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Do Information and Communication Technologies Empower Female Workers? Firm-Level Evidence from Viet Nam

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Abstract

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Keywords

gender inequality, ICT, information technology, infrastructure, wage inequality

Comments

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ABSTRACT

This paper studies the effects of firms' investments in information and communication technologies (ICT) on their demand for female and skilled workers. Using the gradual liberalization of the broadband Internet sector across provinces from 2006 to 2009 as a source of exogenous variation to identify the causal impacts of ICT, we find evidence from the country's comprehensive enterprise survey data that firms' adoption of broadband Internet and other related ICT increased their relative demand for female and college-educated workers. The effect of ICT on firms' female employment is particularly strong among the college-educated workers, and is stronger in industries that are more dependent on highly manual and physical tasks. These results suggest that ICT can lower gender inequality in the labor market by shifting the labor demand from highly manual, routine tasks in which men have a comparative advantage toward more nonroutine, interactive tasks in which women hold a comparative advantage. However, the effect of ICT is weaker in industries relying more on complex and interactive tasks, suggesting that gender differences in education may have limited female labor supply for the most innovative industries that require highly technical skills to complement ICT.

Keywords: gender inequality, ICT, information technology, infrastructure, wage inequality

JEL codes: I24, J16, J21, J22

I. INTRODUCTION

Since the 1990s, advances in information and communication technologies (ICT) across the world have substantially changed the way people live, work, and interact. The ICT revolution has reduced the distance between individuals, lowering the costs of information acquisition and coordination of activities within and between firms. Accompanying these changes has been the rapid rise in income inequality within countries, which has caught significant attention from both policy makers and academics.[1] Developed countries facing strong pressure from globalization and import competition, particularly from the People's Republic of China, have experienced rising labor market polarization and wage inequality.[2] However, research on the interplay between ICT and labor market inequality has been relatively sparse for developing countries, despite the increasing importance of ICT in creating opportunities for employment and economic growth in these countries.

There are numerous reasons why the labor market effects of ICT and globalization could deviate from those of developed markets, such as high informality of labor markets, limited capacity to provide complementary skills, and depressed wages. Our paper contributes to the literature on income inequality by studying how ICT affects female and skilled employment within firms. In contrast to the research that focuses on developed countries, we explore the research question using firm-level data from Viet Nam, a large developing country. In particular, we study how firms' ICT adoption, triggered by Viet Nam's central government policy to develop broadband Internet infrastructure, changes firms' employment by gender and skill groups.

Table 1: Quality of Broadband Internet across Select Countries

	Speed (bits per second per Internet user)	Affordability ($ per month)
PRC	6,530	19
Indonesia	6,584	29
Cambodia	17,792	12
Viet Nam	24,374	3
Malaysia	34,119	10
Philippines	37,409	22
Thailand	64,907	19
United States	99,147	16

PRC = People's Republic of China.
Source: World Bank. World Development Indicators. http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators (accessed 10 October 2017).

[1] For example, Piketty's 700-page "Capital in the Twenty First Century" (2014) has drawn global attention.

[2] See Autor, Dorn, and Hanson (2016) for a comprehensive review on the effects of the so-called "China shock" on developed economies.

Studying the employment effects of ICT in Viet Nam comes with several additional strengths. The country's enterprise survey data contain unique and detailed information about various types of ICT in which a firm invested over several years. In addition, the central government of Viet Nam implemented policies to liberalize the broadband Internet sector between 2006–2008, which we exploit in constructing the instruments for firms' adoption of ICT. In particular, the policies aimed to provide coverage in the most impoverished provinces since 2007. The reform encouraged private firms to enter the Internet sector, driving up market competition and thereby lowering prices while enhancing the quality of Internet services.[3] The monopoly power of state-owned enterprises in the broadband Internet sector was substantially reduced. As a result of several years of bold ICT reforms, Viet Nam has become the country with the highest penetration rates of ICT among developing countries, offering greater opportunities for firms to use digital technology to acquire information for both production and sales. According to World Bank's World Development Indicators for 2015, Viet Nam's broadband Internet was one of the most affordable in the world and its average Internet speed was faster than both the People's Republic of China and Indonesia (see Table 1).

An important contribution of the paper is the construction of several indexes capturing the quality and accessibility of broadband Internet in Viet Nam, which we use as instruments for firms' adoption of ICT. These instruments vary across provinces and time from 2005 to 2009, due to the Government of Viet Nam's sequential implementation of reforms to improve the broadband Internet infrastructure. Using these province-specific time-varying instruments, we establish the causal effect of firms' ICT on their demand for skilled and female workers, respectively. Due to the reforms, the number of firms adopting various ICT increased significantly. In particular, between 2007 and 2008, the fraction of firms using broadband Internet increased by 20%. Figure 1 shows significant upward trends of the (log) number of workers with computers connected to the Internet, workers with computers connected to local area network (LAN), the fractions of firms having Internet access, LAN, and websites, respectively since 2005.

Using the firm panel data set over the 2005–2009 period, we find that within the same industry and region, firms that adopted broadband Internet and other related ICT raised their relative demand for female and college-educated workers, respectively. Specifically, we find that a 10% increase in a firm's number of computers connected to broadband Internet induces the firm to increase the share of female workers by about 3.5 percentage points. This amounts to roughly a 10% increase over the 32% baseline share of females employed by Vietnamese firms in our sample. Firms that have access to broadband Internet, compared to those that did not, have a female labor share that is on average 14 percentage points higher. The effect of ICT on firms' female employment is even stronger among college-educated employees—the female labor share in the college-educated workforce of firms that adopted broadband Internet is on average 46% higher than those that did not.

The effect of ICT on firms' female employment is particularly strong among college-educated workers, and is stronger in industries that depend more on highly manual and physical tasks, according to the United States (US) Department of Labor's Occupational Information Network (O*Net) task database for occupations in the US. These results suggest that ICT may have shifted the relative demand for different tasks, in which male and female workers have different comparative advantages. They are consistent with the findings by Pitt, Rosenzweig, and Hassan (2012) that males have a comparative advantage in brawn while females have a comparative advantage in skills, contributing to

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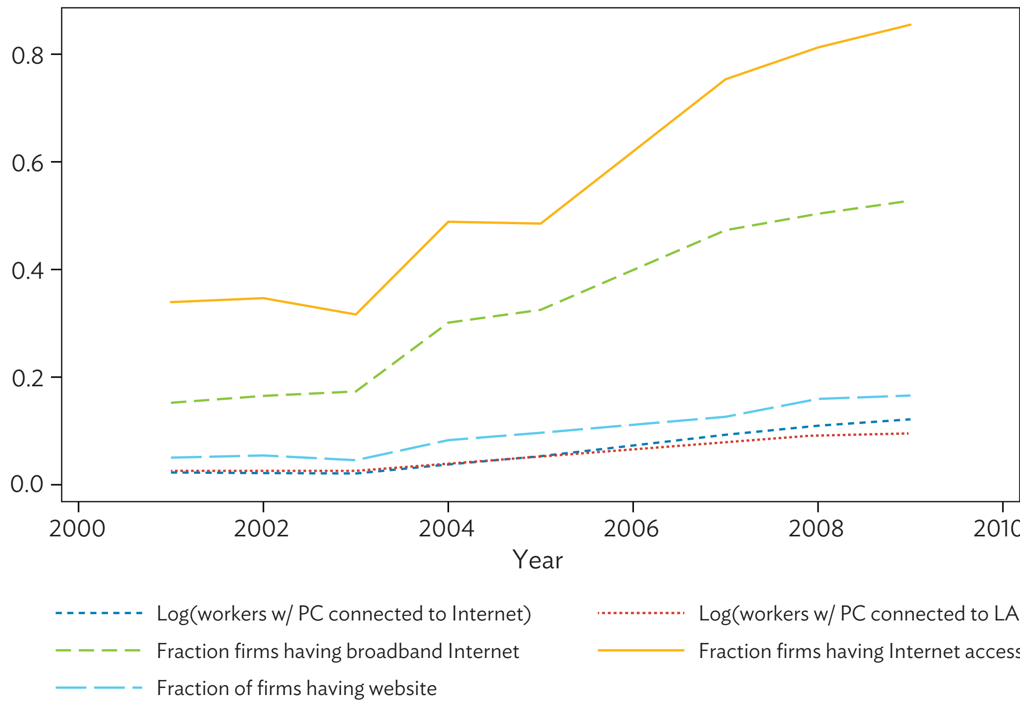
[3] Key regulatory changes are listed in Appendix Table A.1. Increased competition has also coincided with Viet Nam's accession to the World Trade Organization which significantly reduced tariffs on imports of information and communication technology (ICT) products from 2007 to 2010.

a relatively larger return to investments in schooling for females. In our study, the rise of ICT raises the marginal product of nonroutine, interactive tasks, shifting the demand for tasks that favor females.[4] However, the effect is weaker in industries that rely more on complex and interactive tasks. These findings suggest that gender differences in education, specifically in technical training, may have limited the supply of female labor in more complex sectors due to fewer females having the critical technical skills required for undertaking the more complex technical tasks.

Figure 1: Internet and Broadband Penetration



LAN = local area network, PC = personal computer.
Source: Vietnamese Enterprise Surveys (2000–2009).

Research findings of this paper will offer important development policy implications for Viet Nam and developing countries in general. Low wages and barriers to education in developing countries imply that there may be vastly different effects of ICT adoption on labor market outcomes, compared to developed countries. Larger information asymmetry and market frictions in developing countries imply more significant economic gains from ICT investments. In developing countries, females often face greater disadvantages of accessing formal employment opportunities leaving them more vulnerable to poverty. These disadvantages arise from perceived gender roles that limit job access, differences in levels and types of education and training, and a higher degree of labor-intensive firms employing highly manual and physical processes.

4 Consistent with this conjecture, Black and Spitz-Oener (2010) find that in Germany, partly driven by computerization, women have experienced a relative increase in their supply of nonroutine analytic and interactive tasks, while there is no such change in the task supplied by men. See the literature review for a more detailed discussion.

The paper proceeds as follows. Section II provides a literature review. Section III discusses the policy changes that happened during the sample period, which offer an instrument for the regression analysis. Section IV discusses the data source and the construction of the key variables. Section V discusses the conceptual framework and outlines two testable hypotheses. Section VI presents our empirical specifications, followed by section VII that presents the empirical results. The final section concludes.

II. LITERATURE REVIEW

This paper has wide ranging implications and contributes to four broad strands of literature. First, it relates to the research on the effects of ICT on firm performance. Black and Lynch (2001) find that increased use of computers by nonmanagerial employees raise firms' productivity. Brynjolfsson and Hitt (2003) use a sample of US firms to show that firms' computerization is associated with faster productivity and output growth, especially in the long run.[5] Bartel, Ichniowski, and Shaw (2007) find that after adopting new IT-enhanced equipment, plants produce more customized products, experience efficiency growth, and raise the demand for skilled machine operators. Using data for thousands of firms in Brazil and India, Commander, Harrison, and Menezes-Filho (2011) find positive effects of and significantly larger returns to ICT investment than those documented for developed countries.[6] A subset of this literature focuses on the impact of ICT on firms' organizational changes (e.g., Bresnahan, Brynjolfsson, and Hitt 2002; Bloom et al. 2014). For instance, Tambe, Hitt, and Brynjolfsson (2012) show that in the US the extent of firms' external focus is correlated with both their information technology investment and organizational decentralization.

Second, our paper contributes to the literature on the relationship between ICT and labor market outcomes. Autor, Katz, and Krueger (1998) show that computerization of production raises the relative demand for college-educated workers in US industries. Crandall, Lehr, and Litan (2007) find that a 1 percentage point increase in ICT penetration in a US state is associated with 0.2–0.3 percentage point higher employment. Forman, Goldfarb, and Greenstein (2012), however, find a quantitatively small effect of ICT adoption on employment and wage growth across US counties. Using industry-level panel data for 11 advanced economies, Michaels, Natraj, and Van Reenen (2014) find that industries with faster ICT growth are associated with a larger demand for highly educated workers. Using Norwegian firm-level data, Akerman, Gaarder, and Mogstad (2015) show that broadband Internet improves the labor market outcomes and productivity of skilled workers.

