Do Information and Communication Technologies Empower Female Workers? Firm-level Evidence from Vietnam*

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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 in Vietnam as an instrument, 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 non-routine, interactive tasks in which women hold a comparative advantage. However, we find 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 into the most innovative industries that require highly technical skills to complement ICT.

Keywords: Information Technology, ICT, Infrastructure, Gender Inequality, Wage Inequality

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1 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 nations that has caught substantial attention from both policy makers and academics.[1] Developed countries facing strong pressures from globalization and import competition, particularly from China, have observed labor market polarization and rising 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 that ICT is having on the creation of employment opportunities and economic growth within these countries.

Highly informal labor markets, capacity to provide complementary skills, and lower wages are just a few reasons why the labor market effects of ICT and globalization could deviate from the findings of developed markets. Our paper contributes to the inequality literature by studying how ICT affects female and skilled employment within firms. In contrast to the research that focuses on developed nations, we explore the research question using firm-level data from a large developing country. In particular, we study how firms' ICT adoption, triggered by the Vietnam's central government policy to develop broadband Internet infrastructure, changes firms' employment by gender and skill groups.

Studying the employment effects of ICT in Vietnam 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 Vietnamese central government 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. Private firms were encouraged to enter, driving 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

[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.

[3] Key regulatory changes are listed in Appendix 1. Increased competition has also coincided with Vietnam's

sector was substantially reduced. As a result of several years of bold ICT reforms, Vietnam has become the country with the highest penetration rates of ICT among developing nations, offering greater opportunities for firms to use digital technology to acquire information for both production and sales. World Bank's World Development Indicators for 2015 show that Vietnam's broadband Internet was one of the most affordable in the world and had an average Internet speed that was faster than both China and Indonesia (see Table 1).

An important contribution of the paper is the construction of several indices capturing the quality and accessibility of broadband Internet in Vietnam that are used as instruments for firms' adoption of ICT. These instruments vary across provinces and time from 2005 to 2009, due to the Vietnamese government's sequential implementation of reforms to improve the broadband Internet infrastructure. Using these province-specific time-varying instruments, we establish the causal relationship between firms' ICT and 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 the five series—log number of workers with computers connected to the Internet, log number of workers with computers connected to local area network (LAN), the fractions of firms having internet access, LAN, and websites, respectively. All of the five averages show significant upward trends 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 raise 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.

ascension to the WTO which significantly reduced tariffs on imports of internet and communication technology (ICT) products from 2007-2010.

The effect of ICT on firms' female employment is particularly strong among the college-educated workers, and is stronger in industries that depend more on highly manual and physical tasks, according to the O*Net task database for occupations in the U.S. These results suggest that ICT may have shifted the relative demand for tasks, which have different effects on the demand for male and female workers. Male workers have a comparative advantage in highly physical tasks, but ICT has been more complementary with non-routine, interactive tasks that favor females.[4] However, the effect is weaker in industries that rely more on complex and interactive tasks. This suggests 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 that are needed to undertake more complex technical tasks.

Research findings of this paper will offer important development policy implications for Vietnam 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 nations 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.

The paper proceeds as follows. Section 2 provides a literature review. Section 3 discusses the policy changes that happened during the sample period, which offer an instrument for the regression analysis. Section 4 discusses the data source and the construction of the key variables. Section 5 discusses the conceptual framework and outlines two testable hypotheses. Section 6 presents our empirical specifications, following by Section 7 that presents the empirical results. The final section concludes.

[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 non-routine 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.

2 Literature Review

This paper has wide ranging implications and contributes to three broad strands of literature. First, it relates to the research on the effects of ICT on firms' productivity and overall performance. Black and Lynch (2001) find that increased use of computers by non-managerial 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 a positive productivity effect of ICT investment and significantly larger rates of return to 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 U.S. firms' external focus is correlated with both their IT 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 in U.S. industries increase the relative demand for college-educated workers. Crandall, Lehr, Litan (2007) find that a one percentage-point increase in ICT penetration in a U.S. state is associated with 0.2-0.3 percentage-point increase in employment. Forman, Goldfarb, and Greenstein (2012), however, find a quantitatively small effect of ICT adoption on employment and wage growth across U.S. 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. In Africa, the Internet is found to have significantly contributed to improved

[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 variables 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.

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).

