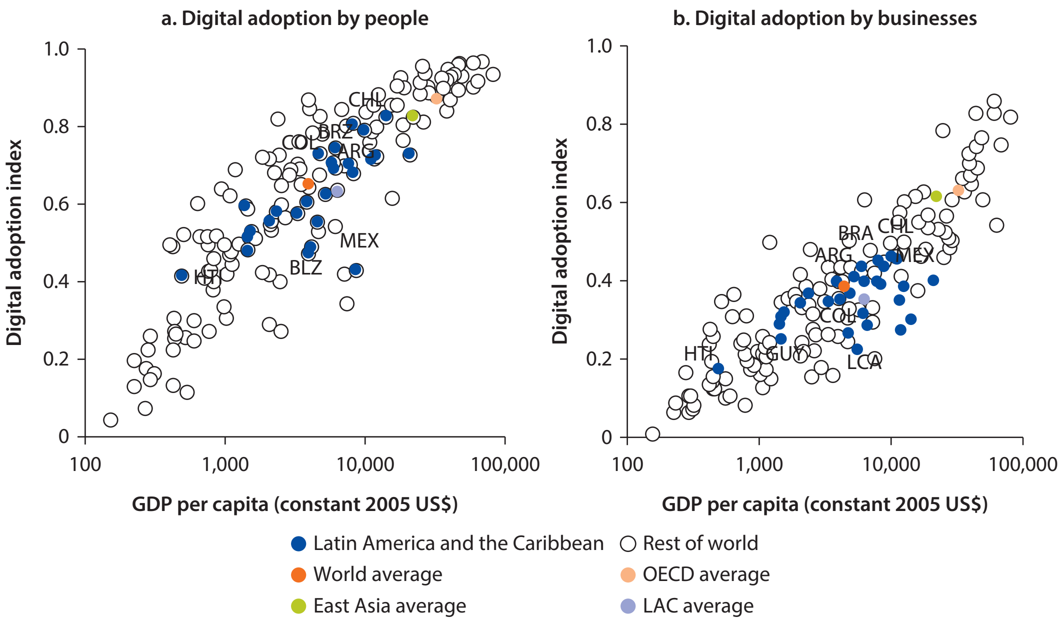
Figure 2.4 Rates of Internet and Mobile Phone Use by Households across Latin America and the Caribbean, Latest Year



Source: International Telecommunication Union.
Note: OECD = Organisation for Economic Co-operation and Development.

from as low as 7 percent and 15 percent of households in Haiti and Nicaragua, respectively, to as high as 68 percent in Uruguay. In OECD member countries, the average rate is already 85 percent. Although closely correlated with wealth and development (represented by GDP per capita), there are substantial differences in digital technology penetration by people and businesses, even across countries in LAC at very similar levels of development, as highlighted in figure 2.5.

Figure 2.5 Digital Adoption in Latin America and the Caribbean Is Still Far from the East Asia and OECD Averages

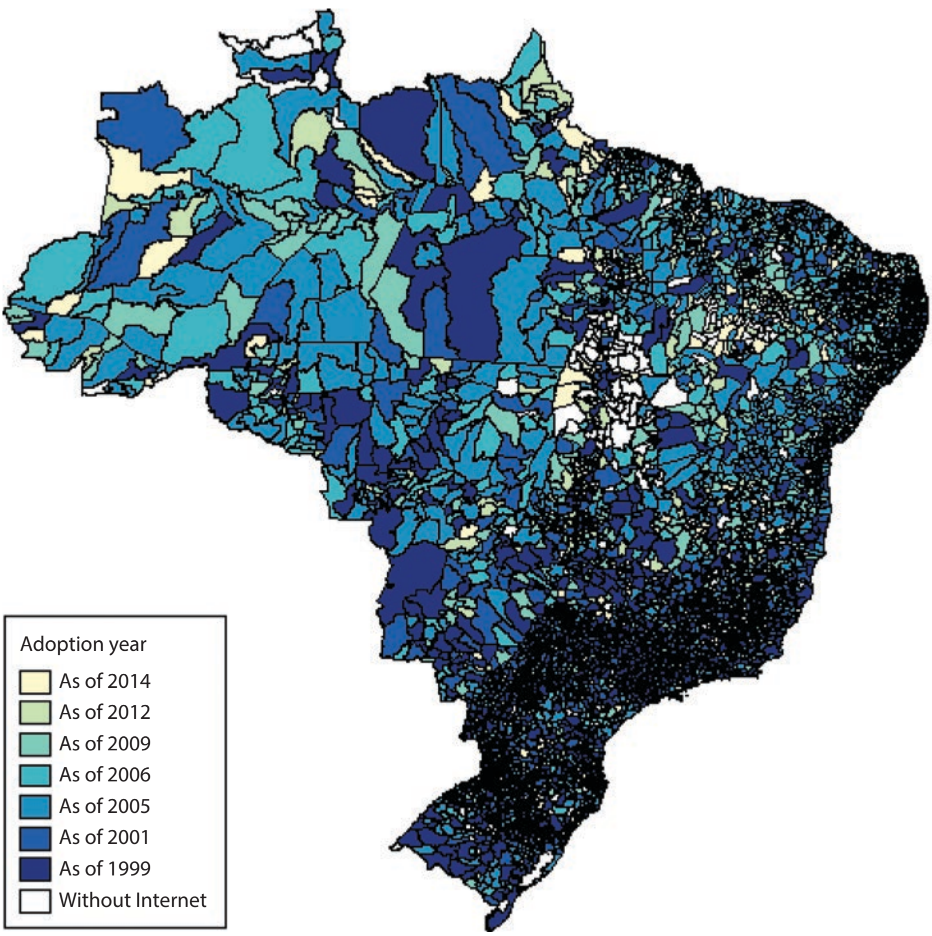


Source: World Bank *World Development Report 2016*.
Note: The Digital Adoption Index was compiled for *World Development Report 2016* and is described in detail in chapter 5. LAC = Latin America and the Caribbean; OECD = Organisation for Economic Co-operation and Development.

Even in the wealthiest, institutionally most advanced LAC countries, digital technology adoption by households and businesses is well below that of peer countries and members of the OECD. Figure 2.5 plots countries according to the Digital Adoption Indices (DAIs) created for *World Development Report 2016: Digital Dividends* (World Bank 2016). Countries in LAC are highlighted along with three benchmarks: the LAC average, the average in East Asia and Pacific (a region that many countries in LAC regard as peers and trading partners), and the average level in the OECD. It is unsurprising that the highest levels of the DAI in LAC are observed in Chile, Brazil, and Argentina, and that the lowest levels of digital adoption are observed in lower-income Haiti. What is more intriguing are the substantial differences in the DAI across countries with similar levels of economic development, and conversely how a relatively poor country like Haiti has about the same level of digital adoption by people as much-wealthier Mexico. What should cause additional concern for policy makers across LAC is that even the LAC countries where the levels of digital adoption are highest lie well below the average level of adoption for countries in East Asia and for the OECD. For countries in LAC, the room for improvement is starkly apparent.

The adoption of digital technologies, including Internet penetration, also varies substantially within countries in the LAC region. The variations in access to the Internet by firms within countries at the subnational level are exploited by all the country studies. For instance, between 1999 and 2014 access varied substantially across the more than 5,000 Brazilian municipalities. Larger population centers benefited from earlier access to the Internet. In 1999, only 15 percent of all municipalities had local Internet service, accounting for roughly 60 percent of the Brazilian population. Access to digital technologies has grown considerably since then. By 2006, more than half of all municipalities had a local Internet service provider, accounting for almost 90 percent of the population. Map 2.1 illustrates the spreading of the Internet across the country over time. The darker areas of the map obtained Internet service earlier than the lighter areas. The municipalities in the center of the country and remote Amazon region, represented by white areas, remained without Internet service as of 2014.

Map 2.1 Internet Service Provision across Brazilian Municipalities, 1999–2014



Source: Almeida, Corseuil, and Poole 2017.

References

Almeida, Rita, Carlos Corseuil, and Jennifer Poole. 2017. "The Impact of Digital Technologies on Routine Tasks: Do Labor Policies Matter?" Policy Research Working Paper 8187, World Bank, Washington, DC.

de La Torre, A., A. Ize, G. Beylis, and D. Lederman. 2015. *Jobs, Wages and the Latin American Slowdown*. Washington, DC: World Bank.

Lederman, Daniel, and Guido Porto. 2014. "The Price Is Not Always Right: On the Impacts of (Commodity) Prices on Households (and Countries)." Policy Research Working Paper 6858, World Bank, Washington, DC.

Pagés, C., ed. 2010. *The Age of Productivity: Transforming Economies from the Bottom Up*. Washington, DC: Inter-American Development Bank.

Perry, Guillermo, William F. Maloney, Omar S. Arias, Pablo Fajnzylber, Andrew D. Mason, and Jaime Saavedra-Chanduvi. 2007. *Informality: Exit and Exclusion*. World Bank Latin American and Caribbean Regional Study. Washington, DC: World Bank.

World Bank. 2016. *World Development Report 2016: Digital Dividends*. Washington, DC: World Bank.

CHAPTER 3

A Conceptual Framework

This chapter presents a new conceptual framework designed to address the key research questions of this book regarding the challenges and opportunities for productivity enhancement and job creation through technology adoption. The conceptual framework is intended to provide testable predictions that are explored in the subsequently presented country-based empirical studies. A review of the relevant economic literature (appendix B) helps put the conceptual framework and the later summary of this book's empirical findings into a broader context. The research questions can be grouped into three broad categories:

- *Productivity, jobs, and skills:* How does technology adoption affect productivity, overall levels of employment, and the demand for workers with different types of skills? Does technology adoption generate a sufficiently large boost to output, with sufficiently responsive product demand, to expand jobs for both high-skilled and low-skilled workers? How do impacts differ depending on technology, sector, and the regulatory environment within which firms operate?
- *Job dynamics, complementary investments (on-the-job training), and the role of labor market regulations:* How does technology adoption affect firms' incentives to dynamically adjust jobs or invest in workforce skills that may not be readily available? How do labor market regulations, such as a statutory minimum wage and employment protection, affect firms' decisions to adjust the workforce to their new needs? Do labor regulations promote or hinder the adoption of technologies?
- *Trade and labor mobility:* Under which conditions does access to digital technologies reduce wage inequality through trade between countries and raise labor mobility across sectors and regions?

What Do We Know?

Productivity upgrading through creative destruction is the main driver of long-term per capita income growth. This dynamic involves innovation (both the commercialization of frontier technologies and technology adoption, namely, the adoption of existing improvements in product, process, marketing, managerial, organizational, and related practices by firms) and the reallocation of resources across industries and across firms within industries (Aghion and Howitt 2009; Comin and Ferrer 2013; Cirera and Maloney 2017). Rising country-level productivity has been found to be associated with growing aggregate employment over time (Autor and Salomons 2017).

The distributional impact of technology adoption is more complex, particularly as it affects productivity and firms' demand for labor and human capital. The existing literature shows that the impact of technology adoption on the welfare of different groups is ambiguous. On the one hand, technology adoption can lead to income inequality if the benefits are disproportionately appropriated by owners of physical capital, managers, and high-skilled workers able to implement new technologies, without sufficient benefit to low-income or less skilled workers. At the limit, specific types of technology adoption that substitute machines for labor can make certain categories of workers redundant and unemployable (see Acemoglu and Autor 2011; Acemoglu and Restrepo 2016, 2017, 2018; and the related large literature on automation and skill-biased technological change). For example, technology adoption has recently been associated with a decline in mid-skill occupations relative to low- and high-skill ones in the United States (Autor and Dorn 2013). On the other hand, automation and other forms of technology adoption may complement labor, decreasing variable costs and increasing productivity, thereby raising output in ways that lead to higher demand for labor and increased earnings (Autor 2015). Such types of technology adoption (or catch-up innovation) generate higher productivity, sales, and employment when spurred by a competitive business environment. Indeed, technology adoption has recently been shown to be associated with a larger employment share of low-skilled workers and women in an empirical study of more than 26,000 manufacturing establishments across 15 Organisation for Economic Co-operation and Development and 56 developing countries (Dutz et al. 2012). This finding suggests that firm growth from innovation can be more inclusive. The use of the Internet and the presence of job-training programs are shown in these data to make significant contributions at every stage of the flow from idea generation to inclusive employment growth.[1]

Most of the literature exploring the impact of technology adoption focuses on high-income countries, with some recent and interesting exceptions from Latin America and the Caribbean. Appendix B provides a more detailed summary of the existing literature on the impacts of technology adoption on jobs and the skill content of tasks, on trade and labor mobility, and on the impact of labor market regulations. The literature review serves as context for the book's conceptual framework and for the nine empirical studies commissioned for this book (see appendix A). A contribution of this book, which becomes apparent through the differing frameworks adopted in the literature review, is the value of empirical studies across different Latin American countries all linked to a similar conceptual framework.

Predictions about the Diverse Impacts of Technology Adoption

The conceptual framework developed for this book is designed to illuminate the effects of technology adoption on firm-level outcomes by allowing technologies and wages to vary across firms within each product market. In her theoretical paper, "Digital Technology Adoption and Jobs: A Model of Firm Heterogeneity," Brambilla extends Acemoglu and Autor's (2011) task-based model of technical progress and labor markets by allowing firm heterogeneity in technology (firms differ in their efficiency, with some able to produce higher output per unit of the composite of production tasks than others) and wage heterogeneity across firms (wage rates vary across firms within each market because of assumed noncompetitive labor markets with rent-sharing combined with firm heterogeneity in technology). These extensions allow the outcomes of the book's basic model to better approximate the high variance in labor force composition and wages across firms highlighted by empirical firm-level studies—so that the predictions will be more realistic when technology adoption (firm investment in and use of information and communication technologies [ICT]) is introduced.

The model, summarized in box 3.1, combines assumptions about firms' production technology, labor markets, and individual preferences to generate outcomes that are compatible with observed, firm-level outcomes. In line with the task-content-of-jobs approach, production is assumed to have a two-tier structure: production of final goods is carried out by a combination of production tasks (which correspond to production stages such as design, development, assembly, management, commercialization, and distribution), with each of the underlying tasks in turn requiring differing numbers of high-skilled and low-skilled workers. For more complex tasks, the comparative advantage of high-skilled workers increases. In the assumed noncompetitive labor markets, firm-level wages for high-skilled and low-skilled workers follow rent-sharing schedules that are increasing in profits, with workers assumed to have fair-wage demands (the wage schedules can result from an efficiency wages model or from a bargaining solution after job search).

Greater productivity translates to higher demand, growth in output, and more jobs. The implication of these assumptions is that more productive firms charge a lower output price and thus have higher output, profits, jobs, skill intensity, and task complexity, and pay higher wages to workers across all skill types. High-skilled workers are paid more than low-skilled workers, and workers of the same type are paid the same wage across tasks. The demand side uses a standard

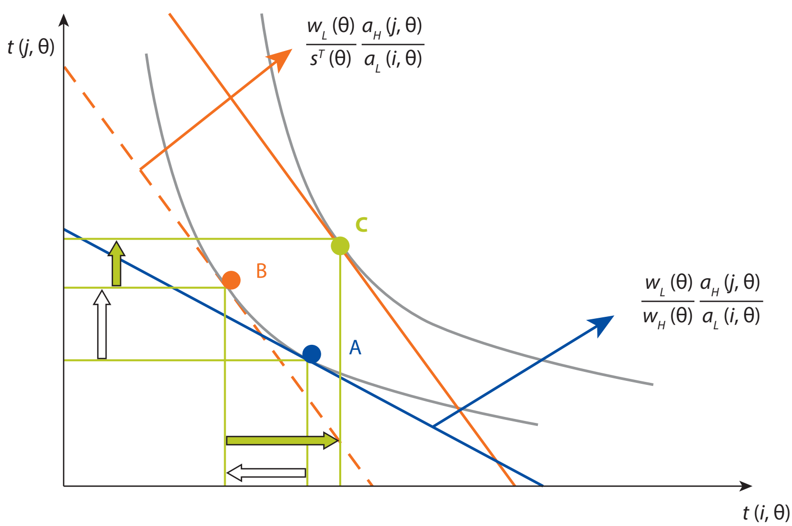
Box 3.1 A Model of Firm Heterogeneity with Predictions of the Impacts of Technology Adoption

The conceptual framework developed by Brambilla extends Acemoglu and Autor's (2011) task-based model of technical progress and labor markets by realistically allowing firms to differ in their efficiency (production at differing levels of output per unit of input) and allowing workers' wages to vary across firms (in addition to skilled workers being paid more than low-skilled workers, wages increase with profits across firms because of the assumption of rent-sharing wage schedules resulting from bargaining after job search or from an efficiency wages model in which workers only exert effort if they perceive their wage to be fair).

In a given industry, each differentiated variety is produced by a single-product firm under economies of scale. In a situation in which information and communication technologies (ICT) are not available, a firm that decides to stay in the market (because its fixed cost is sufficiently low relative to its technology parameter θ, with higher θ corresponding to higher output per unit of the composite variable input) chooses to produce each task, for instance, less complex task *i* and more complex task *j*, with either low-skilled or skilled labor according to which option is less costly, where the parameters $a_H(j, \theta)$ and $a_L(i, \theta)$ are the inverse requirements of high-skilled and low-skilled workers needed to produce one unit of task *i*, which vary across firms with θ.