Third, our work contributes to the literature on gender inequality in the labor market.[7] The seminal paper by Autor, Levy, and Murnane (2003) shows that ICT is more substitutable for routine tasks, which require relatively little interaction and communication between people, while complementing nonroutine tasks. Black and Spitz-Oener (2010) find that in Germany, women have experienced a relative increase in their supply of nonroutine analytic and interactive tasks. The relative decline in females' supply of routine tasks, partly driven by technological changes, contributed to a substantial closing of the gender wage gap. Ngai and Petrongolo (2017) develop a formal model to show how the rise of the service economy driven by technological changes benefits women who have a

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5 The authors emphasize the importance of complementary investments that amplify the productivity effect of ICT, such as organization capital, that take time to be implemented.

6 Other studies include Grimes, Ren, and Stevens (2012), who use both propensity score matching and instrumental variable approaches to show that in New Zealand broadband adoption raises firm productivity by 7% to 10%. Ogutu, Okello, and Otieno (2014) find that farms in Kenya that adopt ICT are more productive, partly because of information about input uses.

7 See Goldin's (2006) Ely Lecture at the American Economic Association Meeting for a discussion about the economic, sociological, and political factors behind the trends of female labor market performances in the US in the 20th century.

comparative advantage in supplying services. Based on micro data from multiple countries, Olivetti and Petrongolo (2016) find that cross-country variation in industrial structure explains the bulk of the differences in labor demand between the US and other countries, and about one-third of the overall cross-country differences in wage and hour gaps. Our work is closely related to Juhn, Ujhelyi, and Villegas-Sanchez (2014), who link ICT to changes in gender inequality in a developing country. They find rising females' relative wage and employment in Mexico in blue collar jobs, due to trade-induced computerization that lowered firms' demand for physically demanding tasks.

While digital technologies have brought many changes to job compositions, closing the gender employment gap, it could be driving gender inequalities in the most innovative and highly skilled sectors. For instance, Lindley (2012) finds that while the overall gender gaps have closed in the United Kingdom, females have lost ground in certain sectors, such as finance and machine manufacturing, which have experienced the fastest changes related to computerization. A hypothesis is that the underlying social prejudice against female students acquiring technical skills and knowledge may have limited the female labor supply response to an increased demand for highly technical tasks.

Fourth, this paper is broadly related to the impact of ICT on poverty and inequality in developing countries. Existing studies reveal that new technologies and infrastructure investments will not always benefit people equally and can sometimes have adverse consequences (e.g., Duflo and Pande 2007). In South Africa, electrification was found to significantly raise female employment, but led to increasing wage inequality between males and females (Dinkelman 2011). One of the more notable positive findings has been the study by Jensen (2007), who shows that mobile service provision helped reduce information asymmetry, reducing price volatility and thus excess supply by fisherman in India. In Africa, the Internet was found to have significantly contributed to improved employment prospects and declines in job inequality between less educated and more educated workers in 13 of the 14 countries examined (Hjort and Poulsen 2017).

In Viet Nam, the interplay between ICT, task complexity, and female labor market outcomes might be very different because wages in high-skilled sectors are still relatively low, resulting in different implications on the gender wage gap compared to developed countries. Furthermore, constraints on the availability of highly skilled labor might make it more difficult to complement complex technological processes leading to relatively less skilled sectors experiencing faster ICT adoption and contributing more to economywide growth and the closing of the gender gap in the short run.

Our paper contributes to these strands of research by providing firm-level evidence of the effects of ICT on firms' employment and organizational structure, focusing on firms' relative demand for female workers. We also examine how the employment of ICT varies across industries based on their task complexity.

III. CHANGING INFORMATION AND COMMUNICATION TECHNOLOGY POLICIES, TECHNOLOGICAL ADOPTION, AND GENDER DIFFERENCES IN THE LABOR MARKET

The liberalization of the telecommunications sector has created vast improvements in access to ICT in Viet Nam. In a little over a decade, Viet Nam's strategic investments have transformed it from a Southeast Asian laggard to a leader in technological competitiveness. In 2005, access to the Internet in Viet Nam was poor with available bandwidth of 44 bits per second per person. However, according to the World Bank's World Development Indicators, by 2015 its bandwidth had risen to more than 24,000 bits per second per person with entry level plans available for only $3 per month providing an extremely low threshold for firm's and individuals to access the Internet (see Table 1 for details).

Efforts to liberalize the telecommunications sector started in 2002, with the Ministry of Post and Telecommunications passing legal regulations to foster competition in the sector that had been previously monopolized by state-owned enterprises. A series of policies that provided for joint ventures opened the path to competitiveness bringing ICT investments and protocols that were in line with global standards, increasing speed, expanding access, and driving down prices. The government envisioning ICT as a driver of social change also invested heavily in conducting monitoring and evaluation to understand the dynamic effects of ICT investments across the provinces. By 2011, ICT provision was competitive with 90 different Internet providers and five companies providing cellular data (Tuan 2011).

Viet Nam's accession to the World Trade Organization complemented improvements in ICT infrastructure by substantially reducing the costs of importing various equipment including computers and machines and introducing greater competition into the ICT sector by paving the way for foreign direct investment. The removal of tariffs between 2007–2009 caused average tariffs on ICT equipment to sink to 9.2% in 2010 compared to 14.5% in 2005 (WTO 2017). The combination of improved Internet speed and affordability accompanied by price reductions in technological equipment were primary drivers of the rapid expansion in the number of households and firms using the Internet since 2005. By 2015, the Internet penetration rate was above 50% of the population providing significant incentives for firms concentrated on the domestic market to leverage Internet technologies to grow their business (World Bank 2017). Appendix Table A.1 lists the major policy changes that affect the quality and cost of ICT in the country.

Against the backdrop of changing ICT is a labor market with relatively minimal differences in labor market participation. According to Viet Nam's Labor Force Surveys, in 2013, 85% of males and 77% of females ages 15–64 were participating in the labor force (see Appendix Table A.2). Still, gender differences continue to operate through employment and wage outcomes. Like many developing countries, the informal sector characterizes a large proportion of the population and female workers are less likely to participate in formal wage work at 30% compared to 40% of males. While gender wage gaps have declined between 2007 and 2013, particularly among workers with a lower level of education, men still made about 15%–30% higher wages that could be driven by different occupations, tasks, and skills (see Appendix Table A.3). These patterns suggest that ICT could play an important role in closing gender gaps in employment outcomes if ICT adoption improves the relative returns to the comparative advantage that females have in tasks, inducing firms to offer higher wages and more stable employment.

Despite progress in ICT, the availability of higher order skills could be a major constraint to Viet Nam's ambitions to become a premier ICT country. Within the country, only a small percentage of the population has the necessary ICT skills to complement more complex computerized and digital tasks. Males continue to dominate the science, technical, engineering, and mathematics (STEM) degrees driven in part by biases within the country that view males as more capable in performing technical jobs.[8] This has potentially led to significant gender gaps in the proportion of females trained in STEM degrees in Viet Nam even while there is near parity in matriculation to higher education (Nguyen 2013). Education and skills ultimately could play a large role in the incentives of firms to adopt ICT and their demand for female labor across industries.[9]

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8 While there has been a rapid increase in the the share of youth going onto tertiary education, the share remains small in the overall labor force at < 10%.

9 Newman and Tarp (2014) suggest that most technological adoption has been low-tech and concentrated on adoption of machines to complement human labor and using computer for basic processes rather than implementing aggressive strategies on the Internet for market expansion.

IV. DATA

A. Firm-Level Data

The main data source of this paper is the Annual Enterprise Census of Viet Nam, over the period of 2005–2009, conducted by the General Statistics Office (GSO) of Viet Nam. The GSO conducts the annual census of all enterprises, across both manufacturing and nonmanufacturing sectors, operating in the country. The censuses cover state-owned, collectively owned, private, and foreign enterprises. The enterprise censuses contain detailed balance sheet information of each firm. For example, each firm's total employment, employment by skill and gender, capital, revenue, expenses, profits, liabilities, and most importantly, investments in various ICT are reported.

A unique aspect of the Vietnamese enterprise censuses is its comprehensive and detailed information on firms' use of ICT. Specifically, the censuses contains indicators of a firm's usage of personal computers, access to Internet, usage of LAN, emails, websites, and usage of digital methods for purchase and sales transactions. Each firm has a unique firm identifier, that can be used to construct a firm panel data set. Thus, an analysis on firms' productivity growth and changing employment structure can also be conducted. Table 2 provides summary statistics of firms' key ICT variables and other characteristics that are used in the regression analysis. Appendix Table A.5 summarizes these key firm variables and also their female labor shares used in the regression sample. It shows that by 2009, Internet penetration reached nearly 86% of all firms in the sample, but that more modern e-commerce activities were far smaller with only 17% of all firms having a website. Female employment in formal firms is unequal at 33%. For 2006, the GSO of Viet Nam did not report information on firms' ICT in their surveys, implying that we have to exclude 2006 from the main regression sample. Appendix Table A.4 reports the number of firm observations included in the regression sample by broad sector and year.

Partly due to the reforms described in section III above, firms across Viet Nam have been significantly increasing their usage of ICT over time. Figure 1 shows the averages of firms' measures of adoption of ICT—log number of workers with computers connected to the Internet, log number of workers with computers connected to LAN, the fractions of firms having Internet access, LAN, and websites, respectively. These five firms' ICT measures, which were all increasing over the sample period on average, will be the main regressors of interest in the regression analysis below.

B. Provincial Measures of Information and Communication Technology Quality

To construct the instrument for firms' adoption of ICT, we use a second data source that provides province-level panel data on ICT quality, compiled and made publicly available by Viet Nam's Ministry of Science and Technology. The index captures a province's readiness for ICT and has been available since 2005. It was designed to be a policy tool for local governments to identify their jurisdictions' ICT efficiency and reduce income inequality in the region by enhancing households' and firms' technological access. There are five indexes that aim to capture the different aspects of ICT development, namely technical infrastructure, human infrastructure, applications, manufacturing and businesses, and organization and policy environments. Our analysis focuses on the ICT's technical infrastructure, which is based on actual adoption of and investments in various types of ICT technologies, ranging from fixed telephone lines, Internet accounts, broadband and mobile phone subscribers per household, the number of broadband companies providing services in the region, among others.

Table 2: Summary Statistics of the Information and Communication Technology Variables