Third, our work contributes to the literature on the relationship between ICT, tasks, and gender inequality.[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 non-routine tasks. Black and Spitz-Oener (2010) find that in Germany, women have experienced a relative increase in their supply of non-routine 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) develops a formal model that shows how the rise of the service economy driven by technological changes benefits women in world where women have comparative advantages in producing services. Based on micro data from multiple nations, Olivetti and Petrongolo (2016) find that cross-country variation in the industry structure explains the bulk of the overall differences in labor demand between the U.S. and other countries, with about one third of the overall cross-nation differences in wage and hours gaps. Juhn et al. (2014) is the only paper that we are aware of that links ICT to changes in gender inequality for a developing country. They find evidence that the relative wage and employment of women in Mexico improved primarily in blue collar jobs due to increased computerization that occurred from trade-tariff reductions as it lowered the need for physically demanding tasks.

While digital technologies have brought many changes to the jobs and the tasks in demand closing gender gaps in employment, there is the concern that it could be driving gender inequalities in the most innovative and highly skilled sectors. In particular, Lindley (2012) finds that while gender gaps have closed in the UK overall, females have lost ground in sectors that have experienced the fastest changes due to computerization such as finance and machine manufacturing. This is due to females being less well-placed to undertake highly technical tasks due to far fewer shares being trained or educated in highly technical engineering skills.

In Vietnam 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

[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 U.S. of the 20th century.

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 economy-wide 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.

3 Changing ICT 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 Vietnam. In a little over a decade, Vietnam's strategic investments have transformed it from a Southeast Asian laggard to a leader in technological competitiveness. In 2005, access to the Internet in Vietnam 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 thousand 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 (SOEs). 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 5 companies providing cellular data (Tuan 2011).

Vietnam's accession to the WTO 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 fifty percent of the population providing significant incentives for firms concentrated on the domestic market to leverage Internet technologies to grow their business (WDI 2017). Table A1 in the appendix 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 Vietnam's Labor Force Surveys, in 2013, 85% of males and 77% of females ages 15-64 were participating in the labor force (see Table A2 in the appendix). 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 percent higher wages that could be driven by different occupations, tasks and skills (see Table A3 in the appendix). 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 Vietnam'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 [8] in part by biases within the country that view males as more capable

[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 $< 10\%$.

in performing technical jobs. This has potentially led to significant gender gaps in the proportion of females trained in STEM degrees in Vietnam even while there is near parity in matriculation to higher education.[9][10] 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.

4 Data

4.1 Firm-level Data

The main data source of this paper is the Annual Enterprise Census of Vietnam, over the period of 2005-2009, conducted by the General Statistics Office of Vietnam (GSO). The GSO conducts the annual census of all enterprises, across both manufacturing and non-manufacturing 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. Table A5 in the appendix 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 Vietnam

[9] Nguyen, H. (2013) *Despite Rapid Modernization in Vietnam, Survey Reveals Gender Bias Persists Among Youth.* Asia Foundation Blog: http://asiafoundation.org/2013/03/06/despite-rapid-modernization-in-vietnam-survey-reveals-gender-bias-persists-among-youth/

[10] 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.

did not report information on firms' ICT in their surveys, implying that we have to exclude 2006 from the main regression sample. Table A4 reports the number of firm observations included in the regression sample by broad sector and year.

Partly due to the reforms described in Section 3 above, firms across Vietnam have been significantly increasing their uses 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.

4.2 Provincial Measures of ICT 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 Vietnam'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 indices 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.

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 Table A6 in the appendix 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 indices. Both the overall and technical infrastructure ICT indices 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 Vietnam. 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.

4.3 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 the US Department of Labor's Occupational Information Network (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 U.S. 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 U.S. 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 non-routine, 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 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 U.S. Census's Current

Population Survey, covering both manufacturing and non-manufacturing sectors.[11] This data is then collapsed to a distinct NAICS 3-digit code which is then mapped into the latest international industry 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.[12] See Table A7 in the appendix for details about these two sector measures at the 3-digit ISIC level.

5 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) (ALM hereafter). Their model assumes that firm production requires tasks that can be described broadly along two dimensions: routine versus non-routine and manual versus analytic or interactive. Thus, tasks can be grouped into four broad categories of routine interactive, routine manual, non-routine interactive, and non-routine manual. ALM provide some specific examples from Dictionary of Occupational Titles (DOT) 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. Non-routine interactive tasks include forming and testing hypotheses, legal writing, marketing and sales. The classic examples of non-routine 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 non-

[11] Industries are classified based on the U.S. Census 2007 classification.
[12] https://unstats.un.org/unsd/cr/registry/regot.asp?Lg=1

routine tasks that often involve unexpected contingencies, such as driving on the road, with ICT.[13] Based on these intuitions, ALM develop a model that features constant elasticity of substitution and production functions that use routine labor, non-routine labor and computer capital as inputs. There model makes three assumptions, which we modify in the context of ICT as:

A1. ICT is more substitutable for human labor in carrying out routine tasks than non-routine tasks.