The isoquant graph in figure B3.1.1 represents a situation at A in which task *i*, on the horizontal axis, is performed by low-skilled workers and task *j*, on the vertical axis, is produced by skilled workers, with the optimal combination A depending on the relative cost of

Figure B3.1.1 Substitution and Inclusive Output Expansion Effects from Technology Adoption



box continues next page

Box 3.1 A Model of Firm Heterogeneity with Predictions of the Impacts of Technology Adoption *(continued)*

each task (the quotient represents the ratio of the relative costs of the two tasks, with an increase in the wage of low-skilled labor or in the unit requirements of low-skilled labor for task *i* implying an increase in the production of task *j*, and vice versa).

Investment in ICT increases the participation of more complex tasks because the combination of ICT with skilled workers increases the firm's productivity and reduces variable costs of production. The cost of a combined unit of skilled labor and ICT is represented by $s^T(\theta)$, lower than both the skilled wage and the price of one unit of ICT capital. The dashed orange line represents the changed relative cost or productivity of tasks due to ICT investment. The movement from A to B is the substitution effect, that is, the shift in the combination of tasks conditional on no change in output (with zero output expansion effect, the movement along the initial isoquant by assumption has to result in a decrease in the production of noncomplex tasks requiring fewer low-skilled workers and an increase in the production of more complex tasks, represented by the white arrows). However, total production of tasks depends on total output produced. The movement from B to C is the output expansion effect, represented by the extent to which the dashed orange line shifts out and by the green arrows for each task. The magnitude depends on the drop in the firm's marginal cost due to the adoption of ICT; the level of competitive rivalry in the firm's market (which will affect how much the firm is disciplined by the market to reduce output prices); the availability of added labor, capital, materials, energy, and distribution inputs for expansion opportunities; and the elasticity of market demand, that is, how much consumer demand expands in response to a given drop in output price (which will depend on substitution possibilities from rival suppliers and other industries as well as regional and international export possibilities).

The model provides predictions for within-firm variation due to skill-biased technology (for example, ICT) adoption. Firms that invest in these technologies experience an increase in productivity and a reduction in variable costs, have larger sales, pay higher wages to both skilled and low-skilled workers, and perform a larger share of complex tasks with a combination of skilled labor and ICT. However, the predicted impact on jobs is ambiguous. For skilled workers, both the output and substitution effects (including two additional substitution effects not depicted here, namely, a within-firm shift to new tasks using ICT and skilled workers and an across-firm shift of industry output to firms that become relatively more productive because of their relatively more intense employment of both ICT and skilled workers) work in their favor, except for the possibility of an additional adverse substitution effect of ICT replacing skilled labor (as figure B3.1.1 is drawn, skilled labor performing the more complex task *j* is complementary to ICT, with the movement from B to C resulting in a further increase in the more complex task). Jobs for low-skilled workers will increase to the extent that the output expansion effect dominates the substitution effects (as figure B3.1.1 is drawn, the movement from B to C results in a sufficient increase in the less complex task *i* to increase production of this task as well and require more low-skilled workers).

monopolistic competition set-up, with consumers having constant elasticity of substitution–type preferences across product varieties. Industry expenditures across varieties allow for an "outside good" that captures substitution with the rest of the economy.

The model yields predictions of the impacts of firms' technology adoption on productivity, jobs, and wages, depending on the skill type of workers. When a firm invests in ICT, it incurs a fixed cost, including all the costs associated with installing the technology within the firm and adjusting the firm's labor force—costs such as training existing less-skilled and possibly also higher-skilled workers to use the technology, training newly hired workers, and paying severance costs to any displaced workers. By assumption, high-skilled workers can be combined with the new-to-the-firm technology, which increases the firm's productivity and reduces variable costs of production. Low-skilled workers, however, are assumed not to be combinable with the new technology, and only benefit to the extent that the firm's profits increase and therefore their wages also increase (the empirical studies clarify that this is an extreme assumption, and that lower-skilled workers also use these new technologies and become more productive as reflected in higher wages over time).[2]

The model assumes that varying degrees of complementarity between ICT and skilled workers are possible, including as perfect substitutes, whereby the technology replaces skilled workers. The firm's technology adoption decision depends on whether the benefits of lower variable costs and higher profits outweigh the fixed adjustment costs of adoption. The model also assumes that profits are proportionately higher for initially higher-productivity firms, given that they are able to distribute the fixed cost over a larger output base. The implication is that more productive larger firms invest in and adopt ICT, whereas less productive smaller firms apply a less efficient combination of inputs. To the extent that digital technology is a substitute for certain types of workers or tasks, investment in ICT is associated with employment reallocation. Employment protection regulation that makes labor adjustment costly is, therefore, expected to negatively affect firms' decisions to adopt ICT.

The model predicts that the impacts of ICT investments on productivity, output growth, task complexity, and wages for both higher- and lower-skilled workers can be positive. First, the productivity of technology-adopting firms increases as the new-to-the-firm technology enables a more efficient combination of inputs, reducing variable costs. Second, and most important for jobs, firm output increases because of a reduction in variable costs and prices. Although not explored in this model, firm output can also expand through increases in product quality and market outreach efforts, and the added quality and marketing expenses are worthwhile because of the lower costs enabled by the ICT. In addition, the use of digital technologies such as the Internet allows the firm to acquire better knowledge of existing and prospective customer tastes and to facilitate faster product delivery and payment. Third, conditional on total output, the participation of tasks carried out with the combination of high-skilled labor and ICT increases, resulting in a greater share of more complex tasks. Finally, the increase in profits that results from the ICT investment (because lower variable costs outweigh the fixed adjustment costs) is shared with workers through the fair-wage schedules, and therefore wages increase for both high-skilled and low-skilled workers. A number of these predicted impacts are summarized with plus signs in table 3.1.

The theoretical model also predicts ambiguous effects that can only be determined empirically. Importantly, table 3.1 also highlights that the impacts of technology adoption on total jobs, high-skilled and low-skilled workers, firm-level skill intensity (the relative share of high-skilled to low-skilled workers, or "jobs gap"), and firm-level wage inequality (the ratio of high-skilled to low-skilled worker wages, or "wage gap") are ambiguous. Although all these impacts are not clearly determined in one direction or the other, the model helpfully sheds light on the factors on which the direction of these impacts depends. The model therefore significantly helps in delineating the relevant empirical and policy issues.

Whether firms' technology adoption is inclusive in job outcomes depends on the size of the output effects: lower-skilled workers will benefit if the output effect dominates the substitution effects. The effect of ICT investments on both low-skilled and high-skilled employment is ambiguous. As discussed above, when a firm invests in ICT, output increases because of the reduction in variable costs, working through a reduction in prices. The increase in total output increases the output of all tasks, including both high-skilled and low-skilled tasks. However, at the same time, three substitution effects operate against the employment of low-skilled workers: fewer tasks are performed by low-skilled workers because they are replaced by tasks that use ICT and high-skilled workers; the activity levels of low-skilled (noncomplex) tasks are reduced in favor of the activity levels of the now less expensive tasks that use ICT and high-skilled workers, conditional on output; and output shifts to the firms that become relatively more productive because of their relatively more intense use of both ICT and high-skilled workers. Although these three substitution effects work in favor of high-skilled workers, a fourth substitution effect—the possibility that ICT will replace high-skilled labor—may work against them. On the other hand, ICT adoption may support increased high-skilled employment insofar as they are net complements at the level of task performance. So while the overall effects of ICT adoption on employment are theoretically ambiguous, sufficiently strong output effects can increase both high-skilled and low-skilled employment, while likely substitution effects can increase the ratio of high-skilled to low-skilled labor.

Table 3.1 Predicted Impacts of Technology Adoption on Productivity, Jobs, and Wages

Employment				*Wages*				*TFP*
Total	*High-skill*	*Low-skill*	*Jobs gap*	*Total*	*High-skill*	*Low-skill*	*Wage gap*	*(Labor productivity)*
?	?	?	?	+	+	+	?	+

Note: "Jobs gap" refers to the predicted impact on the relative share of high-skilled to low-skilled workers. "Wage gap" refers to the predicted impact on the ratio of high-skilled to low-skilled worker wages. TFP = total factor productivity, that is, how efficiently all measured inputs are being used to produce a given level of output.

The impact of technology adoption on the wages of high-skilled and low-skilled workers will depend on their relative scarcity and bargaining power. Whether firm-level wage inequality increases or decreases depends on the extent to which the rent-sharing schedules are relatively more increasing in profits for high-skilled or low-skilled workers, which, in turn, depends on factors such as the relative scarcity and bargaining power of higher- versus lower-skilled workers. The extent to which the wages of higher- or lower-skilled workers are more tied to firm performance will depend on factors such as whether it is more costly for the firm to lose one or another type of worker, which, in turn, could lead the firm to pay higher wages to secure the workers' commitment.

The size of output effects at the product market level depends on demand elasticity and general equilibrium effects. Interfirm substitution effects arise through the demand side, including parameters in the utility function that govern output effects from substitution both from other competing firms and from the rest of the economy. As part of product market–wide effects, the output and employment of competitive rivals that do not adopt the new technology will both decline. Although nonadopting rivals will lose output and employment, the overall product market is expected to gain demand since the assumed preferences imply substitution across categories. Importantly, positive industry-wide output effects and associated inclusive job effects are more likely the larger the elasticity of product market demand. To the extent that total expenditures on the industry's output are more elastic because of substitution from other industries and regional or international export possibilities, output expansion effects will be even larger. In addition, positive employment spillover effects are possible from neighboring firms' process innovation associated with ICT adoption.

The extent of firm-level ICT investments and the size of overall output effects also depend on technology diffusion, product market, education, skills, and labor market policies. Regarding product market policies, the responsiveness of output expansion (as well as quality and market outreach efforts) to the lowered variable costs enabled by technology adoption depends on, among other factors, the following:

- *The intensity of domestic market contestability and competition* (including entry, expansion, and exit policies). For example, output will expand more if there is a lower risk of losses from the possibility that any output expansion needs to be retracted, which is influenced by, among other things, the ability of firms to retrain or lay off workers at moderate cost, and by the ability of bankruptcy protection to guard investors' interests if retraction is necessary.
- *Policies affecting product tradability* across regions within the country and internationally for all potentially tradable products, including policies lowering transportation and logistics costs, and critically including policies to lower tariff and nontariff barriers to external trade.
- *Access to finance* to purchase required inputs and promotion efforts.

- *Policies supporting the upgrading of the quality of firm management* and other factors affecting firms' ability and know-how to enlarge production and distribution in response to lower variable costs.

Regarding education, skills, and labor market policies, firms will be better able to pay the fixed costs of adjustment (technology setup costs, worker training, hiring and firing costs) associated with ICT adoption with, among others, the following:

- *Education systems that deliver skills that are needed to adopt and use digital technologies*
- *Worker training and job-search support to facilitate skills upgrading and higher worker mobility*
- *Lower transactions costs for hiring and dismissing workers* (flexible labor policies to facilitate worker choices by firms).

Notes

1. Based on a sample of more than 26,000 manufacturing establishments across 71 countries (both Organisation for Economic Co-operation and Development countries and developing countries) using World Bank Enterprise Survey data collected between 2002 and 2006, Dutz et al. (2012) find that technology-adopting innovating firms have higher employment growth rates and employ a higher share of low-skilled and female workers than noninnovating firms, with country and industry fixed effects, as well as firm-level controls by ownership, level of organization and legal status, size class, and age group. However, because of data limitations, that paper could not address issues of causality nor study the implications of technology adoption for relative earnings, income growth, and attainment of higher skills. Accordingly, that paper motivated the search for the more complete data sets and their analyses that have allowed this book to address the broader scope of the implications of technology adoption.
2. Acemoglu and Restrepo (2017) explore the impact of industrial robots on employment and wages in a model in which lower-skill tasks are completely automated and replaced rather than partially displaced through substitution effects. Based on their estimates from U.S. labor markets between 1990 and 2007, one more robot per thousand workers reduces the employment-to-population ratio by about 0.18–0.34 percentage point and wages by 0.25–0.5 percent.

References

Acemoglu, Daron, and David Autor. 2011. "Skills, Tasks and Technologies: Implications for Employment and Earnings." *Handbook of Labor Economics*, volume 4, edited by David Card and Orley Ashenfelter, 1043–171. Amsterdam: Elsevier.

Acemoglu, Daron, and Pascual Restrepo. 2016. "The Race between Machine and Man: Implications of Technology for Growth, Factor Shares and Employment." Working Paper 222521, National Bureau of Economic Research, Cambridge, MA.

———. 2017. "Robots and Jobs: Evidence from US Labor Markets." Working Paper 23285, National Bureau of Economic Research, Cambridge, MA.

———. 2018. "Artificial Intelligence, Automation and Work." In *Economics of Artificial Intelligence*, edited by Ajay Agarwal, Avi Goldfarb, and Joshua Gans. Forthcoming.

Aghion, Philippe, and Peter Howitt. 2009. *The Economics of Growth*. Cambridge, MA: MIT Press.

Autor, D. H. 2015. "Why Are There Still So Many Jobs? The History and Future of Workplace Automation." *Journal of Economic Perspectives* 29 (3): 3–30.

Autor, D. H., and D. Dorn. 2013. "The Growth of Low-Skill Service Jobs and the Polarization of the US Labor Market." *American Economic Review* 103 (5): 1553–97.

Autor, D. H., and A. Salomons. 2017. "Robocalypse Now: Does Productivity Growth Threaten Employment?" Conference Paper prepared for the European Central Bank Sintra Forum on Central Banking, June 26–28.

Cirera, Xavier, and William Maloney. 2017. *The Innovation Paradox: Developing-Country Capabilities and the Unrealized Promise of Technological Catch-Up*. Washington, DC: World Bank.

Comin, Diego, and M. Mestieri Ferrer. 2013. "If Technology Has Arrived Everywhere, Why Has Income Diverged?" Working Paper 19010, National Bureau of Economic Research, Cambridge, MA.

Dutz, Mark, Ioannis Kessides, Stephen O'Connell, and Robert Willig. 2012. "Competition and Innovation-Driven Inclusive Growth." In *Promoting Inclusive Growth: Challenges and Policies*, edited by Luiz de Mello and Mark Dutz. Paris: Organisation for Economic Co-operation and Development.

CHAPTER 4

New Lessons from the Region on the Impacts of Technology Adoption

Based on the predictions of the conceptual model summarized in the preceding chapter, the impacts of technology adoption on the total number of jobs, on the jobs of high-skilled and low-skilled workers, on firm-level skill intensity ("jobs gap"), and on firm-level wage inequality ("wage gap") are theoretically ambiguous. These are, therefore, empirical issues that need to be addressed by applying economic theory to the available data. The first section of this chapter presents information about the impacts of technology adoption on skills, types of jobs, wages, and productivity based on six new firm-level studies of Argentina, Brazil (two studies), Chile, Colombia, and Mexico. The second section presents information from these studies about the impacts of technology adoption on job dynamics and the role of complementary training investments. The third section presents information on the effect of labor market regulations on firms' decisions and jobs outcomes based on studies exploring both firm-level data and cross-country data. Finally, the fourth section presents information on the impacts of technology adoption on firms and workers through trade and labor mobility based on two new cross-country studies exploring household data. Across these sections, the nine new empirical studies clarify how the effects of digital technology adoption by firms have played out across different Latin American countries.[1]

The country studies identify causal effects rather than correlations by focusing on drivers that are exogenous to output and the demand for jobs, skills, and labor earnings. Firm fixed effects are used to control for unobservable time-invariant firm heterogeneity. This is important because unobserved firm characteristics, such as the quality of products, firms' commercial ties, and the professional background of top-tier managers, might simultaneously affect the propensity to adopt new-to-the-firm technologies and the outcome variables. The effects of adoption on productivity and jobs-related outcomes therefore are identified using within-firm changes over time and not the cross-section variation of heterogeneous firms across industries. Technology adoption could also be endogenous to unobservable time-variant factors such as technology, productivity, or labor market shocks. These shocks could simultaneously affect the scale and skill mix of labor demand as well as information and communication technologies (ICT) adoption among firms. A number of the studies exploit plausibly exogenous subnational changes in the availability of ICT access or in its quality over time and space. These exogenous variations are exploited as instruments for the otherwise possibly endogenous firm-level use of ICT. For example, the Brazil tasks and labor policies impact study exploits the arrival of Internet access at the municipal level over time and compares skill outcomes in municipalities with different degrees of exposure to digital technology due to sectoral and technological characteristics. In Chile, the analysis allows the adoption of complex software over time to affect firms differently depending on preexisting subnational technological intensity (based on the subnational share of households with access to computers). The Mexico study interacts average sector ICT intensity in the United States with the average elevation of municipalities to reflect the geographical challenges of Internet availability in more difficult-to-access areas.