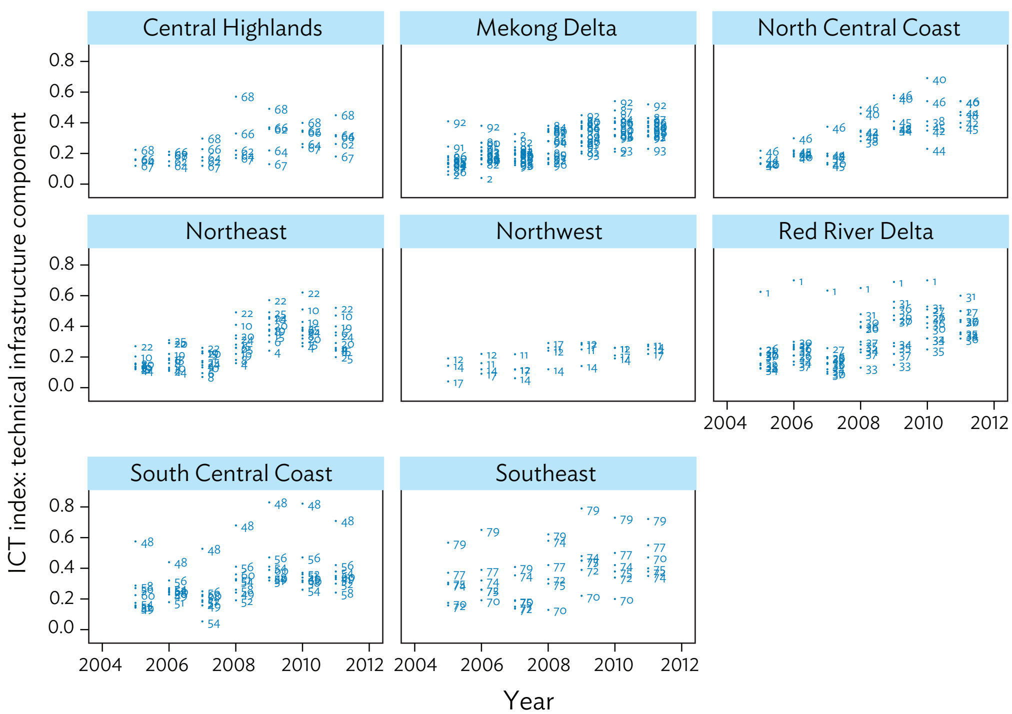
	Short Name	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Number of Obs (w/ info on ICT)		18,691	22,588	25,132	33,240	42,708		46,101	48,470	52,733	51,696	80,253
Continuous variables												
Number of PCs	so_pc	6.83	7.58	6.46	8.47	8.43	–	11.1	12.03	13.27	14.62	12.73
		(18.31)	(25.88)	(27.07)	(33.77)	(38.00)	–	(42.11)	(41.89)	(74.35)	(130.13)	(51.93)
Number of PCs connected to Internet	pc_int	1.14	1.45	1.47	2.78	3.7	–	6.73	8.79	10.36	–	–
		(7.45)	(13.99)	(12.72)	(21.85)	(26.19)	–	(23.79)	(31.57)	(38.79)	–	–
Number of PCs connected to LAN	pc_lan	2.39	2.87	2.71	4.36	5.05	–	7.32	9.67	10.57	–	–
		(13.67)	(20.03)	(19.93)	(29.64)	(31.89)	–	(38.06)	(38.50)	(43.47)	–	–
Fraction of PC Connected to Internet		0.17	0.19	0.23	0.33	0.44	–	0.61	0.73	0.78	–	–
Dummies												
Have PC?	dpc	0.9	0.88	0.84	0.94	0.87	–	0.99	0.99	0.98	0.99	0.98
Access to Internet?	dint	0.35	0.35	0.32	0.5	0.49	–	0.76	0.82	0.86	–	–
Have LAN?	dlan	0.16	0.17	0.18	0.31	0.33	–	0.48	0.51	0.53	–	–
Have electronic transactions?	demail	0.08	0.07	0.07	0.04	0.04	–	0.02	0.03	0.02	–	–
Have website?	dweb	0.05	0.06	0.05	0.08	0.1	–	0.13	0.16	0.17	–	0.24

ICT = information and communication technology, LAN = local area network, PC = personal computer.
Note: Firms with over 20 employees or above are surveyed. Observations with missing values on revenue, material, or total expenses are dropped. Sample means of each variable are reported, with standard errors reported in parentheses.
Source: Annual Enterprise Census by the General Statistics Office of Viet Nam.

The human infrastructure index is comprised of integration of computerization classes in education and governmental staff using computers in their work. The ICT applications index captures governmental agencies openness to ICT through provision of websites and digitalization of operations. The ICT manufacturing or business index focuses on business measures production of ICT. Finally, the ICT policy environment index aims to capture openness by the local government to drive ICT growth and adoption. See Appendix Table A.6 for the constituents of the index by year.

To check the robustness of our main results, we use an overall index that is a weighted average of the five indexes. Both the overall and technical infrastructure ICT indexes vary substantially across provinces and time, allowing us to use them as instruments to predict a regions' ICT efficiency and thus firms' cost and adoption of various ICT technologies in the first stage. Figure 2 shows the time trend of the ICT technical infrastructure index for each of the eight regions in Viet Nam. Across the regions, there is a general upward trend in the ICT infrastructure index. Some regions, such as the Red River Delta and Mekong Delta regions, started with a higher level of ICT. These regional differences will be accounted for by region fixed effects in the regressions.

Figure 2: Information and Communication Technology Index by Province



ICT = information and communication technology.
Source: Authors' computation based on official documents from Viet Nam's Ministry of Science and Technology.

C. Sector Measures

In the last section of the paper, we examine whether the effects of ICT on firms' employment patterns vary across industries. In particular, we relate the effects to the complexity of the tasks involved in the production processes and the extent of female comparative advantage of the industry. We measure an industry's task complexity using measures from Keller and Yeaple (2008). The foundation of their measures is at the occupation level. The authors construct an index on an occupation's complexity, which is a measure of the degree to which complex problem solving skills are needed to evaluate options and implement solutions in a given occupation according to O*NET, as the basis of an industry's task complexity. More complex sectors are those sectors which rely heavily on highly technical, engineering skills and are the most innovative sectors of an economy while less complex are industries providing basic services and products. A US North American Industry Classification System (NAICS) 6-digit industry's task complexity is the weighted average of the tasks, with weights equal to the fractions of occupations in the industry based on data from the US Current Population Surveys. The 6-digit NAICS is harmonized to the international standard classification of occupations 2008 (ISCO2008) at the 3-digit level.

We also draw on measures from Acemoglu and Autor (2011) capturing the degree to which tasks in an occupation are nonroutine, manual, and physical using occupation data from O*NET in 2007. These measures are constructed to have mean value of 0 and a standard deviation of 1. They can potentially capture strong gender differences in occupations that relate to comparative advantages that different genders face in supplying labor for different types of tasks. This data is connected by occupation to data on total employment defined by the US Census's Current Population Survey, covering both manufacturing and nonmanufacturing sectors.[10] This data is then collapsed to a distinct NAICS 3-digit code which is then mapped into the latest International Standard Industrial Classification codes revision 4.4 (ISIC rev 4.4), using a concordance file from the website of the United Nations Statistics Division. Food services, mining, and manufacturing are some of the industries requiring more manual and physical labor while industries that are far less physically intensive are in the ICT sector and marketing.[11] See Appendix Table A.7 for details about these two sector measures at the 3-digit ISIC level.

V. CONCEPTUAL FRAMEWORK

In this section, we outline a conceptual framework that provides a guide for understanding the interplay between firms' demand for tasks, ICT adoption, and employment by skill and gender groups. To this end, we borrow the key features and assumptions of the task model of Autor, Levy, and Murnane (2003). Their model assumes that firm production requires tasks that can be described broadly along two dimensions: routine versus nonroutine and manual versus analytic or interactive. Thus, tasks can be grouped into four broad categories of routine interactive, routine manual, nonroutine interactive, and nonroutine manual. Autor, Levy, and Murnane (2003) provide some specific examples from the Dictionary of Occupational Titles for each of the four categories (see Table 1 in their paper). Routine interactive tasks include, for example, record-keeping, calculation, and repetitive customer service. Routine manual tasks include picking, sorting, and repetitive assembly. Nonroutine interactive tasks include forming and testing hypotheses, legal writing, marketing, and sales. The classic examples of nonroutine manual tasks include driving and janitorial services. It is also assumed that tasks differ along a dimension of complexity where more complex tasks require higher order thinking and problem solving skills that are critical to building innovative products. For example, software development and scientific research are occupations relying more heavily on complex tasks.

Intuitively, we can expect that computerization and ICT are more substitutable for routine tasks that are repetitive and codifiable. It is probably more difficult to completely substitute nonroutine

[10] Industries are classified based on the US Census 2007 classification.
[11] United Nations Statistics Division. https://unstats.un.org/unsd/cr/registry/regot.asp?Lg=1.

tasks that often involve unexpected contingencies, such as driving on the road, with ICT.[12] Based on these intuitions, Autor, Levy, and Murnane (2003) develop a model that features constant elasticity of substitution and production functions that use routine labor, nonroutine labor, and computer capital as inputs. Their model makes three assumptions, which we modify in the context of ICT as:

(i) ICT is more substitutable for human labor in carrying out routine tasks than nonroutine tasks.
(ii) Routine and nonroutine tasks are themselves imperfect substitutes.
(iii) Greater intensity of routine inputs increases the marginal productivity of nonroutine inputs.

Making the same set of assumptions, we can expect that an increase in ICT usage by firms will reduce their relative demand for routine tasks but raise their relative demand for nonroutine tasks. What is new in our framework is that we have workers differentiated by gender in terms of their comparative advantage in different tasks. Existing empirical research provides some evidence that females have a comparative advantage in nonroutine, interactive tasks, while men have a comparative advantage in the manual and physically intensive tasks. As a result of the rise in digital technologies, there has been a relative increase in the complementary value of interactive, service-oriented tasks compared to tasks that require little interaction (Mathiowetz et al. 1985, Guiso et al. 2008, and Black and Spitz-Oener 2010). This suggests that there is a higher complementary value between ICT and nonroutine, interactive tasks where females have a comparative advantage compared to ICT and tasks that are noninteractive and physical.

With the assumption of this mapping, we have the following testable hypothesis.

Hypothesis 1: All else equal, a firm's adoption of ICT has a positive effect on the share of female employment if ICT is more complementary to nonroutine interactive tasks for which females have a comparative advantage.

Nevertheless, task complexity may play a significant role in labor demand that cuts along gender dimensions due to differences in education and skills training. Males may have a stronger comparative advantage in more complex and highly technical tasks because there are far more males that have science, technical, engineering, and mathematics (STEM) training compared to females. This is consistent with the finding of Lindley (2012) and basic statistics from both developing and developed countries that show men train in (STEM) fields in far higher proportions compared to females (e.g., UNESCO and KWDI 2015).

Since we do not observe the task components of each worker in our data, it is hard to verify directly our assumption about males' comparative advantage in tasks that are more complementary to ICT, but are also highly complex requiring a specific set of technical skills. However, if our assumption is right, we should expect a weaker effect of ICT on female employment in sectors that are more dependent on technical and complex skills, due to a higher extent of training in STEM among males compared to females. In other words, in sectors that depend on more complex, interactive, and communication-intensive tasks, the effects of ICT proposed in Hypothesis 1 should be weaker. We summarize these predictions in the following hypothesis, which we will empirically examine in the last part of the analysis:

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[12] With the recent innovations in driverless cars, the claim that nonroutine tasks such as driving, which traditionally was not much affected by ICT and artificial intelligence more specifically, needs to be revisited.

Hypothesis 2: The effects of ICT on firms' female labor shares are weaker in industries that depend more on complex tasks, for which ICT is complementary, due to a lower acquisition of STEM skills among women.

VI. REGRESSION SPECIFICATIONS AND IDENTIFICATION STRATEGY

To examine the effects of ICT adoption on firms' share of female workers in total employment, we estimate the following specification:

$$\frac{f_{it}}{l_{it}} = \alpha + \beta ICT_{it} + X_{it}\delta + \left[FE_r + FE_j + FE_t\right] + \omega_{it} \quad (1)$$

where *i*, *r*, *j*, *t* stand for firm, province, industry, and year, respectively. The dependent variable f_{it}/l_{it} stands for the share of female workers (f_{it}) in firm *i*'s total employment (l_{it}) in year *t*.

On the right-hand side of (1), the main independent variable ICT_{it} is one of the following five firm measures of ICT:

(i) (log) Number of personal computers (PCs) per worker,
(ii) (log) Number of PCs connected to broadband local area networks (LAN) per worker,
(iii) have access to broadband Internet,
(iv) have access to Internet, and
(v) have a company website.

Notice that the first two measures are continuous variables, while the last three measures are dummy variables, which take the value of 1 if the firm has adopted the corresponding ICT, 0 otherwise. A positive and statistically significant estimate of β will provide support to Hypothesis 1.

The variable X_{it} is a vector of firm-level controls, including firm sales, employment, fixed asset, employment (all in logs), as well as age, foreign ownership dummy, state ownership dummy. The variable *FE* stands for fixed effects, which include region (FE_r) (8 of them), sector (FE_j) (11 of them), and year (FE_t) (4 of them) fixed effects, respectively, to capture any time-invariant unobserved factors that may affect a firm's decision to adopt ICT.[13] For instance, the Red River Delta in northern Viet Nam, which contains the country's capital Ha Noi, started with a higher level of ICT infrastructure. As shown in Figure 2, the Red River Delta region appeared to have a higher ICT index compared to other regions in 2005. Sector fixed effects control for the varying importance of ICT across industries. For example, firms in the agriculture, forestry and fishing sector have a lower average ICT adoption rate than those in manufacturing. Year fixed effects control for the overall macro trends of ICT adoption, such as the positive correlation between income per capita and the use of technology.

[13] See the list of sectors in Appendix Table A.4 and that for regions in Figure 2.