A2. Routine and non-routine tasks are themselves imperfect substitutes.

A3. Greater intensity of routine inputs increases the marginal productivity of non-routine 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 non-routine 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 non-routine, 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 non-routine, interactive tasks where females have a comparative advantage compared to ICT and tasks that are non-interactive 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 non-routine interactive tasks for which females have a comparative advantage.

Nevertheless, task complexity may play significant role in labor demand that cuts along gender

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

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:

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.

6 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:

$$\frac{f_{it}}{l_{it}} = \alpha + \beta ict_{it} + \mathbf{X}_{it}\delta + [FE_r + FE_j + FE_t] + \xi_{it}, \tag{1}$$

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:

1. (log) Number of PCs per worker;
2. (log) Number of PCs connected to broadband local area networks (LAN) per worker;
3. Have access to broadband Internet;
4. Have access to Internet;
5. 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 $\mathbf{X}_{it}$ 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,[14] respectively, to capture any time-invariant unobserved factors that may affect a firm's decision to adopt ICT. For instance, the Red River Delta in northern Vietnam, which contains the country's capital Hanoi, 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.

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 OLS estimates are likely to be biased. To tackle reverse causality and other endogeneity

[14]See the list of sectors in Table A4 and that for regions in Figure 2.

issues, we estimate (1) using a 2SLS model, with the province-specific ICT quality index being the instrument for ict_{it}, as described in Section 4. Specifically, the first stage of our 2SLS specification is

$$ict_{it} = \alpha' + \beta' ICT_{rt} + \mathbf{X}_{it}\delta' + [FE_r + FE_j + FE_t] + \varepsilon_{it}, \tag{2}$$

The variable ICT_{rt} stands for province r's ICT quality in year t. The regressors on the right hand side are already defined for eq. (1) 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 *ict*, triggered by improved ICT competitiveness in a province.

7 Empirical Results

7.1 The Effects of ICT 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). As firms' management quality and readiness to adopt technology are omitted factors in the regressions the simple OLS estimates of ICT on female employment shares are likely to be biased.

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 to 5, we use the technical component of the ICT quality as an instrument for the five measures of firms' ICT, while in columns 6 to 10, we use the average over the five components of province-level ICT indices. 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 personal computers (PC) 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_{ict} in column 2, a 10% increase in the number of personal computers (PC) 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 to 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 to 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.[15] The empirical results support our hypothesis that the rise of non-routine, interactive type tasks that complement ICT have increased the relative proportion of females employed within firms.

7.2 The Effects of ICT 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 U.S., computerization has reduced the demand for non-routine, manual and physical tasks, but increased the demand for non-routine 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 non-routine 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 $tech_{ict}$ in column

[15]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.

1, a 10% increase in the number of personal computers (PC) 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 to 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 to 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 variables 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 personal computers (PC) 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 to 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 to 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.

7.3 Differential Effects across Industries

Next, we examine the differential effects of ICT across industries. The findings in Table 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 non-routine 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 UK 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 eq. (1) along with an additional interaction term between a sector's characteristic (T_j) and firm-level ICT adoption (ict_{it}) as follows.

$$\frac{f_{it}}{l_{it}} = \alpha_1 + \beta_1 ict_{it} + \theta_1 T_j \times ict_{it} + \mathbf{X}_{it}\delta_1 + FE_r + FE_j + FE_t + \omega_{it} \tag{3}$$

As described in Section 5.3, 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_1 is positive, while that on θ_1 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 advantages due to their relatively tendency to invest in STEM education and training, as we postulate in Hypothesis 2, we should expect a negative θ_1. On the other hand, if T_j captures an industry's intensity of manual and tasks, with which ICT is more substitutable and in which male workers have a comparative advantage, we should expect a positive θ_1.

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. 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 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 non-routine, 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]

8 Concluding Remarks

In this paper, we empirically study the effects of firms' investments in information and communication technologies (ICT) on their demand for female and skilled workers. By exploiting the rapid liberalization of the broadband Internet sector between 2006 and 2009 in Vietnam and using the country's comprehensive enterprise census data, we find that firms' adoption of broadband Internet

[16]Interactions with non-routine 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.

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 (non-routine) 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.

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