Table 4.1 Empirical Impacts of Technology Adoption on Jobs, Wages, and Productivity

				Employment				*Wages*				*TFP*
Country	*Years*	*Industries*	*Focus variable*	*Total*	*High-skill*	*Low-skill*	*Jobs gap*	*Total*	*High-skill*	*Low-skill*	*Wage gap*	*(LP)*
Argentina	2010–12	Manufacturing	Investment in ICT capital	+	+	+	+	+	+	+	+	(+)
Brazil sectoral impacts	2000–14	Economy-wide	Percent Internet availability	0	–	–		–	–	0	–	+
		Tradables	Percent Internet availability	+	+	0		0	+	0		
		Nontradables	Percent Internet availability	–	–	–		–	–	0		
Brazil tasks and labor policies	1996–06	Economy-wide	Internet availability × labor market regional enforcement	0	+	–	+					
Chile	2007–13	Economy-wide	Complex software use	+	0	+	–					
Colombia	2008–14	Manufacturing	High-speed Internet use	+	+	+						+
Mexico	2008–13	Manufacturing	Internet use	+	+	+	+	+	+	+	–	+
		Services	Internet use	+	+	+	0	–	–	–	–	+
		Commerce	Internet use	+	+	+	0	–	0	–	+	+

Note: ICT = information and communication technologies. "High" refers to high-skilled (or white-collar) workers, "Low" refers to low-skilled (or blue-collar) workers. Productivity measures are based on TFP (total factor productivity) wherever possible; labor productivity is used elsewhere (shown in parentheses). +, –, and 0 refer to adoption resulting in an increase, decrease, or no effect on the specified variable. Blank cells reflect the inability to calculate the effect on the specified variable. All studies are at the firm level except for the Brazil studies, which are at the municipal level (except for the reported Brazil TFP estimate, which is based on firm-level manufacturing data).

Impact on Firm Productivity and the Demand for Jobs, Types of Skills, and Wages

Across all countries except Brazil, ICT adoption by firms is associated with increases in total employment and in employment of low-skilled labor (table 4.1). In line with the predictions of the theoretical model, the productivity of technology-adopting firms increased in all country studies where data were available, with the finding in Argentina based on labor productivity. The total number of jobs grew in most countries as a result of ICT adoption, with the only exception being Brazil. Although there was no positive economy-wide net effect on jobs in the Brazil sectoral impacts study with both contemporaneous and lagged effects, jobs increased in tradable sectors with output expansion opportunities, in line with the book's conceptual framework; and the Brazil tasks and labor policies impact study found that though the total number of jobs was reduced, it was reduced by less among firms in the tradable sectors. It is likely that policy distortions, including high trade and other product market expansion barriers, played a more important role in constraining opportunities for efficient global output expansion in Brazil than in other countries. In Argentina, firm employment increased by 60 percent, on average, because of investment in ICT. Employment rose by 50 percent for low-growth firms and by 72 percent for high-growth firms. This result is compatible with the predicted output effect in which the increase in jobs is driven by the increased output. Importantly, jobs growth was inclusive, in the sense that increases in lower-skilled jobs were observed in Argentina, Chile, Colombia, and Mexico. This empirical finding across all country studies except Brazil on the link between technology adoption and increased employment of lower-skilled workers is an important empirical result documented by this book, since it is theoretically ambiguous and relates to the main question of whether technology adoption can drive inclusive growth.

The extent to which the impact of ICT adoption on jobs is inclusive depends on whether the product market provides opportunities for significant output expansion and on the nature of the technology adopted. Most of the findings where the impact of technology adoption is inclusive—that is, it boosts lower-skilled jobs—are in tradable manufacturing industries. In the Argentina study, manufacturing firms that invested in increasing their stock of ICT capital experienced job increases for low-skilled as well as high-skilled workers. Importantly, job increases for the low-skilled were larger for high-growth firms, supporting the importance of strong output expansion effects in driving inclusive growth: the increase in employment of low-skilled workers is 10 percent larger for firms in which revenue growth is above the median. In the Brazil sectoral impacts study, where skills were split into thirds (high skill, middle skill, and low skill), the jobs for middle-skilled workers increased only for the tradable manufacturing sector, even though there was no change in the bottom third, with middle-skilled workers in other nontradable sectors such as wholesale and retail trade losing jobs. In Colombia, firms' use of high-speed broadband directly increased demand for laborers and production (lower-skilled) workers as well as for professional (higher-skilled) workers. In the Mexico study, a 10-percentage-point increase in the share of labor using the Internet in manufacturing was associated with an 11 percent increase in white-collar workers together with a 6 percent increase in blue-collar workers, with much smaller positive effects for the less tradable commerce industries.[2] Finally, regarding the effect of the nature of the adopted technology, the Chile study found that the adoption and use of complex software by firms increased the number of low-skilled production worker jobs in the medium term. Over the six-year period analyzed, the levels of employment of high-skilled production workers and managers did not change significantly.

Greater investment and use of the Internet are also associated with a relatively larger increase in the use of high-skilled workers. The assumption of skill-biased technological change included in the conceptual framework is borne out in most of the country-level studies. Even though the number of low-skill jobs increases across most studies, a substitution effect occurs in favor of more skilled workers with increased use of the Internet. This increased job demand gap in favor of more skilled workers is found in the Argentina, Brazil tasks and labor policies impact, and Mexico (for manufacturing industries) studies. In the manufacturing industries in Mexico, for instance, the number of workers increased for both white- and blue-collar occupations, with the increase being larger for white-collar, therefore increasing the ratio of white- to blue-collar workers. Consistent with this pattern, evidence from studies beyond those commissioned for this book shows that the distribution of jobs in some countries in Latin America and the Caribbean (LAC), including Guatemala, Honduras, and Panama, has become increasingly polarized with a rise in the number of very-high-skill and low-skill occupations, but with fewer jobs in middle-skill occupations (World Bank 2016).

Technology adoption is also likely to affect the task content of occupations and the degree to which they involve more- or less-routine or cognitive versus manual tasks. Firms' access to digital technologies may lead to greater demand for occupations that perform less-routine and less-manual tasks because some of these tasks can be more easily automated. However, whether and how digital technology adoption is actually affecting different types of jobs in LAC through the automation of some tasks remains an open question, with critical implications for education and training systems.

The Brazil tasks and labor policies study and the Chile study go beyond the more traditional classification of workers and assess impacts of digital technology adoption on the skills content of occupations. These two studies exploit panel data sets at the firm level and match firm-level occupations with detailed measures of skills' task content, that is, abstract, routine-cognitive, routine-manual, and manual tasks. The Brazil study relies on a unique concordance between the Brazilian Classification of Occupations and the U.S. Department of Labor's Occupational Information Network to assign a numerical index capturing the importance of distinct activities in each occupation. For Chile, the concordance relies on the 2014 Program for the International Assessment of Adult Competencies survey, collected by the Organisation for Economic Co-operation and Development. Based on these data, measures of cognitive, manual, routine, and nonroutine tasks are constructed for each occupation. Drawing on Acemoglu and Autor (2011) and Autor and Handel (2013), the task content of occupations using routine and nonroutine tasks in each occupation is defined. The work further distinguishes routine and nonroutine tasks into routine-manual, routine-cognitive, nonroutine-manual, and nonroutine-cognitive tasks. The Brazil study also disaggregates nonroutine, cognitive tasks into tasks requiring communication, analytical, and social and emotional skills, following Deming (2015).

In Chile, the adoption of advanced software at the firm level is associated, in the medium term, with a reallocation of employment away from abstract tasks and toward more routine and manual tasks. The study exploits the relationship between each firm's complex software adoption and a measure of workforce skill composition. It instruments the firms' adoption of complex software with a measure of household use of computers at the subnational level and exploits the fact that industries vary in their degree of reliance on ICT: industries that intensively use technology and that are located in regions where there is a greater availability of computers and related technologies are most likely to adopt complex software. The findings suggest that the adoption of complex software increases the use of routine and manual tasks and decreases the use of abstract tasks. These results are driven by the composition of employment. Even though firms expand their overall activity, the share of high-skilled labor decreases following the adoption of complex software.

In Brazil, the subnational rollout of Internet access nationwide is strongly associated with a shift away from more routine and manual tasks and toward nonroutine and cognitive tasks. The Brazil study's methodology exploits the variation in firms' use of different types of skills over time as Internet access is rolled out, comparing localities with more- versus less-technology-intensive industries. The results show that in the aftermath of the technology shock, the composition of the workforce changes toward more nonroutine skills within each of the Brazilian municipalities. In addition, technology adoption is found to be strongly associated with a change in workforce composition toward more cognitive tasks and away from manual tasks. This finding validates, for a large middle-income country, some of the concerns that routine, manual tasks are increasingly being replaced by technology, displacing less-skilled workers (Autor, Levy, and Murnane 2003).

Whether the effect of ICT adoption on wages is inclusive also depends on whether firms invest in human capital—that is, in workers. Inclusivity of wages within technology-adopting firms can refer to increasing wages for lower-skilled workers, a reduction in wage inequality (or the wage gap), or both. In line with the conceptual framework's prediction, the wages of low-skilled workers increased in Argentina, in Brazil (where wages increased for the middle-skilled group in manufacturing), and in Mexico (in the manufacturing sector). And importantly, the wage gap actually decreased in Mexico in the manufacturing and services industries, which addresses another question that was theoretically ambiguous. In the Mexico study, a 10-percentage-point increase in Internet use in manufacturing was associated with a 14 percent increase in white-collar wages versus a 16 percent increase in blue-collar wages. So ICT adoption can narrow wage inequality between types of workers. Based on additional analyses of Mexico's national survey of enterprise ICT use, the higher wage increase for low-skilled workers appears to be explained by the increased sophistication of these workers over time as they learn on the job: as information becomes more available in adopting firms through the use of business management software for specific activities or more integrated enterprise resource planning systems, it likely becomes easier for low-skilled workers to make more informed and decentralized decisions.[3] Instead of being substituted for by ICT, these workers appear to be growing into stronger complements of technology.

Finally, whether the impact of technology adoption on wages is inclusive also depends on the sector. The Mexico study highlights the importance of sectoral effects. Contrary to what is found for manufacturing, wages in services industries decrease for both groups, but the reduction is higher for white-collar workers, thus decreasing the wage gap for services as well. These differences could be explained by the fact that jobs in services appear to be comparatively more at risk of automation than jobs in manufacturing (World Bank 2016). Therefore, as routine and nonroutine tasks within the services sector are automated, the skill value of both white- and blue-collar workers who perform these tasks is reduced, but the effect is stronger on white-collar workers, thus reducing the wage gap. The commerce sector also has a higher risk of automation, but the wage reduction affects blue-collar workers while the wages of white-collar workers do not change significantly. The wage reduction could indicate that these types of workers are performing simpler, less valuable tasks as the use of technologies allows some processes to be at least partially automated.

Impacts on Job Dynamics and the Role of Complementary Investments in Skills

In addition to the impacts on employment and skills levels, access to ICT also affects the dynamics of job creation. Latin America is characterized by relatively low levels of job creation (Alaimo et al. 2015). Access to ICT can create pressure for firms to adjust production processes, creating new occupations and destroying others, and changing the skills content of occupations. In Argentina, evidence shows that investment in ICT has had an impact on employment turnover. Firms that invest in ICT capital report that in roughly 5 percent of cases, it led to replacing workers; in 10 percent, it led to replacing occupations; and in 32 percent, it led to the creation of new occupations. The most relevant characteristic associated with all three forms of changes in employment is the firm's undertaking of operations through the Internet. The Brazil tasks and labor policies impact study also provides evidence that this dynamism in job creation, at least in the short term, is accompanied by job destruction through the exit of firms from the relevant market. During the period from 1996 to 2014, access to the Internet is correlated with a reduction in the number of firms. This finding is consistent with reduced variable costs allowing more efficient firms to expand while driving others out of the market.

ICT adoption at the firm level is also strongly correlated with firms' complementary investments in the human capital of the workforce. The Mexico study finds that firms that make more intensive use of ICT also provide more training for both white- and blue-collar workers, with blue-collar workers receiving significantly higher levels of training. These blue-collar workers likely become more sophisticated and increase their use of digital technologies because of increased access to information as firms make organizational improvements by using enterprise resource planning systems more intensively and by increasing training for workers in these technologies. In Chile, the adoption of complex software by firms is also associated with increased investment in technical, on-the-job training for managers, with a focus on digital skills.

The human capital of managers is also an important factor driving firms' investment in ICT in the region. Formal education and work experience serve as a proxy for managers' human capital. In Argentina, the propensity to invest in ICT is higher for firms with younger, experienced, and more educated managers (managers with college or graduate degrees are 15–26 percentage points more likely to invest in ICT). In Chile, the evidence shows that younger managers with more formal education and past relevant experience are also more likely to invest in technology adoption.

The Role of Labor Market Regulations on Firms' Decisions and Jobs Outcomes

The constraints on firms' human capital management decisions from de jure labor regulations also influence the extent of digital technology use in the region. Evidence from a country-level analysis of a large sample of very diverse countries, including almost all the countries in LAC, shows that the prevailing labor market regulatory instruments—and other social protection institutions—are significantly associated with firms' adoption of digital technologies.[4] Importantly, the significance and direction of the relationship vary across regulatory instruments such as statutory minimum wages, restrictions on hours and hiring, dismissal procedures, severance costs, and contributions for social insurance.

A higher statutory minimum wage is positively associated with the extent of digital technology use by firms. Two obvious economic factors help explain this observed relationship. First, a higher statutory minimum wage is more likely to bind, particularly at the lower end of the labor force distribution, by skill and productivity levels. Therefore, the higher minimum wage could increase firms' incentives to invest in digital technology that *substitutes* for labor inputs and thus saves on labor costs. Second, faced with a policy-mandated lower bound on wages, firms will have an incentive to make investments that pair labor more efficiently with ICT tools to raise the marginal product of labor well above the mandated minimum wage.

However, more restrictions on firms' employment decisions are associated with lower levels of digital technology use. Several measures of labor market restrictiveness were used to analyze the relationship, including indices constructed by the International Labour Organization and the Organisation for Economic Co-operation and Development (and expanded to cover most countries in the LAC region by the Inter-American Development Bank), along with the World Bank's Doing Business data. Where these indices were found to be statistically significant, a more restrictive regulatory framework for firms' human resource decisions was strongly associated with lower use of digital technology. As with the level of the statutory minimum wage, the possible economic explanation for this statistical relationship is easy to understand. All other things being equal, more onerous procedures for firms' choices of productive inputs impede businesses' ability to adopt and adjust to new technologies. If firms are more constrained in their human resource decisions, they will find it more difficult to embed new technologies into their production models, to adopt the processes that the new technologies entail, and to find the complementary labor and human capital they require to reach a new optimal level of operation.

Important nuances become apparent when different forms of employment protection measures (that is, restrictions on hours of work, restrictions on the use of temporary employment, and procedures and monetary costs of dismissals) are analyzed separately. Cumbersome dismissal procedures appear to have the strongest significant association with firms' use of digital technology: business use of digital technology is lower in countries that require firms to follow more burdensome procedures to dismiss workers. Again, there are intuitive economic explanations for why different forms of employment protection regulations could relate differently to firms' digital technology use. On the one hand, restrictions on hours and limits on the use of fixed-term and temporary workers can constrain a firm's ability to experiment and adapt to new technology and changes to its production function. On the other hand, firms and workers might welcome the certainty of an up-front dismissal payment (severance) to workers displaced by technology to speed the adjustment process. The more cumbersome the bureaucratic procedures that the labor code requires firms to follow to dismiss one or more than one worker, the greater firms' uncertainty about what the total adjustment costs of technology adoption will be. The uncertainty created by cumbersome de jure dismissal procedures is likely to be a formidable deterrent to adopting new technology.

Yet what is written in the labor code is not always what is enforced in practice by inspectors and hence what firms and workers react to. The gap between de jure and de facto labor regulations is particularly wide in LAC economies, where many firms and workers operate beyond the reach of the government's capacity to enforce regulations. The so-called informal economy—unobserved, unregulated, and thus untaxed—is extraordinarily diverse, and is made up of a wide array of firms and people (Perry et al. 2007). The advent and widespread adoption of digital technology can simultaneously create opportunities for avoidance and evasion of restrictive regulations and increase the ability of government agencies to observe economic activity and enforce compliance. But a large and diverse informal economy—sometimes tightly integrated with the formal economy through the production chains of even large, international, formal firms—also offers the sort of variation in the actual incidence and costs of labor regulation that is critical to testing its actual impact on workers' prospects in the wake of a technology rollout. The Brazil tasks and labor policies impact study exploits just such an opportunity.

The enforcement of labor regulations in Brazil limits the degree to which companies shift away from labor as technology becomes available. In Brazil, as in all the LAC countries, labor market regulations exist to protect workers from unanticipated shocks. But often these labor market protections also have the unintended consequence of increasing businesses' labor costs. The trade-off between job security for workers, on the one hand, and economy-wide productivity and growth, on the other hand, is arguably one of the most prominent public policy debates in the region. Until reforms to its labor code passed in the first half of 2017, Brazil was an outlier, particularly in the restrictions it imposes on the use of fixed-term, temporary, and outsourced employment. The Brazil tasks and labor policies impact study exploits administrative data—specifically, changes in the incidence of labor market inspections led by the Ministry of Labor—that capture within-country and time variation in the de facto enforcement of de jure labor market regulations. The evidence shows that where they are enforced, stringent labor regulations constrain Brazilian firms' flexibility in the short term, as employment falls by more—both for routine and nonroutine tasks—in municipalities with looser enforcement compared with those with stricter enforcement.

In contrast to policy intentions, the evidence shows that strict labor market regulations in Brazil differentially benefit the more skilled workforce, particularly those workers employed in nonroutine and more cognitive tasks. Aside from affecting the level of employment, the Brazil tasks and labor policies impact study also shows that enforcement of labor regulations is found to significantly affect the composition of employment at the local level. Specifically, the results show that in localities with more stringent enforcement of regulations, higher-skilled workers who are performing nonroutine tasks are disproportionally protected following technological adoption. Hence, when adopting ICT, stricter labor protections have the perverse effect of helping the nonroutine workers more because they result in a greater increase in the cost of nonroutine tasks. This evidence is consistent with evidence from studies of regulations in other countries showing redistributive effects of labor regulation that work against the interests of certain groups of workers, such as young workers and women (Montenegro and Pagés 2003; Betcherman 2012).These relatively greater impacts on tasks with more nonroutine and cognitive content may indicate that, in addition to affecting efficiency, employment protection regulations in Brazil may have important redistributive consequences.