As firm productivity and managerial capabilities are unobserved factors that can play a role in the sophistication of technologies employed within the firm and the relative demand for female workers, the ordinary least squares (OLS) estimates are likely to be biased. To tackle reverse causality and other endogeneity issues, we estimate (2) using a 2-stage least squares (2SLS) model, with the province-specific ICT quality index being the instrument for ict_{it}, as described in section IV. Specifically, the first stage of our 2SLS specification is

$$ICT_{it} = \alpha_0 + \beta_0 ICTQ_{rt} + X_{it}\delta_0 + \left[FE_r + FE_j + FE_t\right] + \varepsilon_{it} \quad (2)$$

The variable $ICTQ_{rt}$ stands for province *r*'s ICT quality in year *t*. The regressors on the right-hand side are already defined for equation (2) above. The coefficient on the *ICT* variable, instrumented by the underlying *ICT* quality index, captures the effect of using *ict* on the share of females employed by the marginal firm that increases *ICTQ*, triggered by improved ICT competitiveness in a province.

VII. EMPIRICAL RESULTS

A. The Effects of Information and Communication Technology on Female Employment

Before discussing the 2SLS estimates, we report the OLS estimates of (1) to show the correlation between firms' ICT and shares of female employment. Based on four of the five firms' ICT adoption measures, we find a positive and statistically significant correlation between firms' ICT and female labor share (see Table 3). The only ICT measure for which there is no significant correlation with firms' female labor shares is the indicator for whether the firm has a website or not. The positive correlation is robust after we control for the firm's log sales, log asset, log employment, age, foreign ownership dummy, state ownership dummy, and the host of fixed effects as described in (1). The OLS estimates of ICT are potentially biased as tasks demands, management quality, and readiness to adopt technology are all unobserved factors that are not included in the models. As a result, instrumental variables approach may provide a more accurate estimate of the effects of ICT on female employment.

Table 4 reports the estimates of the 2SLS model described in (1) and (2). Standard errors are clustered at the province level, the level at which the instrument is constructed. In columns 1–5, we use the technical component of the ICT quality as an instrument for the five measures of firms' ICT, while in columns 6–10, we use the average over the five components of province-level ICT indexes. Regardless of which instrument is used, we find a positive and statistically significant effect of a firm's ICT adoption on its female labor share for all five ICT measures. Specifically, according to the coefficient on ICT_{ict} in column 1, a 10% increase in the number of PCs connected to the Internet per worker increases the female labor share of the firm by 3 percentage points. The effect of LAN is larger. According to the coefficient on *ICT* in column 2, a 10% increase in the number of PCs connected to LAN per worker increases the female labor share of the firm by 3.5 percentage points. Based on the coefficients on various dummies, columns 3–5 show that compared to firms sharing similar characteristics within the same region, industry, and year that did not adopt those technologies, a firm's adoption of Internet, LAN, and hosting a website are associated with 15, 14, and 30 percentage point higher female labor share. Quantitatively similar results are obtained in columns 6–10 when a more holistic measure of the ICT quality index is used as an instrument. The coefficients on the instruments, as reported in the lower part of Table 4, are all positive and statistically significant. The corresponding Kleibergen-Paap F statistics of the first stage of the 2SLS model, which are significantly above 10 (the "rule of thumb" cutoff proposed by Stock and Yogo [2005]), suggest that our instruments pass the weak instrument test.[14] As the 2SLS estimates are higher than the OLS estimates for all ICT indicators, could be indicative of the marginal firm changing subsequent tasks demands that more explicitly favor females as a result of adoption of ICT due to improvements in the infrastructure. The absence of detailed controls on the current level of occupational task demands therefore would make the OLS estimates downward biased relative to the 2SLS estimates.

Table 3: Firms' Female Labor Shares and Adoption of Information and Communication Technology (Ordinary Least Squares)

Dependent Variable	Firm's Female Labor Share				
Firm-Level of ICT Adoption (ICT)	(1) Log (No. of PCs with Internet/ worker)	(2) Log (No. of PCs with LAN/ worker)	(3) Dummy (has Internet access)	(4) Dummy (has LAN)	(5) Dummy (has website)
ICT	0.201***	0.144***	0.029***	0.023**	0.013
	(0.047)	(0.041)	(0.007)	(0.010)	(0.016)
Log (revenue)	−0.013	−0.013	−0.012	−0.012	−0.012
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Log (asset)	−0.020	−0.018	−0.017	−0.017	−0.015
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Log (employment)	0.049	0.044	0.038	0.037	0.037
	(0.047)	(0.047)	(0.048)	(0.048)	(0.048)
Age	0.000	0.000	0.000*	0.000*	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Foreign dummy	0.103***	0.107***	0.114***	0.113***	0.117***
	(0.008)	(0.009)	(0.008)	(0.008)	(0.008)
SOE dummy	0.017	0.021	0.020	0.021	0.021
	(0.028)	(0.028)	(0.028)	(0.028)	(0.027)
Year fixed effect	√	√	√	√	√
Sector fixed effect	√	√	√	√	√
Region fixed effect	√	√	√	√	√
No. of Obs	193,769	188,317	184,328	177,267	168,382
R-squared	0.274	0.268	0.265	0.263	0.260

ICT = information and communication technology, LAN = local area network, PC = personal computer, SOE = state-owned enterprise.
Notes: Standard errors, clustered at the sector level, are reported in parentheses. Two-digit sector (11) and region (8) fixed effects are always included. *** p<0.01, ** p<0.05, * p<0.1.
Source: Annual Enterprise Census by the General Statistics Office of Viet Nam.

The empirical results support our hypothesis that the rise of nonroutine, interactive type tasks that complement ICT have increased the relative proportion of females employed within firms.

[14] The problem of weak instruments is generally less of a concern in this case as the model is just identified since only one instrument is used at a time.

Table 4: Firms' Female Labor Shares and Adoption of Information and Communication Technology (Two-Stage Least Squares)

Second Stage Dependent Variable	Firm's Female Labor Share									
Firm-Level of ICT Adoption (ICT)	(1) Log (No. of PCs with Internet / worker)	(2) Log (No. of PCs with LAN/ worker)	(3) Dummy (has Internet access)	(4) Dummy (has LAN)	(5) Dummy (has website)	(6) Log (No. of PCs with Internet/ worker)	(7) Log (No. of PCs with LAN/ worker)	(8) Dummy (has Internet access)	(9) Dummy (has LAN)	(10) Dummy (has website)
ICT	0.299** (0.147)	0.347** (0.161)	0.149** (0.071)	0.137** (0.061)	0.304*** (0.111)	0.264* (0.146)	0.309* (0.158)	0.128* (0.067)	0.118** (0.057)	0.272** (0.109)
Firm-level controls	√	√	√	√	√	√	√	√	√	√
Year fixed effect	√	√	√	√	√	√	√	√	√	√
Sector fixed effect	√	√	√	√	√	√	√	√	√	√
Region fixed effect	√	√	√	√	√	√	√	√	√	√
No. of Obs	193,008	187,556	183,587	176,529	167,648	193,008	187,556	183,587	176,529	167,648
R-squared	0.271	0.255	0.225	0.218	0.093	0.273	0.259	0.237	0.232	0.127
First Stage										
ICT index (technical infrastructure component)	0.147*** (0.014)	0.136*** (0.015)	0.326*** (0.031)	0.388*** (0.058)	0.184*** (0.019)					
ICT index (five components)						0.185*** (0.018)	0.171*** (0.019)	0.427*** (0.040)	0.510*** (0.074)	0.237*** (0.026)
Firm-level controls	√	√	√	√	√	√	√	√	√	√
Kleibergen-Paap F statistic	114.605	83.912	109.558	44.057	96.198	103.458	78.389	113.419	47.473	86.053

ICT = information and communication technology, LAN = local area network, PC = personal computer.
Notes: Standard errors, clustered at the sector level, are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1 All coefficients are estimated using the two-stage least squares method, with the first stage having each of the firm's ICT variables as the dependent variable, and province-year-specific ICT index, as described in detail in Appendix Table A.6, as the instrument. Columns (1)–(5) use the index that captures the technical infrastructure aspect of ICT as an instrument in the first stage. Columns (6)–(10) use the index that is a weighted average of five aspects of ICT, including (i) technical infrastructure, (ii) human infrastructure, (iii) applications, (iv) manufacturing business index, and (v) organization/policy environment. Firm-level controls, as reported in Table 3, are always included (but with results suppressed to save space) in both stages of each regression.
Source: Annual Enterprise Census by the General Statistics Office of Viet Nam.

B. The Effects of Information and Communication Technology on Skilled Employment

Existing research has consistently shown that ICT complements interactive, complex tasks. For instance, a seminal paper by Autor, Levy, and Murnane (2003) showed that within industries, occupations, and education groups in the US, computerization has reduced the demand for nonroutine, manual, and physical tasks, but increased the demand for nonroutine interactive and highly analytical tasks (e.g., communication-intensive tasks). To the extent that ICT is more likely to replace codifiable tasks, we should expect that the demand for college-educated workers, who have a comparative advantage in nonroutine cognitive tasks, should increase.

In Table 5, we repeat the same exercises as in Table 4, but with the dependent variable replaced by the share of college-educated workers in a firm's total employment. Using our 2SLS model with the province-specific ICT quality as an instrument, we find within a region, sector, and year, a statistically significant and positive effect of firm's ICT on the share of skilled employment. The results are economically significant. For instance, according to the coefficient on *ICT* in column 1, a 10% increase in the number of PCs connected to the Internet per worker increases the college-educated labor share of the firm by about 8 percentage points. This is a large increase given that college-educated labor only accounts for about 15% of all labor within the firms in our sample. The quantitative effect of the same percentage increase in the number of computers connected to LAN is about 9 percentage points. Columns 3–5 show that a firm's adoption of LAN, Internet, and hosting a website are associated with 35, 54, and 65 percentage point higher college-educated labor share, respectively, compared to firms sharing similar observable characteristics and operating in the same region, industry, and year that did not adopt those technologies. The results remain robust and quantitatively similar when a more holistic measure of ICT quality index is used as an instrument in columns 6–10.

In Table 6, we replace the dependent variable by the share of female workers in college-educated employment of the firm and repeat the same exercises as in Table 4. Our instrumental variable regressions show that within a region, sector, and year, a firm's ICT adoption has a positive and significant effect on the share of women in the firms' college-educated employment. The effects are economically significant. For instance, the coefficient on *ICT* in column 1 suggests that a 10% increase in the number of PCs connected to the Internet per worker increases the female share in college-educated employment of the firm by about 8 percentage points. The quantitative effect of the same percentage increase in broadband Internet is about 9 percentage points. Columns 3–5 show that a firm's adoption of LAN, Internet, and hosting a website are associated with 31, 46, and 69 percentage point higher female labor share in firms' college-educated employment, respectively, compared to firms with similar observable characteristics and within the same region, industry, and year that did not adopt those technologies. Once again, the results remain robust and quantitatively similar when we use a more holistic measure of ICT quality index as an instrument in columns 6–10.

In sum, ICT increases not only firms' skilled labor share, as has been highlighted in the literature, but also their female share in skilled employment and thus female skilled labor share in total employment.

Table 5: Firms' Colleged-Educated Labor Shares and Information and Communication Technology Adoption (Two-Stage Least Squares)

Second Stage Dependent Variable	Firm's Share of College Educated Workers									
Firm-Level of ICT Adoption (ICT)	(1) Log (No. of PCs with Internet/ worker)	(2) Log (No. of PCs with LAN/ worker)	(3) Dummy (has Internet access)	(4) Dummy (has LAN)	(5) Dummy (has website)	(6) Log (No. of PCs with Internet/ worker)	(7) Log (No. of PCs with LAN/ worker)	(8) Dummy (has Internet access)	(9) Dummy (has LAN)	(10) Dummy (has website)
ICT	0.835**	0.943***	0.540***	0.351***	0.646**	1.064***	1.193***	0.648***	0.416***	0.854***
	(0.321)	(0.346)	(0.192)	(0.119)	(0.306)	(0.245)	(0.263)	(0.161)	(0.093)	(0.261)
Firm-level controls	√	√	√	√	√	√	√	√	√	√
Year fixed effect	√	√	√	√	√	√	√	√	√	√
Sector fixed effect	√	√	√	√	√	√	√	√	√	√
Region fixed effect	√	√	√	√	√	√	√	√	√	√
No. of Obs	93,850	91,389	90,815	87,521	82,258	93,850	91,389	90,815	87,521	82,258
R-squared	0.064	−0.017	−0.571	−0.262	−0.757	−0.039	−0.174	−0.911	−0.454	−1.481
First Stage										
ICT index (technical infrastructure component)	0.153***	0.138***	0.221***	0.349***	0.186***					
	(0.039)	(0.039)	(0.022)	(0.063)	(0.042)					
ICT index (five components)						0.199***	0.180***	0.311***	0.495***	0.243***
						(0.048)	(0.049)	(0.035)	(0.078)	(0.055)
Firm-level controls	√	√	√	√	√	√	√	√	√	√
Kleibergen-Paap F statistic	106	81.441	43.964	41.785	71.371	81.654	64.203	58.738	40.805	68.048

ICT = information and communication technology, LAN = local area network, PC = personal computer.

Notes: Standard errors, clustered at the province level, are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All coefficients are estimated using the two-stage least squares method, with the first stage having each of the firm's ICT variables as the dependent variable, and province-year-specific ICT index, as described in detail in Appendix Table A.6, as the instrument. Columns (1)–(5) use the index that captures the technical infrastructure aspect of ICT as an instrument in the first stage. Columns (6)–(10) use the index that is a weighted average of the five aspects of ICT, including (i) technical infrastructure, (ii) human infrastructure, (iii) applications, (iv) manufacturing business index, and (v) organization/policy environment. Firm-level controls, as reported in Table 3, are always included (but with results suppressed to save space) in both stages of each regression.

Source: Annual Enterprise Census by the General Statistics Office of Viet Nam.

Table 6: Firms' Female Labor Shares among Colleged-Educated Workers and Information and Communication Technology Adoption (Two-Stage Least Squares)

Second Stage Dependent Variable	Firm's Female Labor Share among the College-Educated Workers									
Firm-Level of ICT Adoption (ICT)	(1) Log (No. of PCs with Internet/ worker)	(2) Log (No. of PCs with LAN/ worker)	(3) Dummy (has Internet access)	(4) Dummy (has LAN)	(5) Dummy (has website)	(6) Log (No. of PCs with Internet/ worker)	(7) Log (No. of PCs with LAN/ worker)	(8) Dummy (has Internet access)	(9) Dummy (has LAN)	(10) Dummy (has website)
ICT	0.798*** (0.185)	0.896*** (0.218)	0.462*** (0.091)	0.313*** (0.064)	0.688*** (0.174)	0.881*** (0.177)	1.000*** (0.218)	0.484*** (0.084)	0.328*** (0.066)	0.764*** (0.170)
Firm-level controls	√	√	√	√	√	√	√	√	√	√
Year fixed effect	√	√	√	√	√	√	√	√	√	√
Sector fixed effect	√	√	√	√	√	√	√	√	√	√
Region fixed effect	√	√	√	√	√	√	√	√	√	√
No. of Obs	57,172	56,302	54,613	52,886	49,609	57,172	56,302	54,613	52,886	49,609
R-squared	0.081	0.038	−0.106	−0.016	−0.340	0.064	0.008	−0.132	−0.034	−0.457
First Stage										
ICT index (technical infrastructure component)	0.140*** (0.013)	0.128*** (0 .014)	0.229*** (0.031)	0.342*** (0.053)	0.160*** (0.024)					
ICT index (five components)						0.177*** (0.018)	0.159*** (0.021)	0.304*** (0.038)	0.454*** (0.081)	0.198*** (0.030)
Firm-level controls	√	√	√	√	√	√	√	√	√	√
Kleibergen-Paap F statistic	115.726	79.687	55.413	41.222	45.693	97.369	56.614	65.021	31.059	43.327

ICT = information and communication technology, LAN = local area network, PC = personal computer.
Notes: Standard errors, clustered at the province level, are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All coefficients are estimated using the two-stage least squares method, with the first stage having each of the firm's ICT variables as the dependent variable, and province-year-specific ICT index, as described in detail in Appendix Table A.6, as the instrument. Columns (1)–(5) use the index that captures the technical infrastructure aspect of ICT as an instrument in the first stage. Columns (6)–(10) use the index that is a weighted average of the five aspects of ICT, including (i) technical infrastructure, (ii) human infrastructure, (iii) applications, (iv) manufacturing business index, and (v) organization/policy environment. Firm-level controls, as reported in Table 3, are always included (but with results suppressed to save space) in both stages of each regression.
Source: Annual Enterprise Census by the General Statistics Office of Viet Nam.

C. Differential Effects across Industries

Next, we examine the differential effects of ICT across industries. The findings in Tables 5 and 6 are consistent with the hypothesis that ICT is complementary to interactive, and more skilled tasks where women potentially have a comparative advantage. As Autor, Levy, and Murnane (2003) show, the tasks that are more substitutable with ICT tend to be routine tasks, that require relatively little interaction and communication between people. Black and Spitz-Oener (2010) show that in Germany, technological change is partly responsible for the rise in firms' demand for nonroutine interactive tasks, for which females have a comparative advantage relative to physical and manual type tasks for which males have a comparative advantage. On the other hand, Lindley (2012) provides suggestive evidence for the United Kingdom that females may have lost ground in highly technical sectors requiring specific education and training. To provide some evidence to support the different channels that could be driving the complementarity between ICT and female labor at the firm level, namely the relative rise of interactive tasks that have occurred in less complex sectors, we examine whether the ICT employment effects differ across industries. To this end, we estimate equation (3) along with an additional interaction term between a sector's characteristic (T_j) and firm-level ICT adoption (ICT_{it}) as follows.

$$\frac{f_{it}}{l_{it}} = \alpha + \beta ICT_{it} + \theta T_j * ICT_{it} + X_{it}\delta + \left[FE_r + FE_j + FE_t\right] + \omega_{it} \qquad (3)$$

As described in section V.C, we use a sector (time-invariant) measure of either task complexity, corresponding to the degree to which the industry entails complex problem solving, or manual and physical task intensity. The expected sign of β is positive, while that on θ can be positive or negative, depending on whether female workers are endowed with the skills that complement (or are less substitutable with) ICT. If T_j captures an industry's intensity of complex tasks, in which males have a comparative advantage due to their relatively tendency to invest in STEM education and training, as we postulate in Hypothesis 2, we should expect a negative θ. On the other hand, if T_j captures an industry's intensity of manual and physical tasks, with which ICT is more substitutable and in which male workers have a comparative advantage, we should expect a positive θ.

Table 7 reports the estimates of (3), using a firm's female employment share as the dependent variable. Using the technical infrastructure component of the ICT index and its interaction with an industry's task complexity as instruments, we find negative and statistically significant coefficients on the interaction terms between each of the five ICT variables and the sectoral measure of complexity in the second stage of the 2SLS model. These results imply that the positive effects of ICT on firms' female employment are on average weaker in industries that are more dependent on complex tasks. This is believed to be driven by the relative scarcity of highly educated females in the labor market to perform more complex tasks.[15] Existing evidence shows that men have a comparative advantage in physically, intensive tasks, while women have a comparative advantage in communication intensive and non-routine tasks (Guiso et al. 2008). However, in more complex sectors males may have comparative advantages relative to females because of a higher proportion of men trained in highly technical skills (Lindley 2012). Thus, in industries that require higher order technical, problem solving skills, females benefit less from ICT possibly due to having lower levels of technical training. To the extent that complex sectors are more complementary to ICT, but also require more technical skills, these findings show that the types of tasks that have grown in relative importance in terms of

[15] While it would be interesting to examine the effects of industry-level interactions with college employment shares, the smaller sample size and variation in the data makes it harder to obtain statistically significant estimates on these effects.

complexity appears to be an important channel through which ICT complements labor along the gender dimension.

In Table 8, we repeat similar regressions with the T_j interaction term replaced by an industry-specific measure to which tasks are nonroutine, manual, and physical. We find that while on average female labor shares are higher in industries requiring more manual and physical tasks, the positive effects of ICT on firms' female employment are smaller in industries that are more dependent on manual and physical tasks. This supports the hypothesis that ICT could be contributing to greater gender inequality in areas that require greater interaction and are less reliant on physical skills.[16]

Table 7: The Differential Effects of Information and Communication Technology on Firms' Female Labor Shares across Industries (Task Complexity)

Second Stage Dependent Variable	Firm's Female Labor Share				
Firm-Level of ICT Adoption (ICT)	(1) Log (No. of PCs with Internet/ worker)	(2) Log (No. of PCs with LAN/ worker)	(3) Dummy (has Internet access)	(4) Dummy (has LAN)	(5) Dummy (has website)
ICT	0.605***	0.753***	0.316***	0.296***	0.532***
	(0.186)	(0.217)	(0.115)	(0.101)	(0.125)
ICT x Industry complexity	−1.086***	−1.378***	−0.563**	−0.533**	−0.899***
	(0.374)	(0.504)	(0.240)	(0.228)	(0.273)
Industry complexity	−0.373**	−0.390**	−0.001	−0.214	−0.440***
	(0.155)	(0.175)	(0.170)	(0.149)	(0.145)
Firm-level controls	√	√	√	√	√
Year fixed effect	√	√	√	√	√
Industry (2-digit) fixed effect	√	√	√	√	√
Region fixed effect	√	√	√	√	√
No. of Obs	188,446	183,188	179,376	172,559	163,863
R-squared	0.431	0.430	0.426	0.428	0.405
First Stage					
Kleibergen-Paap F statistic	55.499	33.602	52.879	20.413	27.001

ICT = information and communication technology, LAN = local area network, PC = personal computer.
Notes: Standard errors, clustered at the province level, are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All coefficients are estimated using the two-stage least squares method, with the first stage having each of the firm's ICT variables as the dependent variable, and province-year-specific ICT index, as described in detail in Appendix Table A.6, as the instrument. The ICT index used as an instrument in the first stage captures the technical infrastructure aspect of ICT. Firm-level controls, as reported in Table 3, are always included (but with results suppressed to save space) in both stages of each regression.
Source: Annual Enterprise Census by the General Statistics Office of Viet Nam.

[16] Interactions with nonroutine tasks along manual and interactive, analytical and cognitive, and analytical and personal by industry were examined. All of the interaction effects between these tasks and ICT had a positive relationship with female employment shares.

Table 8: The Differential Effects of Information and Communication Technology on Firms' Intensity of Nonroutine, Manual and Physical Tasks

Second Stage Dependent Variable	Firm's Female Labor Share				
Firm-level of ICT adoption (ICT)	(1) Log (No. of PCs with Internet/ worker)	(2) Log (No. of PCs with LAN/worker)	(3) Dummy (has Internet access)	(4) Dummy (has LAN)	(5) Dummy (has website)
ICT x Industry manual and physical intensity	−0.038 (0.121)	−0.109 (0.134)	−0.039 (0.047)	−0.005 (0.051)	−0.030 (0.067)
ICT x Industry manual and physical intensity	−0.625** (0.240)	−0.895*** (0.327)	−0.293** (0.125)	−0.229** (0.095)	−0.576*** (0.170)
Industry manual and physical intensity	0.413*** (0.037)	0.437*** (0.036)	0.467*** (0.044)	0.499*** (0.060)	0.416*** (0.043)
Firm-level controls	√	√	√	√	√
Year fixed effect	√	√	√	√	√
Industry (2-digit) fixed effect	√	√	√	√	√
Region fixed effect	√	√	√	√	√
No. of Obs	185,729	180,389	173,913	180,832	165,031
R-squared	0.436	0.425	0.407	0.414	0.373
First Stage					
Kleibergen-Paap F statistic	49.09	38.83	16.02	42.03	33.49

ICT = information and communication technology, LAN = local area network, PC = personal computer
Notes: Standard errors, clustered at the province level, are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All coefficients are estimated using the two-stage least squares method, with the first stage having each of the firm's ICT variables as the dependent variable, and province-year-specific ICT index, as described in detail in Appendix Table A.6, as the instrument. The ICT index used as an instrument in the first stage captures the technical infrastructure aspect of ICT. Firm-level controls, as reported in Table 3, are always included (but with results suppressed to save space) in both stages of each regression.
Source: Annual Enterprise Census by the General Statistics of Viet Nam.