Impacts of Technology on Firms and Workers through Trade and Labor Mobility

When firms access the Internet, they reach larger and more diverse markets at lower cost. Gaining access to international trade through online platforms can have an impact on the wages of their workers, and particularly on the wage gap between high-skilled and low-skilled workers. Exporting through traditional physical channels can be very costly and out of reach for many microenterprises and small firms in developing countries that lack a suitable workforce. Online platforms, which serve as an international marketplace matching buyers and sellers, provide them with a quick and cost-efficient way of reaching a larger number of new customers in foreign countries. Using a standard gravity model for bilateral trade flows on the e-Bay platform, the background study on the impact of online platforms and the skills premiums in wages shows that a 1 percent increase in online exports lowers the wage gap by about 0.01 percent. This effect on the wage gap is driven by countries with a larger proportion of small firms, more precisely by countries above the median of 44 percent share of employment in small firms (those with fewer than 10 employees). The decrease in fixed costs attributable to accessing online export platforms disproportionately benefits smaller firms that also tend to be more low-skill intensive.[5] As the region looks for ways to spur productivity while ensuring social gains, increased access to online trade in LAC can be an additional mechanism through which the reduction in the wage gap observed since the early 2000s can be sustained.

Access to ICT in the LAC region has also supported greater labor mobility and contributed to lower wage inequality. An additional way that digital technologies expand economic opportunities is by reducing information costs and thereby allowing for a better allocation of resources. In the LAC region this is an especially important link because the region has traditionally suffered from relatively low labor mobility across sectors and regions—the typical Latin American worker has had somewhat "sticky feet" (Hollweg et al. 2014). Exploiting household data across several LAC countries and other comparators, the background study on labor mobility adjustment costs highlights several interesting findings. First, on average, sector labor mobility costs are higher than regional mobility costs. The average cost of moving across both sectors and regions (that is, internal migration) is about 1.8 times the average annual real wage, which is higher than the cost of moving only across sectors or across subnational regions. Second, in poorer LAC countries, such as El Salvador, Guatemala, and Honduras, workers face higher mobility costs than do workers in middle-income countries, such as Brazil, Costa Rica, and Mexico. Exploiting cross-country variations, the study also suggests that labor mobility costs are partially driven by information asymmetries and that improved access to the Internet in the region could substantively mitigate these costs.

Notes

1. See appendix A for a list of these studies.
2. Interestingly, increases in the share of blue-collar workers in the services industries are higher than those in the manufacturing industries, and higher than the increase in the number of white-collar workers: for services, a 10-percentage-point increase in the share of labor using the Internet was associated with a 7 percent increase in white-collar workers, together with an 11 percent increase in blue-collar workers.

3. Enterprise resource planning is the integrated management of core business processes, often in real time and mediated by ICT. These business activities can include business intelligence, product and production planning, procurement, manufacturing or service delivery, distribution, marketing, sales and customer service, materials and inventory management, human resource management, accounting, and finance.
4. In a background study for this book, Packard and Montenegro (2017) expand on Alesina, Battisti, and Zeira's (2015) analysis using country-level data. The authors exploit greater economic and regulatory variation across a larger and more diverse sample of countries. The analysis unpacks labor regulation into separate components that are likely to shape firms' decisions differently. Whereas Alesina, Battisti, and Zeira (2015) analyze regulatory instruments such as statutory minimum wages, employment protection, and the power of unions separately, the background paper for this book uses four different measures that separately capture (1) the rigidity of working hours; (2) restrictions on the use of temporary, fixed-term contracts; (3) the procedural difficulty of dismissing workers; and (4) mandated payments to workers upon dismissal (such as employer-paid severance). The paper also captures other statutorily mandated nonlabor costs, specifically contributions required of employers and employees for social insurance (old age pensions; disability, survivor, and unemployment benefits; and health coverage).
5. On average, in the sample in the background paper, 25 percent of workers in small firms with fewer than 10 employees are considered to be skilled (at least a complete secondary education) versus 49 percent in larger firms with more than 50 employees. The larger share of skilled workers in large relative to small firms is observed in all countries in the sample.

References

Acemoglu, Daron, and David Autor. 2011. "Skills, Tasks and Technologies: Implications for Employment and Earnings." In *Handbook of Labor Economics*, volume 4, edited by David Card and Orley Ashenfelter, 1043–171. Amsterdam: Elsevier.

Alaimo, Verónica, Mariano Bosch, David S. Kaplan, Carmen Pagés, and Laura Ripani. 2015. *Jobs for Growth*. Washington, DC: Inter-American Development Bank.

Alesina, A., M. Battisti, and J. Zeira. 2015. "Technology and Labor Regulations: Theory and Evidence." Working Paper 20841, National Bureau of Economic Research, Cambridge, MA.

Autor, D. H., and M. J. Handel. 2013. "Putting Tasks to the Test: Human Capital, Job Tasks, and Wages." *Journal of Labor Economics* 31 (2): 59–96.

Autor, D. H., F. Levy, and R. J. Murnane. 2003. "The Skill Content of Recent Technological Change: An Empirical Exploration." *Quarterly Journal of Economics* 118 (4): 1279–333.

Betcherman, G. 2012. "Labor Market Institutions: A Review of the Literature." Policy Research Working Paper 6276, World Bank, Washington, DC.

Deming, D. 2015. "The Growing Importance of Social Skills in the Labor Market." Working Paper 21473, National Bureau of Economic Research, Cambridge, MA.

Hollweg, C. H., D. Lederman, D. Rojas, and E. R. Bulmer. 2014. *Sticky Feet: How Labor Market Frictions Shape the Impact of International Trade on Jobs and Wages*. Directions in Development. Washington, DC: World Bank.

Montenegro, Claudio E., and Carmen Pagés. 2003. "Who Benefits from Labor Market Regulations? Chile 1960–1998." Working Paper 4126, Inter-American Development Bank, Washington, DC.

Perry, Guillermo, William F. Maloney, Omar S. Arias, Pablo Fajnzylber, Andrew D. Mason, and Jaime Saavedra-Chanduvi. 2007. *Informality: Exit and Exclusion*. World Bank Latin American and Caribbean Regional Study. Washington, DC: World Bank.

World Bank. 2016. *World Development Report 2016: Digital Dividends*. Washington, DC: World Bank.

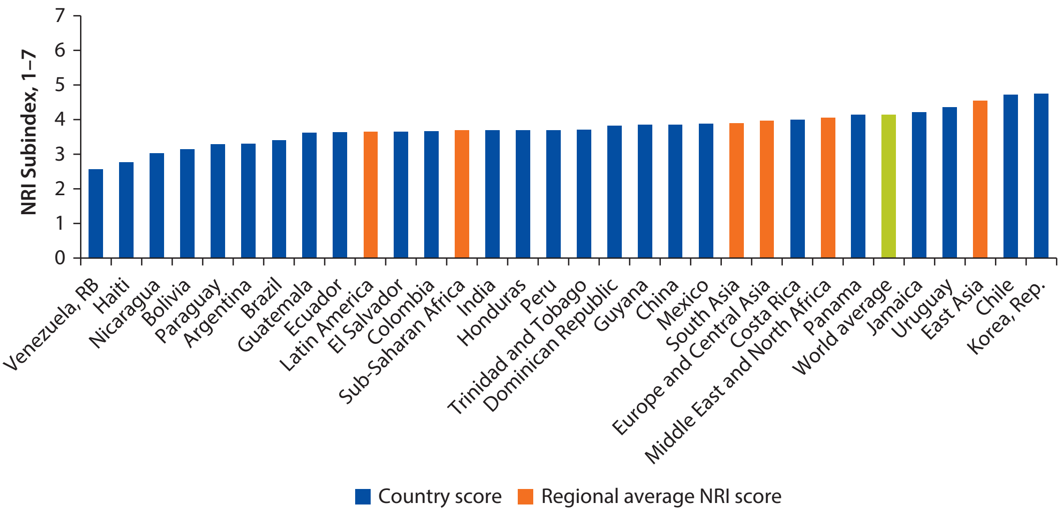
CHAPTER 5

Improving the Environment for Technology Adoption with Inclusion

Countries in the Latin America and the Caribbean (LAC) region have much to do to encourage greater adoption of digital technology. When assessed using benchmarks of the readiness of the business environment, LAC countries appear to be the least ready to support businesses' taking greater advantage of digital technology to boost productivity. Figure 5.1 benchmarks countries in LAC and other regions according the World Economic Forum's Networked Readiness Index subindex of the business environment. This subindex is constructed using 18 indicators that cover product market policies (such as intensity of local competition and ease of starting a business and enforcing contracts), skills and labor market policies (including tertiary education and quality of management schools), and technology generation and diffusion support policies (including availability of the latest technologies; government procurement of advanced technologies; laws related to information and communication technologies [ICT], such as e-commerce and intellectual property protection; and venture capital availability). Countries in the LAC region score, on average, lower than any other of the World Bank Group's operational regions, though the differences between some of these regions is not statistically significant. Importantly, there is considerable variation within the region: Chile is in first place according to this index, but Brazil and Argentina are in 14th and 15th places of the 20 LAC countries for which data are available. This benchmarking suggests that there is enormous potential for reforms to the business environment in LAC countries to encourage greater adoption of digital technologies, along with the boost to productivity and inclusive outcomes that doing so can generate.

Policies should be oriented toward facilitating the diffusion and adoption of technologies and sharpening incentives for output expansion. The empirical work commissioned for this book, along with previous studies, shows that countries can take important policy steps to improve the business environment for technology adoption, with the aim of increasing productivity and inclusive growth.

Figure 5.1 LAC Holds Last Place in the Business Environment Related to Digital Technologies



Source: World Economic Forum 2017.
Note: NRI = Networked Readiness Index.

First, policies should support extensive and rapid Internet rollouts, including enabling markets for the competitive and high-quality provision of Internet access and the diffusion and adoption of other digital technologies—as well as other productivity-enhancing technologies. Second, governments should implement product market policies that enhance opportunities and sharpen incentives for output expansion in response to the productivity increases that technology adoption yields.

Governments should support education and job skills structures that are more likely to ensure that the available skills of individuals in the labor market are complementary to adopted technologies and support workers with increased mobility patterns. Beyond solid foundational skills, new evidence in this book shows that digital technology adoption complements skills that are easily transferable across jobs and occupations, including higher-level cognitive and analytical skills, technical skills (for example, in ICT), and socioemotional skills (such as interpersonal skills). Critically, the education and training systems for the 21st-century worker need to include support for retraining throughout life and for skills renewal, both within firms and within industries, which implies a renewed focus on solid foundational skills. Rather than employment protection designed to make transitions and adjustments difficult, labor policies should be recrafted to assume that more frequent disruption and the need for change will occur and to support the necessary changes.

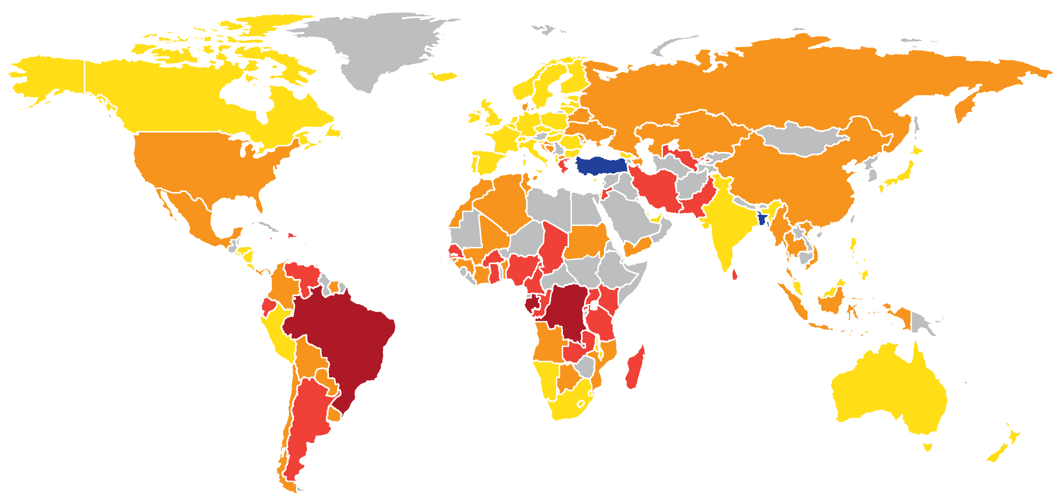
More detailed policy recommendations emerge from analytical findings, and are presented in the remainder of this section. Notwithstanding these overarching policy directions, the results of the more detailed analyses commissioned for this book point the way for addressing more granular and perhaps more manageable policy questions that can be the subject of further research efforts.

Technology Diffusion Support Policies

Policies to facilitate technology diffusion, adoption, and greater use—including digital technology policies to support high-quality and competitively priced Internet rollouts—are essential.[1] The Internet is the oxygen on which digital technologies thrive. Countries can do much more to support Internet rollouts, including by providing procompetitive support for higher-speed broadband rollout regimes.[2] Current adoption of ICT across the LAC region is highly heterogeneous and lags behind comparators in the Organisation for Economic Co-operation and Development (OECD), implying that there is still much potential for significant additional adoption in LAC and for the expected accompanying advances in productivity.

Additional tariffs and taxes on ICT may be holding back per capita GDP growth by 1 percentage point or more per year. Tariffs and taxes on ICT goods and services do not just dissuade businesses from adopting digital technologies, they also may prevent those businesses from existing at all. ICT tariffs and additional ICT taxes can add significantly to consumer and business costs of ICT goods and services (Miller and Atkinson 2014) (map 5.1). Brazil, Argentina, the Dominican Republic, Ecuador, and Jamaica are all in the top 20 of the 125 countries for which the extra costs that government imposes have been calculated, with Brazil's tariffs adding 16 percent and special taxes adding an additional 5 percent to the cost of a basket of ICT goods and services.[3] The estimated increase in annual ICT adoption if these tariffs and special taxes were to be removed in Brazil is significant, with increases in end-user consumer demand ranging between 17 and 37 percent for low- and high-elasticity estimates, respectively.

Map 5.1 LAC Has Some of the Highest Total Tariffs and Taxes for ICT Products



Source: Miller and Atkinson 2014. © Information Technology and Innovation Foundation. Used with permission; further permission required for reuse.
Note: ICT = information and communication technologies.

And middle-of-the-road estimates for the growth effects of removing these ICT tariffs and taxes show that these costs may be holding back growth by 1.5 percentage points of GDP per capita per year for Brazil, 1.2 percentage points for Argentina and the Dominican Republic, 1.0 percentage point for Ecuador, and 0.8 percentage point for Jamaica. An additional indicator of the high cost of digital technology business tools in the LAC region is given by the iPad and iPhone indexes, where two of the four listed Latin American countries (Argentina and Brazil) are in the top two (for the iPhone) and top three (for the iPad) most expensive countries out of 57 countries; the US dollar product cost of the most expensive country (Argentina for iPhones, Brazil for iPads) is more than twice the cost for the least expensive countries.[4]

Product Market Policies

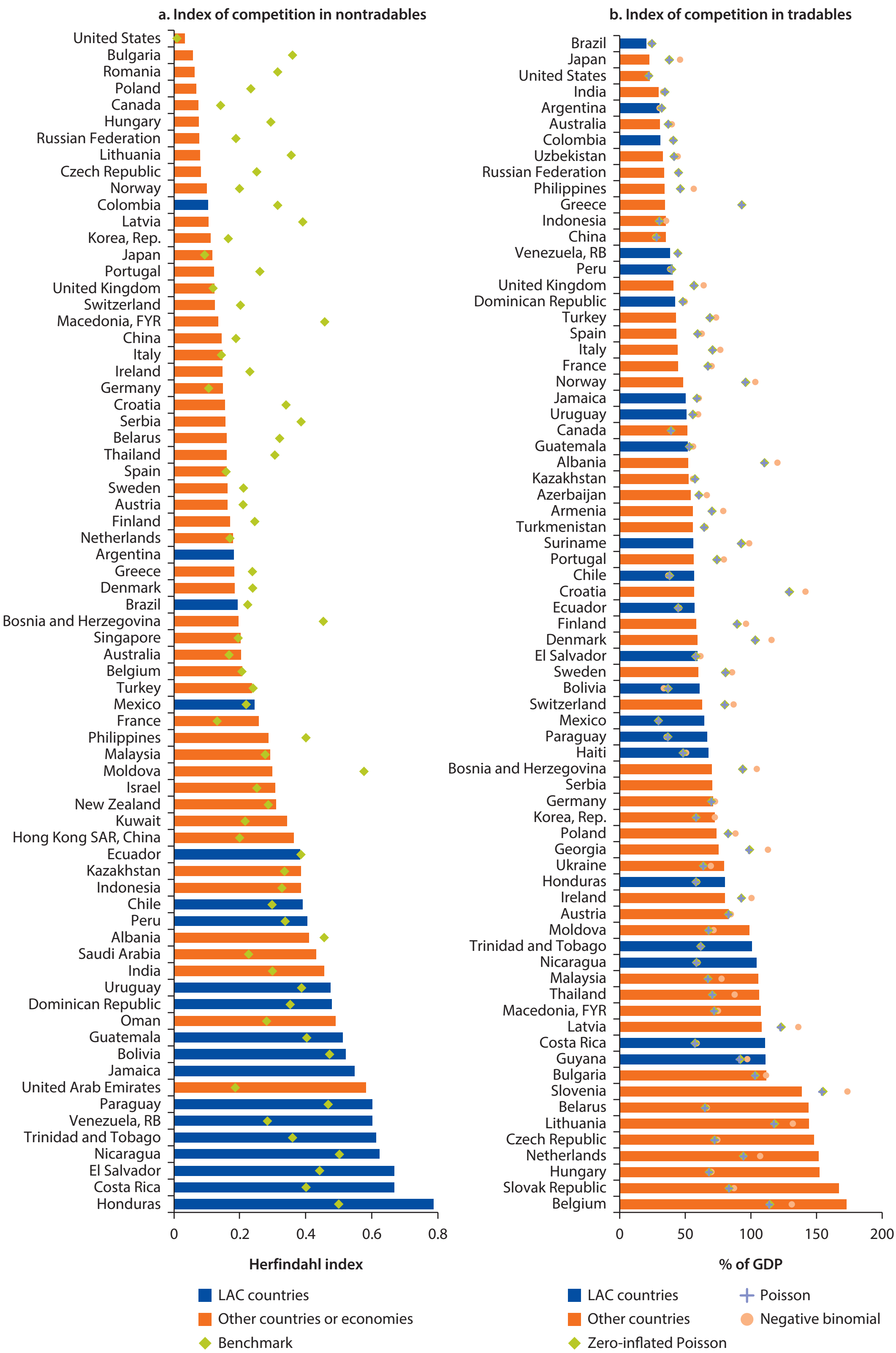
A range of product market policies shape the size of the output expansion effect on which inclusive job outcomes depend. Output expansion effects hinge on the responsiveness of output prices (as well as quality and market outreach efforts) to the lowered variable costs enabled by technology adoption; the availability of added labor, physical capital, energy, distribution inputs, and finance; and the responsiveness of consumer demand to the drop in output prices. Among others, a menu of product market policy reforms could include the following:

- *Increasing the intensity of domestic market competition* (including entry, expansion, and exit policies). For example, firm owners are more likely to pursue new customers using lower prices, higher-quality products, or both where they feel the pressure of competition. Lower variable costs are more likely to lead to larger output increases in contestable, competitive markets. Furthermore, output will expand more if the risk of losses from the possibility that any output expansion will need to be retracted is lower, which is influenced by, among other factors, the ability of firms to retrain or lay off workers at moderate cost and by the ability of bankruptcy protection to guard investors' interests if retraction is necessary.
- *Adopting policies that increase product tradability* across regions within the country and internationally for all potentially tradable products, including connectivity policies lowering transport and logistics costs, and critically including policies to lower tariff and nontariff barriers to external trade.
- *Facilitating access to finance* for adopting firms to purchase required inputs and pay for product promotion efforts.
- *Adopting policies supporting the upgrading of the quality of firm management* and other factors affecting firms' ability and know-how to enlarge production and distribution in response to lower variable costs.

Lack of competition, especially in nontradables, is a strong candidate for explaining the LAC region's lackluster technology adoption and output growth performance. Although the share of entrepreneurs (as measured by the number of firms per capita) is higher in LAC than in comparator countries and regions, this statistic masks a lack of dynamism in the region. Entry by entrepreneurs into the higher firm-size end of the formal sector remains low. New firms do not grow as much as firms in other regions and tend to remain small. Firms in the LAC region introduce new products less frequently than firms in otherwise-similar economies. High-end entrepreneurs tend to be further away from global best practices in the management of their enterprises, firms' investment in research and development is low, and patent activity is well below benchmark levels. Lack of competition also helps explain LAC's flat innovation and business growth performance, including technological adoption and catch-up (Lederman et al. 2014). Panel a of figure 5.2 benchmarks LAC countries' revealed market concentration in industries that are arguably not subject to international competition.[5] Most countries appear at the upper end of the market concentration index, and all but two (Brazil and Colombia) exhibit levels of market concentration well above their international benchmarks. Panel b of figure 5.2 benchmarks LAC's level of openness based on the ratio of international trade flows (imports plus exports) to GDP. The two countries that performed somewhat better relative to their international benchmarks with respect to nontradables are the worst performers. Brazil, in particular, has the lowest level of openness across all available countries, underperforming by about 3 to 5 percentage points of GDP. Of the 13 LAC countries with deficits in innovation, 10 have deficits in competition in nontradables, and 6 have deficits in competition in tradables.

In addition to stimulating larger output expansion effects, market competition also provides firms with incentives to adopt and use more digital technologies. Manufacturing firms in Mexico are more likely to invest in digital technologies and use them more productively when they sell products in markets where they face more intense rivalry (Iacovone, Pereira-Lopez, and Schiffbauer 2016). Firms that faced the external shock of higher foreign competition from China between 2000 and 2008, either in the domestic or the U.S. (export) market, increased their number of computers per employee, their share of labor using the Internet, and their share of online purchases in total purchases in the subsequent four-year period 2008–12. As a result, the share of labor using the Internet in 2012 was 11 percent higher for firms that faced more Chinese competition, and the share of online purchases was 114 percent higher. The more intensive use of digital technologies translated into productivity growth among firms, driven by a combination of cost efficiencies and output expansion. By contrast, ICT use had no impact on labor productivity growth among Mexican firms that did not face import competition from China. Similarly, manufacturing firms facing an increase in competition in Brazil were found to be more likely to adopt and use e-commerce systems, and to adopt more advanced e-commerce systems (Cirera, Lage, and de Oliveira 2015). More generally, aggregate sector and country data highlight a negative correlation between regulatory barriers to product market competition and firms' adoption of digital technologies.[6]

Figure 5.2 Indices of Competition



Source: Figures 6.4 and 6.5 in Lederman et al. (2014).
Note: LAC = Latin America and the Caribbean.

Education, Skills, and Labor Market Policies

Human capital plays a critical role for both the adoption and the use of technology because the demand for different and often more sophisticated skills generally increases following digital technology adoption. The evidence discussed in the previous chapters suggests substantial shifts in employment composition following Internet rollouts, favoring more educated and high-skilled workers. This presents risks for workers in the LAC region. In Brazil, for instance, in the short term, the adoption of the Internet creates increased local demand for more cognitive and nonroutine tasks, and within these, interpersonal and communication skills are at a premium. In addition, the evidence from Argentina and Chile also suggests that the adoption of technology is heavily influenced by the quality of the manager's human capital (as captured by her or his level of education and past relevant experience). Without a sufficient supply of workers equipped with these skills, the full productivity potential of digital technology adoption will be more difficult to achieve.

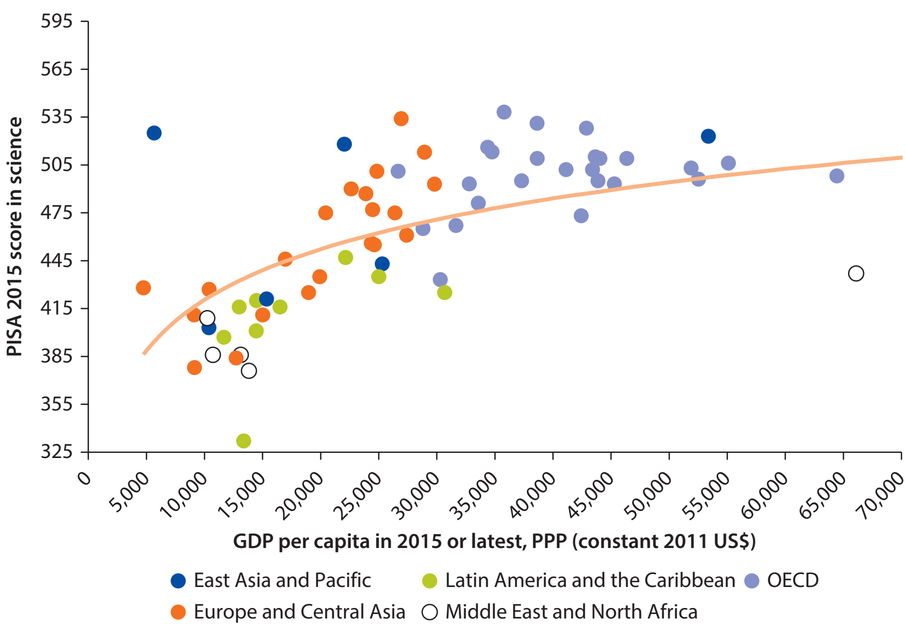
Investing in the skills of the workforce is necessary for individuals to benefit from the productivity and welfare gains from technology adoption. Technology adoption could simply increase inequality in labor markets. However, to lower the likelihood and severity of inequitable outcomes, investments in digital technologies should be accompanied by simultaneous investments in human capital through education and training systems. Without 21st-century skills to perform higher-level cognitive and analytical tasks, workers may find it much harder to be employed in the future, which may eventually increase labor market gaps. Furthermore, without managers who have adequate skills and experience, which could lead to lower-than-expected Internet adoption, firms and workers in the region could be forgoing significant productivity and welfare benefits. Hence, public education and training policies should focus on ensuring that today's youth—the future workforce—are well equipped with solid foundational skills, both cognitive and socioemotional, that allow them to take full advantage of the opportunities created by the digital world. Digital literacy and advanced ICT skills are also critical for the adoption and use of these technologies.

The evidence presented in this book suggests that technology adoption is associated with labor markets becoming more dynamic. To help people manage a more dynamic labor market, it will be essential to ensure that workers have solid foundational skills, both cognitive and socioemotional, that allow them to keep learning and acquiring human capital throughout their professional lives. In addition, assessing—and addressing—any constraints on greater investment by employers in job training is also important. There are market failures that combine to make it difficult for employers to appropriate returns to investments in transferable skills of their workers. Institutional arrangements, such as those that allow employers and employees to write labor contracts in which they agree on training and any eventual reimbursements if the contract is not fulfilled, can help mitigate risks related to the poaching of workers.

The promise of greater productivity from digital technology adoption creates new urgency for reforms to education and skills-training structures in LAC countries. The highest priority should be given to changes in the system that encourage the development of solid foundational skills, higher-order cognitive skills, socioemotional skills, and digital skills (many of which are highly transferable across occupations). Today, most education and training systems in LAC countries still fall far short of ensuring that all children complete lower- or upper-secondary education. And learning outcomes continue to languish below the performance of students in many peer countries. Even the lowest performers among OECD-member countries score well above the top-performing students in LAC (figure 5.3). Important gaps also remain in rates of completion and quality of higher education, as highlighted by the relatively low levels of scientific production in LAC countries compared with countries in Asia, North America, and Western Europe (figure 5.4). Furthermore, large inequalities in learning persist. Children from households in lower quintiles of the income distribution significantly underperform those from households in the upper quintiles. The timeframe required for reforms to education and skills training systems to bear fruit implies that this policy agenda should be given priority.

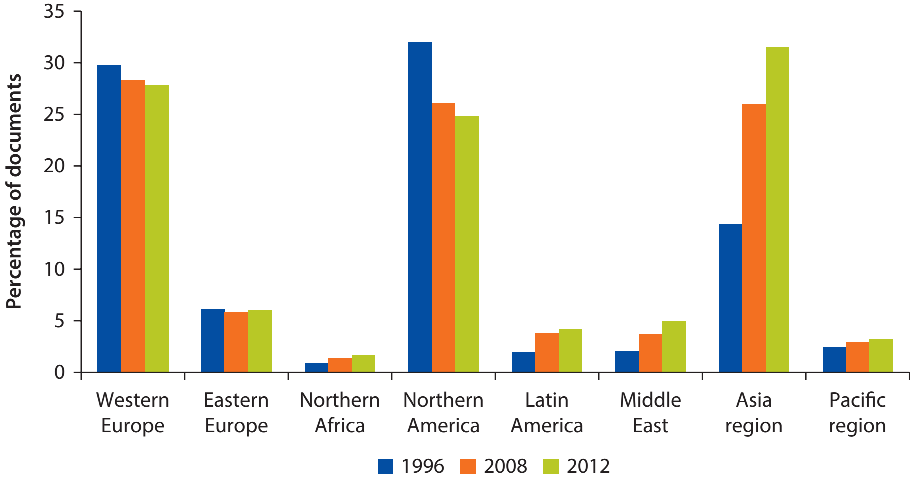
More broadly and more politically contentious, the underlying objectives of labor market policies need to be reformulated. Prevailing labor market policies

Figure 5.3 PISA Results and GDP per Capita



Sources: World Bank 2016a, 2016b.
Note: OECD = Organisation for Economic Co-operation and Development; PISA = Programme for International Student Assessment; PPP = purchasing power parity.

Figure 5.4 Scientific Production by Geographic Region



Source: Ferreyra and others 2017.

were designed for a time when most people reasonably expected to take the skills they learned in school and apply them in a single profession and in the same way for the course of their working lives. Technology adoption has always entailed changes to how people work. But what is different now is the speed of these changes. Technological change has accelerated to an unprecedented pace that would have been difficult to predict when most labor policies were adopted. Rather than a single occupation and place of employment, career disruption and transitions are becoming the new norms. The social norms and expectations on which labor policies rest are shifting away from aspirations for occupational stability and long-term employment relationships, toward occupational dynamism and greater mobility across professions, skill levels, geography, and forms of economic engagement (such as between employment, self-employment, and entrepreneurship). Technological advances are just one of several forces driving this shift. If policies were intended and designed to support people's management of the uncertainties and demands of a dynamic labor market, rather than the more stable labor markets of the past, labor policies—from worker protection and income support to intermediation—would probably look very different from their current form in most countries of the LAC region.

Notes

1. For a review of relevant technology diffusion and adoption support policies, see Cirera and Maloney (2017). They highlight management practices as one particularly promising area for technology adoption and upgrading. Key factors determining adoption that are prone to policy support include competition, human capital, and learning through participation in international markets (through trade, foreign direct

investment, and participation in global value chains), in addition to well-designed management extension programs.

2. Guatemala benefited from a faster reduction in prices for mobile services than the rest of LAC by being an early pioneer in spectrum auctions following its 1996 telecommunications law. Other LAC countries that have adopted similar policies have now overtaken Guatemala in the spectrum allocated to mobile communications (see box 4.6 and figure B4.6.1 in World Bank 2016b). Prices of mobile and fixed broadband services remain, on average, higher in LAC than in OECD countries (see box 4.1 and map 4.1.1 in World Bank 2016b).
3. The basket of ICT goods and services on which tariffs and special taxes are levied includes wired broadband, wireless phone services, and core ICT products, such as basic mobile phones, smartphones, computers, and other digital products like digital cameras and digital audio devices.
4. Differences in prices include tariffs and extra local consumption taxes, freight, and different markups. For iPhones, the product is the Apple 7, 4.7-inch 32GB device, costing US$1,630 in Argentina versus US$649 in California and US$640 in Saudi Arabia. For iPads, the product is the Apple Pro 10.5-inch 64GB Wi-Fi device, costing US$1,619 in Brazil versus US$703 in California and US$638 in Hong Kong SAR, China. Chile is the 7th most expensive location for this iPhone and the 9th most expensive location for this iPad; Mexico is 28th and 30th, respectively (Commonwealth Bank of Australia 2017). Import tariffs on computers and laptops are even higher in Cuba than in Argentina and Brazil (see figure 5.5 in World Bank 2016b).
5. The 17 nonfinancial services industries include electricity, building and specialized construction, civil engineering, wholesale and retail trade, transport and warehousing, telecommunications, insurance, real estate, engineering, and tourism. The index shows the average Herfindahl index of concentration of revenues across a selection of two-digit industries for which data were available for more than 80 countries, with a value of 1 representing a market that is captured by a single firm; lower values indicate lesser market concentration. Revenues were averaged across 2007–10.
6. More restrictive product market regulations on firm entry in services industries are associated with lower digital adoption, with most LAC countries in the sample (including Brazil, the Dominican Republic, Honduras, Mexico, Nicaragua, and Peru) having higher barriers to entry and lower levels of digital adoption than most other countries (World Bank 2016b).

References

Cirera, Xavier, Filipe Lage, and Joao Maria de Oliveira. 2015. "E-Commerce and Productivity in Brazilian Firms." Background paper for *World Development Report 2016: Digital Dividends*. World Bank, Washington, DC.

Cirera, Xavier, and William Maloney. 2017. *The Innovation Paradox: Developing-Country Capabilities and the Unrealized Promise of Technological Catch-Up*. Washington, DC: World Bank.

Commonwealth Bank of Australia. 2017. "Economic Insights: CommSec iPad/iPhone Indexes, Australia No Longer the Cheapest." September 11. Commonwealth Bank of Australia.

Ferreyra, María Marta, Ciro Avitabile, Javier Botero Álvarez, Francisco Haimovich Paz, and Sergio Urzúa. 2017. *At a Crossroads: Higher Education in Latin America and the Caribbean*. Directions in Development. Washington, DC: World Bank.

Iacovone, Leonardo, Mariana Pereira-Lopez, and Marc Schiffbauer. 2016. "Competition Makes IT Better: Evidence on When Firms Use IT More Effectively." Policy Research Working Paper 7638, World Bank, Washington, DC.

Lederman, Daniel, Julián Messina, Samuel Pienknagura, and Jamele Rigolini. 2014. *Latin American Entrepreneurs: Many Firms but Little Innovation*. Washington, DC: World Bank.

Miller, Ben, and Robert Atkinson. 2014. *Digital Drag: Ranking 125 Nations by Taxes and Tariffs on ICT Goods and Services.* Washington, DC: Information Technology and Innovation Foundation.