VIII. CONCLUDING REMARKS

In this paper, we empirically study the effects of firms' investments in ICT on their demand for female and skilled workers. By exploiting the rapid liberalization of the broadband Internet sector between 2006 and 2009 in Viet Nam and using the country's comprehensive enterprise census data, we find that firms' adoption of broadband Internet and other related ICT increased the relative demand for female and highly skilled workers. The positive effect of ICT on firms' female employment is particularly strong among the college-educated employees, but is weaker in industries that are more dependent on complex (nonroutine) tasks. These results are consistent with the hypothesis that the relative rise of interactive tasks in less complex industries for which females have comparative advantages have led to increases in female employment.

Our findings based on firm survey data show that within firms, changes in labor demand are an important factor in reducing employment inequality along the gender dimension. For policy makers concerned with providing greater opportunities for females to enter the labor market and secure more stable employment in formal sector firms, implementing policies and programs that induce firms' adoption of ICT can potentially stimulate female employment growth. Given the positive effects of ICT on firm efficiency, these type of policies could contribute more to creating quality employment and income generating opportunities for females compared to programs that narrowly focus on females by providing access to capital and training. That said, the weaker effects on firms' female employment in more complex sectors could point to a potentially important area for policy intervention. As complex sectors become increasingly more important and garner higher wages, strategic gender policies that incentivize females to enter STEM education and training may be important for ensuring greater gender equality in employment opportunities over the longer term.

It is worth noting that despite our findings of a positive relationship between firms' female labor share and ICT, within-firm gender wage gap may still persist. It is possible that ICT induces firms to employ more women without increasing their average pay relative to men. Moreover, the use of registered enterprises in this research ignores an important part of the Vietnamese economy that is in the informal sector. Extending the current analysis in these two directions is a promising avenue for future research.

APPENDIX

Table A.1: Major Policies that Improve Information and Communication Technology Capability

Year	Major Events
2000	Vietnam Internet Network Information Center established
2002	Start of liberalization of telecommunication industry to foster competition (going from one single state-owned monopoly)
	First time that CDMA technology was used (allow multiple users to use bandwidth)
2006	EVN Telecon enters market and becomes one of the largest CDMA operators.
	Ministry of Post and Telecommunications started banning imports of second hand communication technologies.
	Decision to expand mobile services to 62 of the poorest districts and to reach universalization of basic telecommunications services for extreme poverty.
2007	Ministry of Information and Communication was established to replace the Ministry of Post and Telematics – responsible for policy and regulation.
	Mobile broadband technology was deployed – potentially providing new ways to reach a larger set of customers.
	Viet Nam joins the World Trade Organization. 45% of ICT equipment duty free and another 45% have tariffs ranging from 5%–10%.
2008	Viet Nam launches Vinasat I allowing information to be transmitted to all regions of the country.
	Tariffs for 228 out of 325 ICT products reduced to 0.
2009	September 2009 3G mobile networks based on CDMA technology deployed with four licenses given out.
	Another 25 ICT products tariffs reduced to 0.
2010	Another 72 ICT products tariffs reduced to 0.

CDMA = code division multiple access, ICT = information and communication technology.
Source: Government of Viet Nam's official publications.

Table A.2: Viet Nam Labor Force Statistics by Gender

	2007		2013	
	Male	Female	Male	Female
Labor force participation rate	81.4	75.1	84.6	76.9
Employment status of those in labor force				
Unemployed	2.2	2.0	1.5	1.2
Employer	3.8	2.8	3.4	1.5
Own-account	46.2	56.5	42.8	45.1
Unpaid/Other	12.2	14.1	12.0	22.5
Wage	35.7	24.6	40.4	29.8
Education of those in labor force				
Primary	41.1	47.1	35.5	41.3
Some secondary	29.8	28.9	30.8	31.5
Secondary	13.4	11.2	17.9	12.8
Secondary tech	8.6	6.5	6.7	5.0
College	7.1	6.4	9.1	9.5

Notes: Statistics based on individuals ages 15–65; Percent values shown.
Source: Viet Nam's Labor Force Surveys.

Table A.3: Viet Nam Monthly Wages for Wage Workers by Gender and Education ($)

	2007			2013		
	Male	Female	Ratio	Male	Female	Ratio
Primary	1,057	769	1.37	2,974	2,314	1.29
Some secondary	1,044	754	1.38	3,225	2,791	1.16
Secondary	1,249	1,055	1.18	3,774	3,189	1.18
Secondary tech	1,648	1,406	1.17	4,119	3,567	1.15
College	2,537	2,085	1.22	5,815	4,751	1.22

Note: Statistics based on individuals ages 15–65.
Source: Viet Nam's Labor Force Surveys.

Table A.4: Number of Enterprises

Sector	2005	2006	2007	2009
Agriculture, forestry and fishing	1,071	583	1,477	1,585
Mining and quarrying	711	716	771	926
Manufacturing	13,481	14,665	14,773	16,372
Construction	9,061	9,489	9,806	10,804
Wholesale and retail trade	8,887	9,419	8,183	8,504
Transportation and storage	2,551	2,623	3,187	3,684
Accommodation and food services	1,209	1,360	1,514	1,611
Information and communication	391	487	482	530
Real estate activities	393	468	449	542
Professional, scientific and technical activities	1,581	1,929	1,904	1,989
Administrative and support services	493	706	735	855

Source: Annual Enterprise Census by the General Statistics Office of Viet Nam (2005, 2007–2009)

Table A.5: Summary Statistics of Viet Nam's Manufacturing Enterprise Surveys

	Short Name	2005	2006	2007	2008	2009	2010	2011
Number of Obs		44,727	49,584	57,076	68,748	73,011	77,610	86,264
Number of Obs (w/ info on ICT)		42,708		46,101	48,470	52,733	51,696	80,253
Firm age	fage	5.58	5.42	5.67	5.99	6.43	6.88	6.94
		(19.71)	(16.40)	(15.50)	(24.98)	(26.45)	(29.46)	(30.44)
Firm age <= 2 years	dfage_l2	0.38	0.37	0.33	0.32	0.29	0.25	0.27
Firm age 3–10 years	dfage_l10	0.49	0.51	0.54	0.55	0.58	0.6	0.57
Profit (2010 VND)	rtotprf	3,631.65	4,047.94	4,430.44	2,787.83	4,369.99	3,796.07	2,199.16
		(322,175.00)	(346,716.70)	(290,167.90)	(238,372.00)	(243,731.60)	(207,049.10)	(102,703.60)
Revenue (2010 VND)	rtotrev	67,663.16	66,296.00	71,669.38	62,938.65	69,735.19	75,980.83	76,785.02
		(834,931.40)	(865,657.30)	(857,669.40)	(711,644.40)	(820,762.90)	(930,798.60)	(999,855.50)
Expenses (2010 VND)	rtotexp	64,031.52	62,248.07	67,238.95	60,150.81	65,365.2	72,184.76	74,585.85
		(627,281.60)	(664,734.60)	(701,536.90)	(573,025.00)	(727,795.30)	(858,234.30)	(959,237.40)
Material expenses (2010 VND)	rtotmat	60,087.32	58,542.99	63,200.95	56,695.64	61,400.00	67,971.10	70,601.10
		(613,441.50)	(656,295.00)	(688,747.80)	(564,323.40)	(715,050.40)	(848,844.40)	(949,352.80)
Wage bill (2010 VND)	rlaborwage	3,944.2	3,705.08	4,038.00	3,455.18	3,965.2	4,213.66	3,984.75
		(34,148.66)	(22,805.05)	(36,220.63)	(19,324.90)	(36,536.25)	(27,476.46)	(22,560.55)
Assets (2010 VND)	rassets	54,098.49	51,079.23	59,860.64	49,958.96	69,120.63	84,737.09	58,849.52
		(633,642.40)	(495,105.30)	(761,395.50)	(469,666.70)	(1,269,099.00)	(1,387,491.00)	(672,230.80)
Labor employed (full-time)	laborempl	118.01	107.34	108.36	95.78	97.71	98.05	96.51
		(664.19)	(489.72)	(597.81)	(467.53)	(633.77)	(575.46)	0.00
Labor productivity	laborprod	763.13	788.48	871.47	925.22	1,091.56	1,126.44	947.28
		(3,187.30)	(3,492.76)	(4,952.57)	(6,476.49)	(14,857.88)	(10,906.08)	(4,751.13)

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Table A.5 *continued*

	Short Name	2005	2006	2007	2008	2009	2010	2011
Labor efficiency	laboreffi	29.61	28.97	30.69	29.85	31.5	29.67	29.09
		(120.80)	(143.31)	(318.62)	(170.21)	(657.58)	(246.50)	(172.12)
Female labor share	shemp_female	0.32	0.33	0.33	0.32	0.32	0.33	0.34
		(0.23)	(0.23)	(0.22)	(0.22)	(0.21)	(0.21)	(0.23)
College-edu labor share	shemp_college			0.17		0.09		0.15
				(0.21)		(0.20)		(0.22)
Female share in college-edu emp	shemp_collegefem			0.35		0.22		0.34
				(0.31)		(0.33)		(0.33)
Share SOE	dsoe	0.1	0.08	0.08	0.06	0.06	0.05	0.05
Share FDI	dfdi	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Import dummy	dimp	0.01	0.02	0.01	0.09	0.09	0.08	0.16
Export dummy	dexp	0.02	0.01	0.11	0.08	0.01	0.09	0.14

FDI = foreign direct investment, ICT = information and communication technology, SOE = state-owned enterprise, VND = Viet Nam dong.
Notes: Firms with over 20 employees or above are surveyed. Observations with missing values on revenue, material, *or* total expenses are dropped. Labor Productivity = Total revenue (2010 VND) divided by total employment. Labor Efficiency = Total revenue (2010 VND) divided by total wage bill. Sample means of each variable are reported, with standard errors reported in parentheses.
Source: Annual Enterprise Census by the General Statistics Office of Viet Nam.

Table A.6: Five Different Aspects of Information and Communication Technology Quality

(a) Technical Infrastructure Index

No	Subindicators	2005	2006	2007	2009	2010	2011	2012	2013	2014
1	Number of fixed telephones per 100 inhabitants	x	x	x	x	x	x	x	x	x
2	Number of mobile phones per 100 inhabitants	x	x	x	x	x	x	x	x	x
3	Number of Internet accounts per 100 inhabitants	x	x	x	x	x	x	x	x	x
4	Number of broadband subscribers (ADSL) per 1,000 households	x	x	x	x					
5	Total local connection bandwith per user	x	x	x						
6	Total connection bandwith (cross cities and international) per user	x	x	x						
7	Number of computers per household	x	x	x	x	x	x	x	x	x
8	Percentage of households having broadband Internet access	x	x	x	x	x	x	x	x	x
9	Number of computers per government officer	x	x	x	x					
10	Percentage of computers with Internet access in public agencies at provincial level	x	x	x	x					
11	Percentage of public agencies having broadband Internet access		x	x						
12	Percentage of enterprises having broadband Internet access		x	x	x	x	x	x	x	x
13	Percentage of computers per person among enterprises			x	x	x	x			
14	Percentage of investment in ICT infrastructure per capita in 2005, 2006, 2007			x	x					
15	Percentage of investment in ICT infrastructure per capita in 2007			x	x					
16	Percentage of households having TV				x	x	x	x	x	x

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Table A.6 *continued*

No	Subindicators	2005	2006	2007	2009	2010	2011	2012	2013	2014
17	Percentage of broadband subscribers/100 dân					x	x	x	x	x
18	Percentage of fixed telephones					x	x	x		x
19	Percentage of computers per official staff in state agencies at province level					x	x	x		
20	Percentage of computers in manager public agencies at provincial level having broadband Internet access					x	x			
21	Percentage of computers in public agencies at province level having specific Internet network or Nation (CPNet)						x	x	x	x
22	Percentage of computers per official staff at province level								x	x
23	Percentage of computers in public agencies at province level having broadband Internet access							x	x	x
24	Percentage of computers per staff in enterprise							x	x	x
25	Deployment of information systems security and data safety							x	x	x
26	Percentage of public agencies at province level having large-scale Internet							x	x	x
Number of criteria by year		10	12	15	13	12	13	15	15	15

ADSL = asymmetric digital subscriber line, ICT = information and communication technology.
Source: Authors' computation based on the Government of Viet Nam's official publications.