World Bank. 2016a. "PISA LAC Country Profiles." Unpublished, Washington, DC.

———. 2016b. *World Development Report 2016: Digital Dividends.* Washington, DC: World Bank.

World Economic Forum. 2017. *The Global Information Technology Report 2016*. Geneva: World Economic Forum.

CHAPTER 6

Conclusions

The principal conclusion of this book is that digital technology adoption offers a pathway to higher productivity and inclusive growth, contingent on appropriate enabling policies. This conclusion is supported by the following findings from the background empirical studies commissioned for this book (appendix A):

- *Impacts on workers' labor market outcomes—skills, jobs, and earnings—differ depending on the type of technology adopted*. Some technologies (such as complex software) appear to be inherently more "inclusive" than others (the Internet, for instance). Within firms, Internet availability, adoption, and use typically create a substitution effect away from low-skilled workers and toward more skilled workers. Internet adoption into firms' productive processes also creates a substitution effect away from manual and routine tasks toward more cognitive and analytical tasks. In contrast, use of complex software by firms in Chile creates a substitution effect toward low-skilled workers, and is associated with a reallocation of jobs away from abstract, sophisticated tasks and toward more routine and manual tasks.

- *Output expansion effects can overcome digital technologies' adverse substitution effects on low-skilled labor and result in more inclusive growth*. Importantly, sizable output effects can lead to an overall positive expansion in the levels of employment of both lower-skilled (less-well-off) and higher-skilled workers. Evidence from Brazil and Mexico suggests that these output effects tend to be larger in more tradable sectors that provide larger output expansion opportunities. Complementary evidence from Argentina suggests that these output effects help lower-skilled workers more in firms experiencing faster output growth.

- *Adoption of information and communication technologies (ICT) changes the demand for skills and shifts demand away from more routine, manual tasks toward nonroutine analytical and cognitive tasks.* The Brazil tasks and labor policies impact study finds that this pattern is consistent nationwide but also across all the largest sectors of the economy. This finding validates some of the concerns that routine, manual tasks are increasingly being replaced by technology, thereby displacing less-skilled workers (Autor, Levy, and Murnane 2003). However, the overall impacts depend on the technology in use. The Chile study exploits the impact of advanced software. Over a period of more than five years, firms expanded following the adoption of complex software, and also increased their use of low-skilled labor while relying more on routine tasks.

- *ICT is positively correlated with firm dynamism, as exemplified by job destruction and job creation*. Evidence from both Argentina and Brazil suggests that digital technologies lead firms to replace workers, replace occupations, exit, or expand, creating new occupations. Importantly, in Argentina the share of firms creating new occupations is almost three times larger than the share of firms replacing occupations.

- *Adopting firms have more-skilled managers and invest more in upgrading the skills of their workers.* In Argentina and Chile, adoption of ICT and advanced software, respectively, are highly correlated with the human capital of the manager. More educated and experienced managers are more likely to invest in new digital technologies. The Mexico study documents that firms that make more intensive use of ICT provide more training for both higher- and lower-skilled workers, with lower-skilled workers receiving significantly greater levels of training. In Chile, the adoption of complex software by firms across all sectors of the economy is also associated with increased investment in on-the-job training for digital skills, especially at the managerial level.

- *The adoption and the impacts of ICT on jobs and employment outcomes depend on the stringency of labor market regulations and in what combination they are deployed*. High statutory minimum wages and the direct monetary costs of supporting displaced workers appear less detrimental for the adoption of ICT than burdensome worker dismissal procedures. At reasonable levels, statutory minimum wages can encourage firms to invest in developing the skills of their workforce to maintain and even grow specifically useful human capital. Anticipating a rise in their productivity, firms eager to adopt new technologies and procedures might welcome the chance to contribute to the relatively certain upfront costs of meeting the needs of workers who require up-skilling, re-skilling, or indeed financial support while they look for new jobs. However, keeping the "hassle tax" of making changes to their workforces low (that is, less cumbersome administrative procedures for dismissing workers and fewer restrictions on how workers are employed) could speed the pace of adjustment, the achievement of new levels of productivity, and the types of increases in output that translate into job creation. Furthermore, the Brazil tasks and labor policies impact study shows that enforcement of labor regulations limits the degree to which companies shift away from labor as technology becomes available.

In contrast with policy intentions, they seem to protect more the more skilled workforce, particularly those leading nonroutine and higher-level cognitive tasks.

- *Inclusive employment outcomes from technology adoption are fostered by a business environment in which greater productivity leads to greater output*. Greater productivity and output are more likely where labor can be more easily redeployed within firms or across industries, where there is better connectivity and distribution infrastructure (increasing opportunities to effect sales), and in contestable, competitive markets where firms have strong competitive pressures that provide them with incentives to pass on the productivity gains to customers in the form of lower prices, better-quality products, or both.

- *ICT reduces firms' cost of entering more distant national and foreign markets.* Lower entry costs enabled by online trading platforms and other such connectivity-enhancing technologies allow smaller firms with relatively more low-skilled workers to benefit from international trade by extending their reach to larger, more diverse markets. A boost to their production can increase the wages that firms are able to pay their workers relative to workers in firms that use skilled labor more intensively. Easier and lower-cost access to international trade, therefore, supports more inclusive growth through a market access effect that favors smaller firms and less-well-off workers.

- *ICT reduces individuals' information costs, leading to lower sector and regional mobility costs.* Worker mobility costs across sectors and regions are kept high by, among other factors, information asymmetries. Access to the Internet can lower these mobility costs, thereby supporting more inclusive growth through lower adjustment costs and greater labor market efficiency.

Questions for Further Research

The more detailed analyses underpinning this book point the way for addressing more granular and perhaps manageable policy questions in future work. Two overarching questions remain: First, why does digital technology adoption remain so low in Latin America and the Caribbean? Second, which policies are more likely to foster the kind of technology adoption that will elevate productivity and increase inclusive growth through the output expansion mechanism? Regarding the challenge of improving product market policies, follow-on questions include the following: Can the enhanced availability of new technologies to firms be linked to their participation in industries with potential for substantial output expansion? What policy measures also enhance firms' ability to expand output through the availability of capital financing, and through enhanced avenues for expanding areas of sales, including through managerial assistance for growth strategies? Furthermore, in a region that has always struggled with protected, segmented, oligopolistic markets, the role of domestic competition policy is a potential issue for future research—to address insufficient competition in investments and delivery of ICT services as well as in output and input markets of adopting firms, including high transport costs, import duties and additional taxes, and other policy-related barriers that raise the costs of adoption of ICT and other technologies and that dull adopting firms' output expansion incentives. The role of appropriate domestic competition policy includes the important issue of what policy safeguards can be put in place to ensure contestability and competition, particularly in the face of digital technologies' network effects.

Additional questions arise regarding the challenge of improving education systems and adjusting labor market policies. How can education and training systems better prepare students today for jobs that are increasingly more skill-biased, and oriented toward higher-level analytical and socioemotional skills? How can the business environment better support employers in fostering such investment in human capital throughout workers' lives? What should policy's role be in fostering the use of ICT to reduce information costs to individuals and to lower sector and regional mobility costs? If career disruption is more likely than in the past, what form should labor market policies take to assist workers in making occupational and labor market transitions? And how can technology more effectively support enforcement of regulations as well as enable employers' compliance while providing incentives for firms and workers to keep adopting and adapting new technologies? These questions provide a rich menu of further policy-relevant analytical work to better understand how to make productivity growth more inclusive.

Reference

Autor, D. H., F. Levy, and R. J. Murnane. 2003. "The Skill Content of Recent Technological Change: An Empirical Exploration." *Quarterly Journal of Economics* 118 (4): 1279–333.

APPENDIX A

Background Studies

Conceptual framework:

Brambilla, Irene. 2018. "Digital Technology Adoption and Jobs: A Model of Firm Heterogeneity." Policy Research Working Paper 8326, World Bank, Washington, DC.

Studies exploiting firm-level and municipal-level data with new learning on the impacts of digital technology adoption on productivity, jobs, skills, and wages:

Almeida, Rita K., Carlos H. L. Corseuil, and Jennifer P. Poole. 2017. "The Impact of Digital Technologies on Routine Tasks: Do Labor Policies Matter?" Policy Research Working Paper 8187, World Bank, Washington, DC.

Almeida, Rita K., Ana M. Fernandes, and Mariana Viollaz. 2017. "Does the Adoption of Complex Software Impact Employment Composition and the Skill Content of Occupations? Evidence from Chilean Firms." Policy Research Working Paper 8110, World Bank, Washington, DC, and CEDLAS-FCE-UNLP Working Paper No. 214, Argentina.

Brambilla, Irene, and Darío Tortarolo. 2018. "Investment in ICT, Productivity and Labor Demand: The Case of Argentina." Policy Research Working Paper 8325, World Bank, Washington, DC.

Dutz, Mark A., Lucas Ferreira Mation, Stephen D. O'Connell, and Robert D. Willig. 2017. "Economy-Wide and Sectoral Impacts on Workers of Brazil's Internet Rollout." *Forum for Social Economics* 46 (2): 160–77.

Iacovone, Leonardo, and Mariana Pereira-López. 2018. "ICT Adoption and Wage Inequality: Evidence from Mexican Firms." Policy Research Working Paper 8298, World Bank, Washington, DC.

Ospino, Carlos. 2018. "Broadband Internet, Labor Demand and Total Factor Productivity in Colombia." Policy Research Working Paper 8318, World Bank, Washington, DC.

Studies exploiting household data with impacts of digital technology adoption linked to trade and labor mobility, and links between labor market regulations and digital technology adoption:

Cruz, Marcio, Emmanuel Milet, and Marcelo Olarreaga. 2017. "Online Exports and the Wage Gap." Policy Research Working Paper 8160, World Bank Washington, DC, and Discussion Paper 12092, Centre for Economic Policy Research, London.

Cruz, Marcio, Emmanuel Milet, and Marcelo Olarreaga. 2017. "Labor Adjustment Costs across Sectors and Regions." Policy Research Working Paper 8233, World Bank, Washington, DC.

Packard, Truman, and Claudio E. Montenegro. 2017. "Labor Regulation and Digital Technology Use: Indicative Evidence from Cross-Country Correlations." Policy Research Working Paper 8221, World Bank, Washington, DC.

APPENDIX B

Detailed Literature Review

Impacts of Technology Adoption on Jobs

The effects of technology adoption on labor demand predicted by economic theory are ambiguous. For instance, process innovation can lead to the substitution of capital for labor while also increasing productivity, lowering prices, and increasing demand for firms' output, thereby leading to higher employment. Obversely, while product innovation usually creates more demand, it can also increase the market power of innovators, allowing them to profitably raise their prices and suppress the output of their products (Castillo et al. 2011). With further ambiguity, Bender et al. (2016) show that the enhanced productivity of better-managed firms is accompanied by fewer layoffs since these firms are more likely to recruit higher-ability workers.

People with different skill levels are affected differently by the adoption of technology, which can change the structure of the workforce. The introduction of new technologies can make workers more productive, leading to higher wages, but it can also be associated with employment turnover. A large body of empirical work argues that technology adoption has favored the wage and employment prospects of relatively high-skilled workers while simultaneously dampening the wages and employment of the less skilled (see, for example, Autor, Katz, and Krueger 1998; Bresnahan, Brynjolfsson and Hitt 2002; Caroli and van Reenen 2001).

The key parameters determining the impact of technology on jobs include skills demand, labor costs, productivity, and output demand (including changing price and income elasticities of demand). Novick and Rotondo (2013) estimate a panel model for the period 2007–10 and find that wages and employment growth are higher as the information and communication technologies (ICT) structure becomes more complex for firms in the same sector with the same size, age, and productivity level. The authors argue that the results are contrary to the thesis that posits that technological unemployment is a consequence of the incorporation of labor-saving technologies, particularly affecting low-quality jobs. Moreover, the results are consistent with the perceptions of employers in companies with highly complex ICT adoption processes, who indicated in a set of in-depth interviews that ICT adoption has no obvious impact on staff turnover. A separate group of studies relies on the estimation of partial correlations based on firm-level data from developed countries to analyze the adjustment in employment, skills, and wages due to ICT adoption. The studies use a wide variety of firm-level ICT adoption measures, such as information technology (IT) capital stock, computer adoption, the number of computers, IT investment, and the number of IT workers. Their results indicate that ICT adoption is associated with higher relative demand for high-skilled workers and higher wages (Caroli and van Reenen 2001; Greenan and Topiol-Bensaid 2001; Bresnahan, Brynjolfsson, and Hitt 2002).

Based on country- and industry-level data for 19 high-income countries over more than 35 years,[1] Autor and Salomons (2017) find that rising country-level productivity is associated (correlated) with growing aggregate employment and a rising employment-to-population ratio. They show that this is the result of two different dynamics: on the one hand, industries that experienced rapid productivity growth exhibited diminished internal (own-industry) employment growth over time;[2] on the other hand, other-industry aggregate productivity growth (occurring outside each industry) has strong predictive power for employment growth within each industry, with these cross-industry productivity spillovers accruing through rising final demand (an income effect raising consumer purchasing power) or through inter-industry demand (output) linkages—fueling aggregate output expansion and jobs growth. The indirect positive effect of productivity growth on employment across industries is found to dominate and more than fully offset the direct negative effect on own-industry employment.[3] Although their empirical approach allows economy-wide and industry-specific job effects to be assessed, the authors concede that their approach to measuring technological adoption based on labor productivity does not distinguish among the possible different labor market consequences of different technologies, nor other distinct sources of productivity growth, such as those arising from shifts in infrastructure investments, trade, offshoring, and global production chains.

The findings of Autor and Salomons are perfectly consistent with the impact on jobs of different types of technological advances. On the one hand, there are technological advances like textile weaving machines and robots on the assembly line that directly displace (substitute for) lower-skilled workers, and in substantial quantities, due to the scale economies in their operations and support infrastructure. Even with positive output effects, this is likely to decrease lower-skill jobs in those enterprises, unless the domain of application of this technology is narrow compared to the scope of unskilled tasks in the enterprise; see Bessen (2015) on textiles and Acemoglu and Restrepo (2017) on robots. On the other hand, there are quite different technological advances (like ICT and broadband availability, on which we focus) that do not much directly displace and substitute for lowest-skill work, but might somewhat substitute for work that is part of the hollowed out middle-skill work story-line (see the section on tasks further below). Here there is bound to be productivity gains, and potential positive output effects. The overall country-wide impact on jobs of these different types of technological advances, as highlighted by Autor and Salomons, shows an overall positive country-level association of productivity and employment: even where there is direct substitution for lower-skill work, there will be productivity gains, lower prices for the output which serves as inputs into other industries, and thus output gains in other industries utilizing those inputs and correspondingly needing more labor, without the directly offsetting impacts on employment from substitution that occurred in the upstream industries.

Although current thinking on technology, skills demands, and jobs is shaped mainly by evidence from high-income countries, a recent surge of studies focuses on innovation and labor markets in Latin American countries. The body of empirical work examining the effects of different types of innovation on employment growth and skills composition in Latin America is growing quickly. This is particularly apparent for firm-level studies applying similar analytical techniques (see, for example, Alvarez et al. 2011 for Chile; de Elejalde, Giuliodori, and Stucchi 2011 for Argentina; Monge et al. 2011 for Costa Rica; and Aboal et al. 2011 for Uruguay). And for a broader assessment on these and related questions associated with how emerging trends in technology and globalization are likely to shape the feasibility and desirability of manufacturing-led development as a generator of productivity and jobs from the perspective of all low- and middle-income countries, see Hallward-Driemeier and Nayyar (2017).

Technological innovation in products and processes in Latin American countries appears to affect employment differently and, on balance, positively. The first conclusion from these papers is that while product innovations increase employment, process innovations do not affect jobs. The results do not change when the studies account for firm size. A second result is that product innovation increases both high-skill and low-skill jobs, with a higher proportion of high-skill jobs. However, process innovation, in general, has a weakly negative or zero effect on low-skill employment growth. The third result from these papers is that producing technology internally (in house) has the biggest positive impact on employment, followed by make-and-buy or buy-only strategies. Overall, these papers indicate that innovation does not generally lead to job losses and that it generates greater demand for a more qualified labor force.

Introduction of new products seems to boost employment. Crespi and Tacsir (2012) present a comparative analysis of four Latin American countries that shows product innovation to be an important source of firm-level employment growth due to a boost to demand. Process innovation accounts for a small share of the changes observed in employment, inducing small or zero displacement effects. This last result can be explained by the absence of productivity gains that would lead to a reduction in employment, or the combined effect of productivity gains (displacement or substitution effect) that induce demand growth through market competition (creation or output effect). The results are similar for small and large firms. The researchers also find some evidence of skill bias of product innovation for high-tech sectors. Some public policies related to innovation promotion have also been evaluated through quasi-experimental techniques. Castillo et al. (2011) evaluate the impact of the Argentine innovation support program PRE (Enterprise Restructuring Program) on employment and wages. They find that although support for both process and product innovation–related activities leads to increased employment, the support for product innovation has a higher effect on real wages, exporting, and survival probability.

Impacts of Technology Adoption on the Skill Content of Tasks

Concerns for the impact of technology on jobs has been heightened by evidence of a "bias" that favors people with skills and that many argue is inherent in technological change. This concern is fueled mostly by greater inequality in earnings from shifts in the demand for skills in the United States and other high-income economies. The rise in inequality in the United States that was led by a rise in the skill premium, and especially the college wage premium during the 1980s and 1990s, motivated a large literature that pointed to skill-biased technological change (SBTC) as a driving force behind this phenomenon. SBTC is based on the idea that technology is complementary to skills and therefore its benefits are biased toward more skilled workers, while technology can substitute for less skilled workers. When new technology is adopted, the demand for high-skilled relative to low-skilled workers increases and the wage gap widens, increasing wage inequality. These effects might be avoided by an increasing supply of human capital, in what Goldin and Katz (2009) regard as a race between technology and education. In this sense, if the supply of highly skilled individuals increases at a faster pace than ICT adoption, wage inequality can even be reduced (World Bank 2016).

The available evidence of a skills bias mostly comes from the United States. For instance, Krueger (1993) finds a strong positive correlation between wages and computer use by workers, and Doms, Dunne, and Troske (1997) show that establishments that invested relatively more in computing equipment had larger increases in the share of nonproduction labor. Furthermore, Machin and van Reenen (1998) provide evidence that SBTC is an international phenomenon that has increased the demand for high-skilled workers over demand for less-skilled workers. More recent studies have focused more on the mechanisms through which increases in technology could affect wages and hours worked by introducing a "tasks approach" to labor demand. Autor, Levy, and Murnane (2003) and Acemoglu and Autor (2011) focus on the task content of different occupations. They explore how technology—and ICT in particular—substitutes for routine tasks but complements cognitive and nonroutine tasks that are performed by individuals with more skills. Workers with a certain skill level can change the set of tasks performed to respond to changes in technology, how it is applied in the workplace, and broader labor market conditions.

People in the middle of the skills distribution are particularly affected by advances and adoption of technology. A growing body of theory and empirical work shows that middle-skilled individuals working on routine tasks could also be vulnerable to replacement by ICT. This substitution would lead to job and wage "polarization." Michaels, Natraj, and van Reenen (2014) study whether

ICT has contributed to the rise in polarization. Based on a comprehensive industry-level data set that covers 11 advanced countries from 1980 to 2004, they find that the industries that invested more heavily in ICT demanded more highly qualified workers. By analyzing how the different occupations and tasks for the United States are correlated with education, they find that indeed more highly educated individuals perform cognitive nonroutine tasks, while middle-educated individuals are overrepresented in occupations that require routine but more complex tasks than the noncognitive routine tasks that less-educated workers perform. The estimated effect explains one-quarter of the college wage bill in the economy as a whole. Autor, Katz, and Kearney (2006) present evidence of rising employment in the highest- and lowest-paid occupations. In a later paper the same authors show that wage inequality at the bottom half of the income distribution has not increased since the 1980s and that, instead, wage inequality has risen in the upper tail (Autor, Katz, and Kearney 2008). Finally, Autor and Dorn (2013) examine the impact of computerization on the demand for low-skilled labor. They use district-level data for the United States and show that areas with high levels of routine tasks have experienced greater adoption of ICT, greater reallocation of workers from routine tasks to the service sector, wage polarization, and large inflows of high- and low-skilled workers. These recent approaches based on tasks predict positive effects of ICT adoption on the demand for more-educated individuals and reductions in the demand for medium-skilled individuals, with effects for less-educated workers being less clear.

Different technological advances and types of new technology adopted by firms have very different effects on skills demand and jobs. Looking beyond computerization and adoption of basic ICT, the labor market impacts of more sophisticated technologies, including advances in automation, robotics, and AI (artificial intelligence), have captured the attention of researchers (Frey and Osborne 2013; Brynjolfsson and McAfee 2011, 2014; Graetz and Michaels 2015; Acemoglu and Restrepo 2016, 2017, 2018). In a book that has garnered considerable attention, Brynjolfsson and McAfee (2014) argue that more sophisticated technological innovations are no longer confined to routine tasks, but increasingly can be applied to nonroutine domains, even performing tasks typically performed by higher-skilled workers. An example of this trend is the number of tasks usually performed by lawyers and accountants that are now being undertaken by sophisticated algorithms. Machine learning techniques are advancing in the direction of being able to program a computer to autonomously master a nonroutine task (Autor 2015). The ensuing concern is that such technological innovations may in the future replace many types of jobs that have previously been insulated from more routine-biased technological developments. World Bank (2016) follows Frey and Osborne (2013) in investigating the feasibility of automating existing jobs given current and potential technological advances, based on the occupations of workers, and shows for OECD countries that over the next couple of decades half of jobs could be automated. Following a task-based approach, Arntz, Gregory, and Zierahn (2016) allow for heterogeneity of workers' tasks within occupations and demonstrate that the threat from technological advances is less pronounced, with a much smaller percentage of jobs in OECD member countries being candidates for automation in the future. Acemoglu and Restrepo (2018) extend their task-based framework to study the implications of automation and AI. Their framework emphasizes the substitution (which they call "displacement") effect that automation creates as machines and AI replace labor in tasks that it used to perform, just as in the model in this book. This substitution effect tends to reduce the demand for labor and wages. It is counteracted by an output expansion (which they call "productivity") effect, resulting from the cost savings generated by the productivity gains from automation, which increases the demand for labor in nonautomated tasks, again just as in the model in this book. Their output expansion effect is complemented by additional capital accumulation and the deepening of automation (improvements of existing machinery), both of which further increase the demand for labor. However, they emphasize that these effects, which as in the model in this book counterbalance the substitution effect and therefore are called "countervailing effects" in their paper, are incomplete. Even when they are strong, automation increases output per worker more than wages and reduces the share of labor in national income—which is different from the model in this book. The more powerful countervailing force against automation in their model is the creation of new labor-intensive tasks, which reinstates labor in new activities and tends to increase the labor share to counterbalance the impact of automation. In contrast to their direction of study, which focuses on digitized production equipment, including robots and AI that can replace workers, the work in this book is focused more on the impact of information-based, digitized, cognition-supporting technologies that are typically more complementary to workers.

The firm-level evidence on SBTC, occupations and tasks, and labor outcomes is scarce, but points to an advantage for workers with more skills. Bloom et al. (2014) examine the impacts of complex software on firms' organizational decisions, although they do not address the impact on demand for different types of skills. Their conjecture is that the use of business software reduces the costs for workers to access information, allowing workers to solve more problems and rely less on the training of specialists. Their evidence for firms in the United States and Europe confirms that indeed the use of business software increases decentralization within the firm, leading to more autonomy and a wider span of control for local plant managers. Another firm-level example is in the work of Akerman, Gaarder, and Mogstad (2015), who use Norwegian data and a quasi-experiment to provide compelling causal evidence that suggests that employment and wages of high-skilled (low-skilled) workers increase (decrease) with broadband Internet availability. On the firm side, increased availability of broadband Internet is associated with an increase (decrease) in the output elasticity of low-skilled (high-skilled) labor. They argue that broadband adoption in firms complements high-skilled workers in executing nonroutine, abstract tasks, and substitutes for low-skilled workers in performing routine tasks. Other related studies generally show that firms' ICT adoption does not lead to changes in overall employment but tends to be associated with increased wages and better labor outcomes of high-skilled workers—linked to nonroutine cognitive tasks—and worse outcomes for low-skilled workers—linked to more routine tasks that are automated with the use of ICT (Bartel, Ichniowski, and Shaw 2007; Böckerman et al. 2016; De Stefano, Kneller, and Timmis 2014; Gaggl and Wright 2017).

Occupations that entail more ICT-intensive tasks are more likely to require workers with more cognitive skills. Evidence from Latin America shows that occupations that use ICT more intensively have high demand for cognitive skills and low demand for routine and nonroutine manual skills in developing countries (Santos, Monroy, and Moreno 2015). Messina, Oviedo, and Pica (2016) offer a descriptive perspective of this job polarization in emerging market economies by analyzing the task content of jobs in Bolivia, Colombia, and El Salvador. The authors are only able to present a snapshot of possible job polarization because no information was available with which to measure polarization. They compare their results with data from the United States and find that although the cognitive content of jobs is similar, the tasks performed under routine and manual jobs in Latin America and the United States are different. They also use Mexican and Chilean data to test whether the labor markets in these two countries show a pattern of polarization. According to their analysis, only Chile shows possible job polarization. They find no evidence of wage polarization in any of the other Latin American countries, perhaps suggesting that any impacts produced by ICT adoption could have been overcome by the strong commodity boom experienced by most economies during the 2000s, which benefited primarily low-skilled workers (Cruces et al. 2015; Maloney and Molina 2016). In addition, there is evidence of a wage premium associated with the use of computers at the workplace between 2000 and 2006 (Benavente, Bravo, and Montero 2011).

Job polarization in the wake of technology adoption is far less apparent in low- and middle-income countries. Looking at evidence from 21 countries in Latin America, Asia, the Middle East, and Africa, Maloney and Molina (2016) find little evidence of polarization patterns. Only in Brazil and Mexico did they find a relative reduction of routine jobs, suggesting potentially polarizing forces at work in the labor markets of those two countries. The results for Mexico counter the evidence presented by Messina, Oviedo, and Pica (2016). Maloney and Molina (2016) additionally discuss the channels through which technology affects the labor market, because the effects of automation and offshoring of routine tasks may work in opposing directions in developing countries. They suggest that technical change reduces routine tasks, but the same technical change could promote the development of more complex versions of existing tasks, increasing job opportunities. The routinization effect is similar to that observed in developed countries. Conversely, routine tasks might increase in developing countries because of the new opportunities arriving as a result of the offshoring process in developed countries. In addition, the routinization effect of technical change may be mitigated as the feasibility of automation within the country plays a crucial role. The automation potential would be limited by the technical absorptive capacity of the country and the availability of skills in the workforce.

Consequently, the relationship between technical change and job polarization is not as straightforward as in developed countries.

Impacts of Technology Adoption on Trade and Mobility

Broadband Internet and other digital technologies open access to large and diverse new markets, mainly by substantially reducing entry and transactions costs. Akerman, Gaarder, and Mogstad (2015) contend that the Internet is biased against low-skilled workers. However, online trade specifically could challenge this contention by making the Internet available to everyone, with a possible decrease in wage skill premiums through reductions in the cost of reaching consumers in foreign markets brought about by online platforms (Lendle et al. 2016). As the cost of exporting declines, smaller firms, which generally have a more low-skilled workforce, are able to export. This suggests that as online exports develop, a reduction in the wage skill premium should be expected.

Indeed, the Internet and digital technology are challenging constraints on the mobility and reach of labor and human capital. The literature has recently produced various estimates of mobility costs (Hollweg et al. 2014). Kennan and Walker (2011) develop a model of individual migration in which expected income is the main force influencing migration. They test their model using detailed U.S. data on individual workers. They find that interstate migration is strongly influenced by the prospect of higher income in other states, and estimate an elasticity of 0.5 between wages and the migration decision. They do not consider sector mobility costs and exclusively focus on regional mobility costs.

Lower mobility costs increase the set of opportunities that the Internet and digital technologies offer to working people. Using the same kind of theoretical tools but in a context of trade shocks, Artuç, Chaudhuri, and McLaren (2010) propose a structural estimation of the reallocation cost of workers across sectors. Using panel data in which workers' movements can be observed over time, they estimate the structural parameters of their model on U.S. data and find an average moving cost of about 13 times the average worker's annual wage. Workers are homogeneous in their model, which may explain the large moving cost they obtain. Dix-Carneiro (2014) develops a model that assesses the heterogeneity of workers. Using panel data for Brazilian workers, he estimates an average moving cost of about two times the average annual worker's wage. Considering that heterogeneity across workers appears to greatly affect the magnitude of the moving cost, Artuç, Lederman, and Porto (2015) estimate sector mobility costs in a large number of countries by adapting the methodology in Artuç, Chaudhuri, and McLaren (2010), implemented using repeated cross-sectional data on sectoral employment in each country. They find sector mobility costs that are, on average, three times annual wages. One important difference between all these papers and the analysis conducted by Cruz, Milet, and Olarreaga (2017) in one of the background studies for this book is that the new study simultaneously allows for regional and sector mobility costs whereas the previous papers exclusively focus on only one of these two components. The authors find that simultaneously accounting for both is important to outcomes.

Impacts of Labor Market Policies on Firms' Technology Adoption Decisions

Labor policies are intended to help people manage the uncertainty of shocks to their income, including changes in demand for labor and skills caused by widespread adoption of new technology. Regulations such as a statutory minimum wage and employment protection legislation; interventions such as social insurance for unemployment, disability, or retirement; and institutions such as the labor code and the rights and rules of collective bargaining are formulated according to each country's norms and policy-making processes. However, many features are common across countries. Labor market policies and programs are put in place in an attempt to address well-established labor market failures. These include, but are by no means limited to, uneven power between those who seek (firms) and those who sell (individuals) labor and human capital, information failures on all sides, and limited or weak insurance markets for mitigating the risks to household well-being from loss of work and other shocks to income (Boeri and van Ours 2008; Kuddo, Robalino, and Weber 2015). The predictions of how regulations such as a minimum wage and restrictions on dismissals create a wedge between the cost of labor and what people take home are well known and actively debated (Heckman and Pagés 2004; Pagés, Pierre, and Scarpetta 2009). Furthermore, a large literature has been produced that applies the textbook models to countries where most people work beyond the reach of regulation in the informal economy (Gill, Montenegro, and Domeland 2002; Perry et al. 2007; Packard, Koettl, and Montenegro 2012).

Labor market policies can play an important part in shaping firms' decisions about adopting new technology. The theory and empirical literature show that regulations on the form and duration of matches between firms and workers are likely to have important effects on how quickly or intensively digital technology is adopted and on how much of an impact that technology can have on jobs (World Bank 2016). In their analysis of the extent of technology adoption across developed countries, Alesina, Battisti, and Zeira (2015) find that where labor regulation was more restrictive, firms' take-up of technology was greatest in sectors that used low-skilled labor intensively. They demonstrate theoretically that regulation raises the cost of low-skilled labor and reduces the skill premium. Their model shows that more restrictive labor regulation will lead firms to adopt more labor-saving technology, but in sectors that mainly employ lower-skilled labor. They posit, conversely, that firms in sectors that use high-skilled labor more intensively will adopt less technology. Thus, among the otherwise relatively homogeneous OECD member countries, their model predicts relatively higher levels of technology adoption in lower-skilled manufacturing in countries such as Spain and Italy, where labor regulation is more restrictive on firms' decision than in the United Kingdom and United States, where firms' choices are less constrained by labor regulation. The same prediction is made by Acemoglu and Restrepo (2016) in their consideration of firms' decisions to automate production by investing in industrial robots. Empirically, Alesina, Battisti, and Zeira (2015) show that more restrictive labor regulation lowers the ratio of capital in high-skill sectors to capital in low-skill sectors, which then lowers productivity (output per worker) in high-skill sectors and raises productivity in low-skill sectors. Furthermore, the authors find that countries with more restrictive labor regulation tend to produce more patents in the low-skill sectors. The authors conclude that in countries with more stringent labor regulation, production in the low-skill sectors will become more capital intensive and firms will be more likely to innovate than will firms in the high-skill sectors (and vice versa).

Of the regulatory instruments typically in place, restrictions on firms' hiring and dismissal decisions appear particularly important to technology adoption. Gust and Marquez (2004) present empirical evidence that across industrialized countries, ICT investment is negatively correlated with employment protection legislation: where firms' human resources decisions are more constrained by regulation, investment in digital technology is lower. They develop a dynamic model of vintage capital and SBTC. In each period a firm decides whether to upgrade technology, which, in turn, requires improving the skills of the labor force. Dismissal costs delay or prevent firms' decisions to adopt the latest technology. Employers that are unable to change their workforces to keep up with new technology or otherwise align their workers with changing needs and new processes within the firm can soon find themselves at a competitive disadvantage.

Employment protection legislation can discourage firms from undertaking any risky activity, such as investments in innovation, including adoption of digital technology. The literature shows the discouragement effect of employment protection legislation is particularly strong in ICT-intensive sectors (Bartelsman, Gautier, and de Wind 2016; Saint-Paul 2002; Koeniger 2005; Bartelsman and Hinloopen 2005; Samaniego 2006). Bartelsman, Gautier, and de Wind (2016) argue that, because of the experimentation and changes required in organizational structure, the outcome of investment in ICT is highly uncertain. This theory is supported by the empirical finding that productivity is more dispersed in ICT-intensive sectors (Brynjolfsson and Hitt 2003). If a given firm investment in ICT is unsuccessful, the firm might be forced to exit the market because it cannot break even. Thus, incentives to invest in ICT depend on exit costs, with higher exit costs being detrimental to investment in ICT. In this scenario, employment protection measures such as complex dismissal procedures, direct firing costs, and restrictions on the use of temporary and fixed-term workers are a barrier to investment in ICT.

Industries that require a greater degree of risky innovation may have a smaller footprint in countries with very restrictive labor regulation. Using a cross-industry and cross-country panel data set of the United States and the European Union (EU KLEMS), Bartelsman, Gautier, and de Wind (2016) show that high-risk, ICT-intensive sectors are smaller in countries with stricter labor regulations, measured by the number of people they employ. These empirical facts hold when comparing the European Union with the United States, where labor regulations are more flexible, and when comparing countries within the European Union. Furthermore, the effect of labor regulation is increasing in the risk of the investment. The paper shows that aggregate productivity in the United States would be 10 percent lower as a result of lower investment in ICT if severance payments in the United States were similar to the average severance cost in Europe.