(b) Human Infrastructure Index

No	Subindicators	2005	2006	2007	2009	2010	2011	2012	2013	2014
1	Number of literate people per 100 inhabitants	x								
2	Number of official education and training facilities (university, college, technical) per 100,000 inhabitants	x	x	x						
3	Number of graduates from official education and training facilities in 2005 per 1,000 inhabitants	x	x	x						

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Table A.6 *continued*

No	Subindicators	2005	2006	2007	2009	2010	2011	2012	2013	2014
4	Number of unofficial education and training facilities in IT per 100,000 inhabitants	x	x	x						
5	Number of graduates from official education and training facilities in IT in 2005 per 1,000 inhabitants	x	x	x						
6	Number of people working in ICT industry per 100 inhabitants	x								
7	Number of people with at least college degree in ICT	x								
8	Percentage of primary school teaching computerization		x	x	x	x	x	x	x	x
9	Percentage of secondary school teaching computerization		x	x	x	x	x	x	x	x
10	Percentage of high school teaching computerization		x	x	x	x	x	x	x	x
11	Percentage of official staff in public agencies at province level know to using computer in their work		x	x	x	x	x	x	x	x
12	Percentage of IT staff in charge of the state management agencies at provinces level			x	x	x	x	x	x	x
13	Percentage budget for IT training per person in 3 years (2005, 2006, 2007)			x						
14	Percentage budget for IT training per person in 2007 and 2008			x	x					
15	Percentage of official staff in public agencies training, guiding to using open software						x	x	x	x
16	Percentage of university, college at provincial having specialized training IT							x	x	x
17	Percentage of staff in charge of information security at province's state agencies							x	x	x
Number of criteria by year		7	8	11	6	5	6	8	8	8

ICT = information and communication technology, IT = information technology.
Source: Authors' computation based on the Government of Viet Nam's official publications

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Table A.6 *continued*

(c) Information and Communication Technology Applications Index

No	Subindicators	2005	2006	2007	2009	2010	2011	2012	2013	2014
1	Number of local phone calls per capita	x	x	x						
2	Number of cross-city and international phone call per capita	x	x	x						
3	Budget for ICT per capita	x	x	x						
4	% public agencies having Internet access	x								
5	% enterprises having Internet access	x								
6	% public agencies having official websites	x	x							
7	% enterprises having official websites	x	x	x	x	x		x	x	x
8	% staff granted official email of province, city and using email in their work						x	x	x	x
9	Computerization of administrative procedures					x	x	x	x	x
10	Implement the basic application					x	x	x	x	x
11	Build of the specialized databases							x	x	x
12	Apply to open source software						x	x	x	x
13	Use electronic documents							x	x	x
14	Website of province/city		x	x		x	x	x	x	x
15	Implement public services online							x	x	x
16	% official staff granted official email of province, city						x			
17	% staff use email in their work			x	x	x	x			
18	% management and direction information from provincial leaders on the official internal website of the people's committee at provincial level					x	x			
19	% online public administration service					x	x			
20	Level of online public administration service				x	x	x			

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Table A.6 *continued*

No	Subindicators	2005	2006	2007	2009	2010	2011	2012	2013	2014
21	% staff in public agencies granted email					x				
22	Frequency of update website					x				
23	Public services provided in Internet		x	x						
24	% payment for IT application (software, service, consulting, other) per person in 3 years 2005, 2006, 2007			x						
25	% payment for IT application (software, service, consulting, other) per person in 2007			x						
26	% payment from budget for IT application (software, service, consulting, other) per person in 3 years 2005, 2006, 2007			x						
27	% public administration service in Internet			x						
28	% payment from budget for IT application				x					
29	% operating and directing information upload to Internet				x					
30	Level of deploy document management software and operating jobs				x					
31	Level of deploy website of province level				x					
Number of criteria by year		7	7	11	7	10	10	9	9	9

ICT = information and communication technology, IT = information technology.
Source: Authors' computation based on the Government of Viet Nam's official publications.

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Table A.6 *continued*

(d) Manufacturing and Business Index

No	Subindicators	2005	2006	2007	2009	2010	2011	2012	2013	2014
1	Number of sales and production units in ICT per 1,000 inhabitants	x	x							
2	Total revenue of sales and production units in ICT per capita	x	x							
3	% ICT production, business units per 1,000 inhabitants			x			x	x	x	x
4	% person who worked in ICT production, business units per 1,000 inhabitants			x			x	x	x	x
5	% ICT enterprise per 1,000 inhabitants				x	x				
6	% employee in ICT enterprise per inhabitants				x					
7	% turnover production - business of ICT enterprise per inhabitants				x	x	x			
8	% employee in ICT enterprise per 10,000 inhabitants					x				
9	% turnover per staff in ICT enterprise							x	x	x
Number of criteria		2	2	2	3	3	3	3	3	3

ICT = information and communication technology.
Source: Authors' computation based on the Government of Viet Nam's official publications.

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Table A.6 *continued*

(e) Organization and Policy Environment Index

No	Subindicators	2005	2006	2007	2009	2010	2011	2012	2013	2014
1	Are there administrative agencies for direction and management on ICT (Direction Department on ICT, Posts and Telecommunication Department at provincial level): Is there Direction Department at provincial level on ICT? Number of meetings per year of the department? Is there Posts and Telecommunication Department at provincial level?	x	x	x						
2	Are there any policies in promoting the use and development of ICT: Strategies to develop and apply ICT? Strategies to encourage the use and development of ICT; Strategies to develop human capital for ICT?	x	x	x						
3	The interest of local government leaders in the use and development of ICT is rated at four levels: Not interested or barely interested; Interested at average level; Fairly interested and Very interested	x	x	x						
4	Organization - directing development - IT applications in the province/city				x	x	x	x	x	x
5	Mechanisms - policies for development - IT applications in the province / city				x	x	x	x	x	x
6	Level of interest of local government leaders in use and development of ICT				x	x	x	x	x	x
Number of criteria		3	3	3	3	3	3	3	3	3

ICT = information and communication technology, IT = information technology.
Source: Authors' computation based on official documents from Viet Nam's Ministry of Science and Technology.

Table A.7: Female Comparative Advantage and Task Complexity by Industry

ISIC (rev 4)	Description	Task Complexity	Nonroutine, Manual, and Physical Tasks
620	Computer programming	0.681	−0.605
711	Architectural and engineering activities and related technical consultancy	0.646	−0.685
262	Manufacture of computers and peripheral equipment	0.638	−0.178
721	Research and experimental development on natural sciences and engineering	0.630	−0.696
722	Research and experimental development on social sciences and humanities	0.630	−0.696
582	Software publishing	0.588	−0.415
263	Manufacture of communication equipment	0.582	−0.138
266	Manufacture of irradiation	0.582	−0.152
265	Manufacture of measuring	0.575	−0.135
712	Technical testing and analysis	0.571	−0.499
303	Manufacture of air and spacecraft and related machinery	0.567	−0.166
261	Manufacture of electronic components and boards	0.566	−0.073
267	Manufacture of optical instruments and photographic equipment	0.563	−0.185
611	Wired telecommunications activities	0.556	−0.854
631	Data processing	0.550	−0.506
61	Extraction of crude petroleum	0.547	−0.116
62	Extraction of natural gas	0.547	−0.116
701	Activities of head offices	0.541	−0.675
801	Private security activities	0.540	−0.440
802	Security systems service activities	0.540	−0.438
702	Management consultancy activities	0.536	−0.675
613	Satellite telecommunications activities	0.534	−0.854
691	Legal activities	0.533	−0.675
210	Manufacture of pharmaceuticals	0.533	−0.060
749	Other professional	0.531	−0.528
71	Mining of iron ores	0.530	0.069
72	Mining of nonferrous metal ores	0.530	0.069
619	Other telecommunications activities	0.524	−0.854
332	Installation of industrial machinery and equipment	0.521	−0.256
51	Mining of hard coal	0.521	0.001

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Table A.7 *continued*

ISIC (rev 4)	Description	Task Complexity	Nonroutine, Manual, and Physical Tasks
692	Accounting	0.520	−0.675
803	Investigation activities	0.517	−0.440
191	Manufacture of coke oven products	0.515	−0.181
432	Electrical	0.515	−0.522
192	Manufacture of refined petroleum products	0.514	−0.116
429	Construction of other civil engineering projects	0.514	−0.584
493	Transport via pipeline	0.514	−0.469
203	Manufacture of man-made fibers	0.513	−0.107
422	Construction of utility projects	0.513	−0.522
410	Construction of buildings	0.512	−0.522
302	Manufacture of railway locomotives and rolling stock	0.512	−0.128
602	Television programming and broadcasting activities	0.509	−0.173
182	Reproduction of recorded media	0.509	−0.031
268	Manufacture of magnetic and optical media	0.509	−0.106
811	Combined facilities support activities	0.509	−0.616
774	Leasing of intellectual property and similar products	0.507	−0.639
433	Building completion and finishing	0.506	−0.520
741	Specialized design activities	0.504	−0.563
271	Manufacture of electric motors	0.503	−0.021
279	Manufacture of other electrical equipment	0.503	−0.082
601	Radio broadcasting	0.503	−0.173
201	Manufacture of basic chemicals	0.503	−0.084
264	Manufacture of consumer electronics	0.502	−0.140
331	Repair of fabricated metal products	0.502	−0.176
99	Support activities for other mining and quarrying	0.501	−0.064
282	Manufacture of special-purpose machinery	0.501	−0.227
439	Other specialized construction activities	0.498	−0.521
452	Maintenance and repair of motor vehicles	0.497	−0.540
431	Demolition and site preparation	0.497	−0.522
421	Construction of roads and railways	0.497	−0.522
592	Sound recording and music publishing activities	0.496	−0.104
612	Wireless telecommunications activities	0.496	−0.854
732	Market research and public opinion polling	0.495	−0.675
281	Manufacture of general-purpose machinery	0.495	−0.181
52	Mining of lignite	0.495	−0.093
120	Manufacture of tobacco products	0.492	−0.062

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Table A.7 *continued*

ISIC (rev 4)	Description	Task Complexity	Nonroutine, Manual, and Physical Tasks
325	Manufacture of medical and dental instruments and supplies	0.491	−0.148
293	Manufacture of parts and accessories for motor vehicles	0.491	−0.067
291	Manufacture of motor vehicles	0.491	−0.115
681	Real estate activities with own or leased property	0.491	−0.606
301	Building of ships and boats	0.490	−0.160
309	Manufacture of transport equipment n.e.c.	0.488	−0.190
273	Manufacture of wiring and wiring devices	0.487	−0.057
202	Manufacture of other chemical products	0.487	−0.102
252	Manufacture of weapons and ammunition	0.486	−0.301
272	Manufacture of batteries and accumulators	0.483	0.085
742	Photographic activities	0.482	−0.140
274	Manufacture of electric lighting equipment	0.481	0.018
241	Manufacture of basic iron and steel	0.480	−0.259
682	Real estate activities on a fee or contract basis	0.480	−0.591
275	Manufacture of domestic appliances	0.480	0.030
243	Casting of metals	0.480	−0.271
581	Publishing of books	0.478	−0.192
242	Manufacture of basic precious and other nonferrous metals	0.478	−0.133
329	Other manufacturing n.e.c.	0.478	−0.044
292	Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers	0.476	−0.239
251	Manufacture of structural metal products	0.476	−0.240
259	Manufacture of other fabricated metal products; metalworking service activities	0.475	−0.184
591	Motion picture	0.473	−0.052
221	Manufacture of rubber products	0.470	0.003
323	Manufacture of sports goods	0.470	0.048
322	Manufacture of musical instruments	0.470	−0.089
324	Manufacture of games and toys	0.470	−0.089
321	Manufacture of jewelry	0.468	−0.117
222	Manufacture of plastics products	0.468	−0.015
152	Manufacture of footwear	0.467	0.186
170	Manufacture of paper and paper products	0.466	−0.044
143	Manufacture of knitted and crocheted apparel	0.466	0.047