However, some research shows that restrictions on dismissal can have an enabling effect on firms' technology adoption. Acharya, Baghai, and Subramanian (2013) make the argument that stricter labor laws work as a commitment device by preventing firms from dismissing workers after short-term failures and thus encouraging employees to engage in risky, innovative activities that are profit maximizing in the long term. Furthermore, by creating a "tax on dismissals," employment protection legislation may increase the incentives that firms have to train workers to use new technology and make them more productive.

The dearth of research on labor regulation and technology adoption in emerging market economies reveals an opportunity for learning. The current literature on the relationship between labor market regulation and technology adoption appears only to cover OECD member countries and some higher-middle-income countries in the process of becoming members. The restriction of analytical work to these countries is a critical shortcoming in the existing body of evidence. Considerable added insight could be gained from analyzing the much broader variation in labor market institutions and key contextual factors (such as level of development, economic stability, and degree of openness to trade) across high-, middle-, and low-income countries that firms in emerging market economies face when choosing whether to adopt new technologies.

Notes

1. Their analysis draws on the EU KLEMS data set, an industry-level panel covering OECD countries since 1970, limited to nonfarm employment across 32 industries for developed countries of the European Union, and excluding Eastern Europe plus Australia, Japan, the Republic of Korea, and the United States.
2. Bessen (2017) analyzes the productivity and jobs growth dynamics in industries such as cotton textiles, where labor productivity increased nearly 30-fold and consumption increased 100-fold during the nineteenth century, supporting a rapid increase in employment, followed by a decline in employment in later stages of maturity (the broadwoven fabrics industry using cotton and manmade fibers declined from 300,000 to 16,000 production workers between 1958 and 2011). He interprets this pattern through a model of heterogeneous final demand, in which price declines in the initial stages of productivity growth make formerly prohibitively expensive products affordable for mass consumption, yielding a large positive demand response. Once large unmet needs are saturated and demand becomes less elastic, further productivity gains may bring reduced employment.

3. These findings are consistent with the recent findings of Lawrence (2017), who shows that for many decades, the relatively faster productivity growth interacting with unresponsive demand, and not trade performance, has been the dominant force behind the declining share of employment in manufacturing in the United States and other developed OECD countries—with aggregate job gains driven by more responsive (more income elastic) demand for services.

References

Acharya, V., R. Baghai, and K. Subramanian. 2013. "Labor Laws and Innovation." *Journal of Law and Economics* 56 (4): 997–1037.

Alvarez, R., J. M. Benavente, R. Campusano, and C. Cuevas. 2011. "Employment Generation, Firm Size, and Innovation in Chile." Technical Note IDB-TN-319, Inter-American Development Bank, Washington, DC.

Aboal, D., P. Garda, B. Lanzilotta, and M. Perera. 2011. "Innovation, Firm Size, Technology Intensity, and Employment Generation in Uruguay. The Microeconometric Evidence." Technical Note IDB-TN-314, Inter-American Development Bank, Washington, DC.

Acemoglu, Daron, and David Autor. 2011. "Skills, Tasks and Technologies: Implications for Employment and Earnings." In *Handbook of Labor Economics*, volume 4, edited by David Card and Orley Ashenfelter, 1043–171. Amsterdam: Elsevier.

Acemoglu, Daron, and Pascual Restrepo. 2016. "The Race between Machine and Man: Implications of Technology for Growth, Factor Shares and Employment." Working Paper 22252, National Bureau of Economic Research, Cambridge, MA.

———. 2017. "Robots and Jobs: Evidence from US Labor Markets." Working Paper 23285, National Bureau of Economic Research, Cambridge, MA.

———. 2018. "Artificial Intelligence, Automation and Work." In *Economics of Artificial Intelligence*, edited by Ajay Agarwal, Avi Goldfarb, and Joshua Gans. Forthcoming.

Akerman, A., I. Gaarder, and M. Mogstad. 2015. "The Skill Complementarity of Broadband Internet." *Quarterly Journal of Economics* 130 (4): 1781–824.

Alesina, A., M. Battisti, and J. Zeira. 2015. "Technology and Labor Regulations: Theory and Evidence." Working Paper 20841, National Bureau of Economic Research, Cambridge, MA.

Arntz, M., T. Gregory, and U. Zierahn. 2016. "The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis." Social, Employment and Migration Working Paper 189, Organisation for Economic Co-operation and Development, Paris.

Artuç, E., S. Chaudhuri, and J. McLaren. 2010. "Trade Shocks and Labor Adjustment: A Structural Empirical Approach." *American Economic Review* 100 (3): 1008–45.

Artuç, E., D. Lederman, and G. Porto. 2015. "A Mapping of Labor Mobility Costs in the Developing World." *Journal of International Economics* 95 (1): 28–41.

Autor, D. H., and D. Dorn. 2013. "The Growth of Low-Skill Service Jobs and the Polarization of the US Labor Market." *American Economic Review* 103 (5): 1553–97.

Autor D. H., L. F. Katz, and M. S. Kearney. 2006. "The Polarization of the US Labor Market." *American Economic Review* 96 (2): 189–94.

———. 2008. "Trends in U.S. Wage Inequality: Revising the Revisionists." *Review of Economics and Statistics* 90 (2): 300–23.

Autor, D. H., L. F. Katz, and A. B. Krueger. 1998. "Computing Inequality: Have Computers Changed the Labor Market?" *Quarterly Journal of Economics* 113 (4): 1169–213.

Autor, D. H., F. Levy, and R. J. Murnane. 2003. "The Skill Content of Recent Technological Change: An Empirical Exploration." *Quarterly Journal of Economics* 118 (4): 1279–333.

Autor, D.H., and A. Salomons. 2017. "Robocalypse Now: Does Productivity Growth Threaten Employment?" Conference Paper for European Central Bank Sintra Forum on Central Banking, June 26–28.

Bartel, A. P., C. Ichniowski, and K. L. Shaw. 2007. "How Does Information Technology Really Affect Productivity? Plant-Level Comparisons of Product Innovation, Process Improvement and Worker Skills." *Quarterly Journal of Economics* 122 (4): 1721–58.

Bartelsman, E. J., P. Gautier, and J. de Wind. 2016. "Employment Protection, Technology Choice, and Worker Allocation." *International Economic Review* 57 (3): 787–826.

Bartelsman, E. J., and J. Hinloopen. 2005. "Unleashing Animal Spirits: Investment in ICT and Economic Growth." In *The Economics of the Digital Society*, edited by L. Soete and B. ter Weel, 272–304. Cheltenham, U.K.: Edward Elgar.

Benavente, J. M., D. Bravo, and R. Montero. 2011. "Wages and Workplace Computer Use in Chile." *The Developing Economies* 49 (4): 382–403.

Bender, S., N. Bloom, D. Card, J. van Reenen, and S. Wolter. 2016. "Management Practices, Workforce Selection and Productivity." Working Paper 22101, National Bureau of Economic Research, Cambridge, MA.

Bessen, James. 2017. "Automation and Jobs: When Technology Boosts Employment." Boston University Law and Economics Working Paper No. 17-09, Boston University, Boston, MA.

Bessen, James. 2015. *Learning by Doing: The Real Connection between Inovation, Wages and Wealth*. New Haven, CT: Yale University Press.

Bloom, N., L. Garicano, R. Sadun, and J. van Reenen. 2014. "The Distinct Effects of Information Technology and Communication Technology on Firm Organization." *Management Science* 60 (12): 2859–85.

Böckerman, P., J. Cawley, J. Viinikainen, T. Lehtimäki, S. Rovio, I. Seppälä, J. Pehkonen, and O. Raitakari. 2016. "The Effect of Weight on Labor Market Outcomes: An Application of Genetic Instrumental Variables." Working Paper 22200, National Bureau of Economic Research, Cambridge, MA.

Boeri, Tito, and Jan van Ours. 2008. *The Economics of Imperfect Labor Markets*. Princeton, NJ: Princeton University Press.

Bresnahan, T., E. Brynjolfsson, and M. L. Hitt. 2002. "Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence." *Quarterly Journal of Economics* 117 (1): 339–76.

Brynjolfsson, E., and L. M. Hitt. 2003. "Computing Productivity: Firm-Level Evidence." *Review of Economics and Statistics* 85 (4): 793–808.

Brynjolfsson, E., and A. McAfee. 2011. *Race against the Machine: How the Digital Revolution Is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy*. Lexington, MA: Digital Frontier Press.

———. 2014. *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. New York: W. W. Norton & Company.

Caroli, E., and J. van Reenen. 2001. "Skill-Biased Organizational Change? Evidence from a Panel of British and French Establishments." *Quarterly Journal of Economics* 116 (4): 1449–92.

Castillo, V., A. Maffioli, S. Rojo, and R. Stucchi. 2011. "Innovation Policy and Employment: Evidence from an Impact Evaluation in Argentina." Technical Note IDBTN-341, Science and Technology Division, Social Sector, Inter-American Development Bank, Washington, DC.

Crespi, G., and E. Tacsir. 2012. "Effects of Innovation on Employment in Latin America." Technical Note IDB-TN-496, Inter-American Development Bank, Washington, DC.

Cruces G., G. Fields, D. Jaume, and M. Viollaz. 2015. "The Growth-Employment-Poverty Nexus in Latin America." UNU-Wider, Helsinki.

Cruz, Marcio, Emmanuel Milet, and Marcelo Olarreaga. 2017. "Online Exports and the Wage Gap." Unpublished.

de Elejalde, R., D. Giuliodori, and R. Stucchi. 2011. "Employment Generation, Firm Size and Innovation: Microeconometric Evidence from Argentina." Technical Note IDB-TN-313, Inter-American Development Bank. Washington, DC.

De Stefano, T., R. Kneller, and J. Timmis. 2014. "The (Fuzzy) Digital Divide: The Effect of Broadband Internet Use on UK Firm Performance." Discussion Paper, School of Economics, University of Nottingham.

Dix-Carneiro, R. 2014. "Trade Liberalization and Labor Market Dynamics." *Econometrica* 82 (3): 825–85.

Doms, M., T. Dunne, and K. R. Troske. 1997. "Workers, Wages, and Technology." *Quarterly Journal of Economics* 112 (1): 253–90.

Frey, C., and M. Osborne. 2013. "The Future of Employment: How Susceptible Are Jobs to Computerisation?" Working Paper, Oxford Martin School, University of Oxford.

Gill, Indermit, Claudio Montenegro, and Dorte Domeland. 2002. *Crafting Labor Policy: Techniques and Lessons from Latin America*. Washington, DC: World Bank.

Goldin, C. D., and L. F. Katz. 2009. *The Race between Education and Technology*. Cambridge, MA: Harvard University Press.

Graetz, G., and G. Michaels. 2015. "Robots at Work." Discussion Paper 1335, Centre for Economic Performance, London.

Gust, C., and J. Marquez. 2004. "International Comparisons of Productivity Growth: The Role of Information Technology and Regulatory Practices." *Labour Economics* 11 (1): 33–58.

Hallward-Driemeier, Mary, and Gaurav Nayyar. 2017. *Trouble in the Making? The Future of Manufacturing-Led Development*. Washington, DC: World Bank.

Heckman, James J., and Carmen Pagés. 2004. *Law and Employment: Lessons from Latin America and the Caribbean*. Chicago: University of Chicago Press.

Hollweg, C. H., D. Lederman, D. Rojas, and E. R. Bulmer. 2014. *Sticky Feet: How Labor Market Frictions Shape the Impact of International Trade on Jobs and Wages*. Directions in Development. Washington, DC: World Bank.

Kennan, J., and J. R. Walker. 2011. "The Effect of Expected Income on Individual Migration Decisions." *Econometrica* 79 (1): 211–51.

Koeniger, W. 2005. "Dismissal Costs and Innovation." *Economics Letters* 88 (1): 79–84.

Krueger, A. B. 1993. "How Computers Have Changed the Wage Structure: Evidence from Microdata, 1984–1989." *Quarterly Journal of Economics* 108 (1): 33–60.

Kuddo, Arvo, David A. Robalino, and Michael Weber. 2015. "Balancing Regulations to Promote Jobs: From Employment Contracts to Unemployment Benefits." World Bank, Washington, DC.

Lawrence, Robert Z. 2017. "Recent Manufacturing Employment Growth: The Exception that Proves the Rule." Working Paper 24151, National Bureau of Economic Research, Cambridge, MA.

Lendle, A., M. Olarreaga, S. Schropp, and P.-L. Vezina. 2016. "There Goes Gravity: eBay and the Death of Distance." *Economic Journal* 126 (591): 406–41.

Machin, S., and J. van Reenen. 1998. "Technology and Changes in Skill Structure: Evidence from Seven OECD Countries." *Quarterly Journal of Economics* 113 (4): 1215–44.

Maloney, W., and C. Molina. 2016. "Are Automation and Trade Polarizing Developing Country Labor Markets, Too?" Policy Research Working Paper 7922, World Bank, Washington, DC.

Messina, J., A. M. Oviedo, and G. Pica. 2016. "Job Polarization in Latin America." Unpublished, World Bank, Washington, DC.

Michaels, G., A. Natraj, and J. van Reenen. 2014. "Has ICT Polarized Skill Demand? Evidence from Eleven Countries over Twenty-Five Years." *Review of Economics and Statistics* 96 (1): 60–77.

Monge-González, R., J. A. Rodríguez-Alvarez, J. Hewitt, J. Orozco, and K. Ruiz. 2011. "Innovation and Employment Growth in Costa Rica: A Firm-Level Analysis." Technical Note IDB-TN-318, Inter-American Development Bank, Washington, DC.

Novick, M., and S. Rotondo, eds. 2013. *El desafío de las TIC en Argentina: Crear capacidades para la generación de empleo*. Santiago, Chile: UN-ECLAC.

Packard, Truman, Johannes Koettl, and Claudio E. Montenegro. 2012. *In from the Shadow: Integrating Europe's Informal Labor.* Washington, DC: World Bank.

Pagés, C., G. Pierre, and S. Scarpetta. 2009. *Job Creation in Latin America and the Caribbean: Recent Trends and Policy Challenges*. Washington, DC: World Bank and Palgrave Macmillan.

Perry, Guillermo, William F. Maloney, Omar S. Arias, Pablo Fajnzylber, Andrew D. Mason, and Jaime Saavedra-Chanduvi. 2007. *Informality: Exit and Exclusion*. World Bank Latin American and Caribbean Regional Study. Washington, DC: World Bank.

Saint-Paul, G. 2002. "Employment Protection, International Specialization, and Innovation." *European Economic Review* 46 (2): 375–95.

Samaniego, R. 2006. "Employment Protection and High-Tech Aversion." *Review of Economic Dynamics* 9 (2): 224–41.

Santos, I., S. Monroy, and M. Moreno. 2015. "Technological Change and Labor Market Disruptions: Evidence from the Developing World." IZA conference mimeo, Institute of Labor Economics, Bonn.

World Bank. 2016. *World Development Report 2016: Digital Dividends.* Washington, DC: World Bank.

Environmental Benefits Statement

The World Bank Group is committed to reducing its environmental footprint. In support of this commitment, we leverage electronic publishing options and print-on-demand technology, which is located in regional hubs worldwide. Together, these initiatives enable print runs to be lowered and shipping distances decreased, resulting in reduced paper consumption, chemical use, greenhouse gas emissions, and waste.

We follow the recommended standards for paper use set by the Green Press Initiative. The majority of our books are printed on Forest Stewardship Council (FSC)–certified paper, with nearly all containing 50–100 percent recycled content. The recycled fiber in our book paper is either unbleached or bleached using totally chlorine-free (TCF), processed chlorine-free (PCF), or enhanced elemental chlorine-free (EECF) processes.

More information about the Bank's environmental philosophy can be found at http://www.worldbank.org/corporateresponsibility.

green press INITIATIVE

While adoption of new technologies is understood to enhance long-term growth and average per capita incomes, its impact on low-skilled workers is more complex and merits clarification. Concerns abound that advanced technologies developed in high-income countries could inexorably lead to job losses of low-skilled, less-well-off workers and could exacerbate poverty. Conversely, there are countervailing concerns that policies intended to protect jobs from technology advancement would themselves stultify progress and depress productivity.

The Jobs of Tomorrow squarely addresses both sets of concerns with new research showing that adoption of digital technologies offers a pathway to more inclusive growth by increasing adopting firms' outputs, with the job-enhancing impact of technology adoption assisted by growth-enhancing policies that foster sizable output expansion. The research reported herein demonstrates, using economic theory and data from Argentina, Brazil, Chile, Colombia, and Mexico, that low-skilled workers can benefit from adoption of productivity-enhancing technologies that are biased toward skilled workers, and often do.

The inclusive job outcomes arise when the effects of increased productivity and expanding output overcome the substitution of workers for technology. While the substitution effect replaces some low-skilled workers with new technology and more highly skilled labor, the output effect can lead to an increase in the total number of jobs for less-skilled workers. Critically, output can increase sufficiently to increase jobs across all tasks and skill types within adopting firms, including jobs for low-skilled workers, as long as low-skilled task content remains complementary to new technologies and related occupations are not completely automated and replaced by machines. It is this channel for inclusive growth that underlies the power of competition-enabling policies and institutions—such as regulations encouraging firms to compete and policies supporting the development of skills that technology augments rather than replaces—to ensure that the positive impact of technology adoption on productivity and low-skilled workers is realized.

Cross-country studies highlight additional channels from digital technology adoption to inclusive growth, namely by lowering the fixed costs of exporting through online trading platforms, and by reducing the cost of information about job opportunities through Internet-enabled worker-firm job matches.

WORLD BANK GROUP

ISBN 978-1-4648-1222-4
SKU 211222