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Table A.7 *continued*

ISIC (rev 4)	Description	Task Complexity	Nonroutine, Manual, and Physical Tasks
310	Manufacture of furniture	0.464	−0.133
131	Spinning	0.463	0.015
239	Manufacture of nonmetallic mineral products n.e.c.	0.462	−0.009
231	Manufacture of glass and glass products	0.462	0.041
142	Manufacture of articles of fur	0.461	0.092
731	Advertising	0.461	−0.568
162	Manufacture of products of wood	0.460	−0.022
151	Tanning and dressing of leather; manufacture of luggage	0.459	0.109
91	Support activities for petroleum and natural gas extraction	0.458	−0.418
141	Manufacture of wearing apparel	0.457	0.055
81	Quarrying of stone	0.455	0.065
106	Manufacture of grain mill products	0.455	−0.013
104	Manufacture of vegetable and animal oils and fats	0.454	−0.013
89	Mining and quarrying n.e.c.	0.454	0.063
181	Printing and service activities related to printing	0.453	0.005
465	Wholesale of machinery	0.452	−0.268
823	Organization of conventions and trade shows	0.452	−0.440
750	Veterinary activities	0.452	−0.460
101	Processing and preserving of meat	0.449	−0.013
103	Processing and preserving of fruit and vegetables	0.447	−0.016
781	Activities of employment placement agencies	0.443	−0.070
782	Temporary employment agency activities	0.443	−0.440
783	Other human resources provision	0.443	−0.440
107	Manufacture of other food products	0.442	−0.026
105	Manufacture of dairy products	0.442	−0.013
31	Fishing	0.440	−0.380
102	Processing and preserving of fish	0.440	−0.013
108	Manufacture of prepared animal feeds	0.439	−0.013
821	Office administrative and support activities	0.434	−0.185
161	Sawmilling and planing of wood	0.433	−0.115
110	Manufacture of beverages	0.432	−0.093
512	Freight air transport	0.430	−0.269
812	Cleaning activities	0.427	−0.237
454	Sale	0.427	−0.296

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Table A.7 *continued*

ISIC (rev 4)	Description	Task Complexity	Nonroutine, Manual, and Physical Tasks
511	Passenger air transport	0.427	−0.269
829	Business support service activities n.e.c.	0.427	−0.440
773	Renting and leasing of other machinery	0.422	−0.454
451	Sale of motor vehicles	0.422	−0.250
474	Retail sale of information and communications equipment in specialized stores	0.421	−0.322
464	Wholesale of household goods	0.419	−0.241
491	Transport via railways	0.417	−0.200
479	Retail trade not in stores	0.416	−0.028
453	Sale of motor vehicle parts and accessories	0.414	−0.254
822	Activities of call centers	0.407	−0.440
531	Postal activities	0.406	0.325
461	Wholesale on a fee or contract basis	0.405	−0.163
466	Other specialized wholesale	0.402	−0.247
551	Short term accommodation activities	0.399	0.052
522	Support activities for transportation	0.398	−0.392
813	Landscape care and maintenance service activities	0.397	−0.041
469	Nonspecialized wholesale trade	0.396	−0.237
559	Other accommodation	0.396	0.052
791	Travel agency and tour operator activities	0.394	−0.401
478	Retail sale via stalls and markets	0.391	−0.028
771	Renting and leasing of motor vehicles	0.388	−0.454
462	Wholesale of agricultural raw materials and live animals	0.385	−0.207
463	Wholesale of food	0.381	−0.207
477	Retail sale of other goods in specialized stores	0.379	−0.324
521	Warehousing and storage	0.375	−0.401
22	Logging	0.374	−0.430
24	Support services to forestry	0.374	−0.430
501	Sea and coastal water transport	0.373	−0.300
475	Retail sale of other household equipment in specialized stores	0.372	−0.322
16	Support activities to agriculture and postharvest crop activities	0.369	−0.239
492	Other land transport	0.368	0.024
472	Retail sale of food	0.366	−0.293
772	Renting and leasing of personal and household goods	0.366	−0.454

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Table A.7 *continued*

ISIC (rev 4)	Description	Task Complexity	Nonroutine, Manual, and Physical Tasks
476	Retail sale of cultural and recreation goods in specialized stores	0.366	−0.322
532	Courier activities	0.364	0.325
471	Retail sale in nonspecialized stores	0.363	−0.275
502	Inland water transport	0.361	−0.300
562	Event catering and other food service activities	0.343	0.354
473	Retail sale of automotive fuel in specialized stores	0.341	−0.158
563	Beverage serving activities	0.335	0.354
561	Restaurants and mobile food service activities	0.328	0.354
12	Growing of perennial crops		−0.234
23	Gathering of nonwood forest products		−0.290
13	Plant propagation		−0.325
15	Mixed farming		−0.236
14	Animal production		−0.257
32	Aquaculture		−0.319
21	Silviculture and other forestry activities		−0.430
11	Growing of nonperennial crops		−0.220

ISIC = International Standard Industrial Classification, n.e.c. = not elsewhere classified.
Sources: Complexity (Keller and Yeaple 2008). Nonroutine, physical, and manual (Acemoglu and Autor 2011).

REFERENCES

Acemoglu, Daron, and David H. Autor. 2011. "Chapter 12: Skills Tasks and Technologies: Implications for Employment and Earnings." *Handbook of Labor Economics,* 1043–71. Elsevier.

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

Autor, David H., David Dorn, and Gordon Howard Hanson. 2016. "The China Shock: Learning from Labor Market Adjustment to Large Changes in Trade." *Annual Review of Economics* 8: 205–40.

Autor, David H., Lawrence Francis Katz, and Alan Bennett Krueger. 1998. "Computing Inequality: Have Computers Changed the Labor Market?" *Quarterly Journal of Economics* 113 (4): 1169–213.

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

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

Black, Sandra Eilene, and Lisa M. Lynch. 2001. "How to Compete: The Impact of Work-Place Practices and Information Technology on Productivity." *Review of Economics and Statistics* 83 (3): 434–45.

Black, Sandra Eilene, and Alexandra Spitz-Oener. 2010. "Explaining Women's Success: Technological Change and Skill Content of Women's Work." *Review of Economics and Statistics* 92 (1): 187–94.

Bloom, Nicholas, Luis Garciano, Raffaella Sadun, John Van Van Reenan. 2014. "The Distinct Effects of Information Technology and Communication Technology on Firm Organization." *Management Science* 60 (2): 2859–85.

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

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

Commander, Simon, Rupert Harrison, and Naercio Menezes-Filho. 2011. "ICT and Productivity in Developing Countries: New Firm-Level Evidence from Brazil and India." *Review of Economics and Statistics* 93 (2): 528–41.

Crandall, Robert, William Lehr, and Robert Litan. 2007. "The Effects of Broadband Deployment on Output and Employment. A Cross-sectional Analysis of U.S. Data." Issues in Economic Policy No. 6. The Brookings Institution.

Dinkelman, Taryn. 2011. "The Effects of Rural Electrification on Employment: New Evidence from South Africa." *American Economic Review* 101 (7): 3078–108.

Duflo, Esther, and Rohini Pande. 2007. "Dams." *Quarterly Journal of Economics* 122 (2): 601–46.

Forman, Chris, Avi Goldfarb, and Shane Greenstein. 2012. "The Internet and Local Wages: A Puzzle." *American Economic Review* 102 (1): 556–75.

Goldin, Claudia. 2006. "The Quiet Revolution That Transformed Women's Employment, Education, and Family." Ely Lecture, *American Economic Review, Papers and Proceedings* 96 (2): 1–21.

Grimes, Arthur, Cleo Ren, and Philip Stevens. 2012. "The Need for Speed: Impacts of Internet Connectivity on Firm Productivity." *Journal of Productivity Analysis* 37 (2): 187–201.

Guiso, Luigi, Ferdinando Monte, Paola Sapienza, and Luigi Zingales. 2008. "Culture, Gender, and Math." *Science* 320 (5880): 1164–65.

Hjort, Jonas, and Jonas Poulsen. 2017. "The Arrival of Fast Internet and Employment in Africa." NBER Working Paper No. 23582.

Jensen, Robert. 2007. "The Digital Provide: Information (Technology), Market Performance, and Welfare in the South Indian Fisheries Sector." *Quarterly Journal of Economics* 122 (3): 879–924.

Juhn, Chinhui, Gergely Ujhelyi, and Carolina Villegas-Sanchez. 2014. "Men, Women, and Machines: How Trade Impacts Gender Inequality." *Journal of Development Economics* 106: 179–93.

Keller, Wolfgang, and Stephen Yeaple. 2008. "Global Production and Trade in the Knowledge Economy." NBER Working Paper No. 14626.

Lindley, Joanne. 2012. "The Gender Dimension of Technical Change and the Role of Task Inputs. *Labour Economics* 19 (4): 512–26.

Mathiowetz, Virgil, Nancy Kashman, Gloria Volland, Karen Weber, Mary Dowe, and Sandra Rogers. 1985. "Grip and Pinch Strength: Normative Data for Adults." *Archives of Physical Medicine and Rehabilitation* 66 (2): 69–74.

Michaels, Guy, Ashwini Natraj, and John 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.

Newman, Carol, and Finn Tarp. 2014, Technology and Competitiveness in Viet Nam. Presentation link: https://www3.wider.unu.edu/sites/default/files/Technology-competitiveness-in-VietNam-5772.pdf.

Ngai, L. Rachel, and Barbara Petrongolo. 2017. "Gender Gaps and the Rise of the Service Economy." *American Economic Journal: Macroeconomics* 9 (4): 1–44.

Nguyen, Viet Ha. 2013. "Despite Rapid Modernization in Viet Nam, Survey Reveals Gender Bias Persists Among Youth." *The Asia Foundation*. March 6. https://asiafoundation.org/2013/03/06/despite-rapid-modernization-in-vietnam-survey-reveals-gender-bias-persists-among-youth/.

Ogutu, Sylvester Ochieng, Julius Juma Okello, and David Jakinda Otieno. 2014. "Impact of Information and Communication Technology-Based Market Information Services on Smallholder Farm Input Use and Productivity: The Case of Kenya." *World Development* 64: 311–21.

Olivetti, Claudia, and Barbara Petrongolo. 2016, "The Evolution of Gender Gaps in Industrialized Countries." *Annual Review of Economics* 8 (1): 405–34.

Piketty, Thomas. 2014. *Capital in the Twenty First Century* Belknap Press: An Imprint of Harvard University Press.

Pitt, Mark M., Mark R. Rosenzweig, and Md. Nazmul Hassan. 2012. "Human Capital Investment and the Gender Division of Labor in a Brawn-Based Economy." *American Economic Review* 102 (7): 3531–60.

Stock, James H., and Motohiro Yogo. 2005. "Testing for Weak Instruments in Linear IV Regression" Book." *Identification and Inference for Econometric Models: Essays in Honor of Thomas Rothenberg*, 80–108. Cambridge University Press

Tambe, Prasanna, Lorin M. Hitt, and Erik Brynjolfsson. 2012. "The Extroverted Firm: How External Information Practices Affect Innovation and Productivity." *Management Science* 58 (5): 843–59.

Tuan, Tran Minh. 2011. *Broadband in Viet Nam: Forging Its Own Path*. Washington, DC: infoDev/World Bank.

UNESCO and KWDI. 2015. *A Complex Formula: Girls and Women in Science, Technology, Engineering and Mathematics in Asia.* Paris: UNESCO.

United Nations Statistics Division. https://unstats.un.org/unsd/cr/registry/regot.asp?Lg=1.

World Bank. 2017. World Development Indicators. http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators (accessed 10 October 2017).

World Trade Organization (WTO). 2017. Tariff Download Facility. http://tariffdata.wto.org/ReportersAndProducts.aspx (accessed August 2017).

Do Information and Communication Technologies Empower Female Workers? Firm-level Evidence from Viet Nam

Using Viet Nam's comprehensive enterprise survey data, this paper finds that a firm's adoption of broadband Internet and related information and communication technologies (ICT) increased their relative demand for female and college-educated workers. The effect of ICT on a firm's female employment is particularly strong among the college-educated employees and is weaker in industries that are more dependent on complex and interactive tasks. These results suggest that ICT reduces inequalities in female employment by creating a shift in labor demand from highly manual, routine tasks, where males have a comparative advantage toward more nonroutine tasks, where females hold a comparative advantage.

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