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# Mobile Internet and Income Improvement: Evidence from Vietnam

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## Abstract

New developments of existing technologies over time have led to emergent patterns of technology adoption and accordingly changing impacts on economy and society. Focusing on the arrival of mobile Internet in the early 2010s in developing countries, we identified significant positive effects of mobile Internet on provinces' average household income in Vietnam. The effect sizes are larger for lower-income quintiles groups and for rural areas, suggesting the more inclusive changing impact of the innovation over the last decade. Preliminary evidence of impact mechanisms via skilled employment rates and (formal) wages are also presented. The evidence from Vietnam, a lower middle-income country, can bring further understanding in the extent of development impacts of second-generation mobile for development (M4D 2.0) in particular and ICT for development (ICT4D) in general.

**Key words**: *household income, jobs, wages, mobile Internet, smartphone, technological change, technology adoption, developing countries, M4D, ICT4D.*

**JEL codes**: D31, E20, E24, J24, O30, O53, R50.

## 1. Introduction

Information and Communication Technologies (ICTs) in the past decades have offered multiplier effects on growth and productivity worldwide. The second decade of the 21st century has been characterized by the diffusion of mobile internet and smartphones in both developed and developing countries (see figure 1 in the appendix for timeline of ICTs innovations). While, like other ICT innovations, mobile Internet can provide near-zero marginal costs of information access and communications like other ICT innovations, the combination of internet and mobility characteristics can offer additional pathways to economic growth. In the past few years, the gig or platform economy initiated by mobile internet has created an additional service sector hiring significant numbers of software engineers for mobile applications (Arnold & Taş, 2019; Mandel, 2015). Mobility-based apps like ride-hailing for example have also provided jobs for workers with diverse skill levels. Additionally, its anytime anywhere connection has led to further rise in e-commerce (Google et al., 2019). With affordable devices and data packages, mobile internet offers ubiquitous connection and communication via social media and messaging platforms, and more timely accessibility to a wider range of information resources, as well as next-generation mobile banking or payment. These economic multifunctionalities can help facilitate business transactions, as well as entrepreneurship, particularly for small or informal businesses (Caldarola et al., 2023). This is not to mention the potentially significant increase in social transfers and remittances thanks to lower transaction costs, more time-efficiency, and other user-friendly utilities. Last but not least, there can be benefits from other functionalities like mapping service, calendar and reminder, etc., which help reduce scheduling and travelling time, or access to health information and gaming, entertainment, which can help improve social wellbeing, and thus, possibly, individual productivity. These effects help bring additional income sources for households, potentially in both formal and informal sectors. These benefits can be especially strong for the less advantaged groups e.g., lower-income households, and regions e.g., rural areas, particularly in developing countries who have been less connected to the regional and world economy.

The world in 2018 passed the threshold of 50 percent of people using the internet, according to World Bank data and the digital divide has moved from access or ownership to usage level in terms of time and quality or types of use. Vietnam passed that threshold in 2015 while the average rate for lower-middle income countries 2020 was 45%. Like many developing countries, Vietnam has a large population, especially of low-income, in rural areas, who have skipped personal computers (PCs) and moved directly to smartphones to integrate into the digital world. Distinctively, Vietnam is among the countries with the highest smartphone penetration rate in the world. The country is increasingly becoming a base for ICT outsourcing services for regional and international companies, producing products and services for the app economy (Arnold & Taş, 2019). Human capital with universal literacy and primary education, near-universal lower-secondary education can help facilitate and enhance the effects via better digital skills and use. In terms of cognitive skills, OECD's PISA test scores of math, English, and science for Vietnam have been higher than those for Malaysia and Thailand (both upper-middle income countries) and are only lower than Singapore (a high-income country) in the Southeast Asia region. Measuring the impacts of internet adoption and universal broadband policy using the case of Vietnam can offer additional insights for both policy making and academic research since the Internet has been advocated as a human right by the UN and other international organizations.

In this paper we add to the literature on the development impacts of the diffusion of mobile internet diffusion, in particular household income, for developing countries using evidence from Vietnam (Aker, 2010; Bahia et al., 2020; Blumenstock et al., 2020; Dammert et al., 2013; Donati, 2019; Hartje & Hübler, 2017; Hubler & Hartjie, 2016; Kaila & Tarp, 2019; Muto & Yamano, 2009; Roessler et al., 2020; Suri & Jack, 2016). The rise of 3G coverage in the country in the last decade with disparity between provinces or regions can affect provincial average household income levels. Household income may have been improved through the creation of additional jobs at both high- and low-skilled levels, such as positions for software engineers, user interface designers, user experience analysts, and ride-hailing services, which are facilitated by the gig or app economy. Consequently, wages have increased, along with other income sources arising from self-employment, particularly for micro, small, and medium enterprises (MSMEs), whether formal or informal. Additionally, there has been a rise in remittances, both domestically and internationally, with the country maintaining its position as one of the top recipients of remittances on a global scale. In this paper, we identify whether there are significant positive effects of improved mobile internet coverage on household income in Vietnam and the extent of these effects.

For our empirical analyses, to address the potential endogeneity between mobile internet coverage and income level in measuring the effects, instrumental variable and fixed effects approaches are adopted. Following extant literature and local context characteristics, we used elevation as the main instrument, which is shown to be relevant and reasonably exogenous, and measured a significant positive effect of 3G coverage on provincial household average income. The unit of analysis in this paper is the province (meso-level) due to availability of administrative and geo-referenced data from both the General Statistics Office of Vietnam (GSO) and international organizations.

The detected results are robust under a more restricted sample, under alternative measurements of the main independent variable and units of analysis (gridded cell level of 0.5 degree). The heterogeneity analysis provides evidence of more inclusive or pro-poor effects with stronger effect sizes for rural areas and for lower income quintile groups, while preliminary analyses of the mechanisms underlying the effects indicate improved effects on employment, i.e., skilled or trained employment rates, and wages.

In the following we present case background and preliminary evidence in section 2; then section 3 describes data sources and descriptive analysis while section 4 states our empirical strategy; our research results including robustness tests and heterogeneity analyses are shown in section 5; followed by a brief discussion of impact mechanisms in section 6; and section 7 concludes.

## 2. Background and Preliminary evidence

In this section we provide background information about Vietnam's development progress in the last decades, including broadband coverage, and preliminary evidence of positive effects on household income.

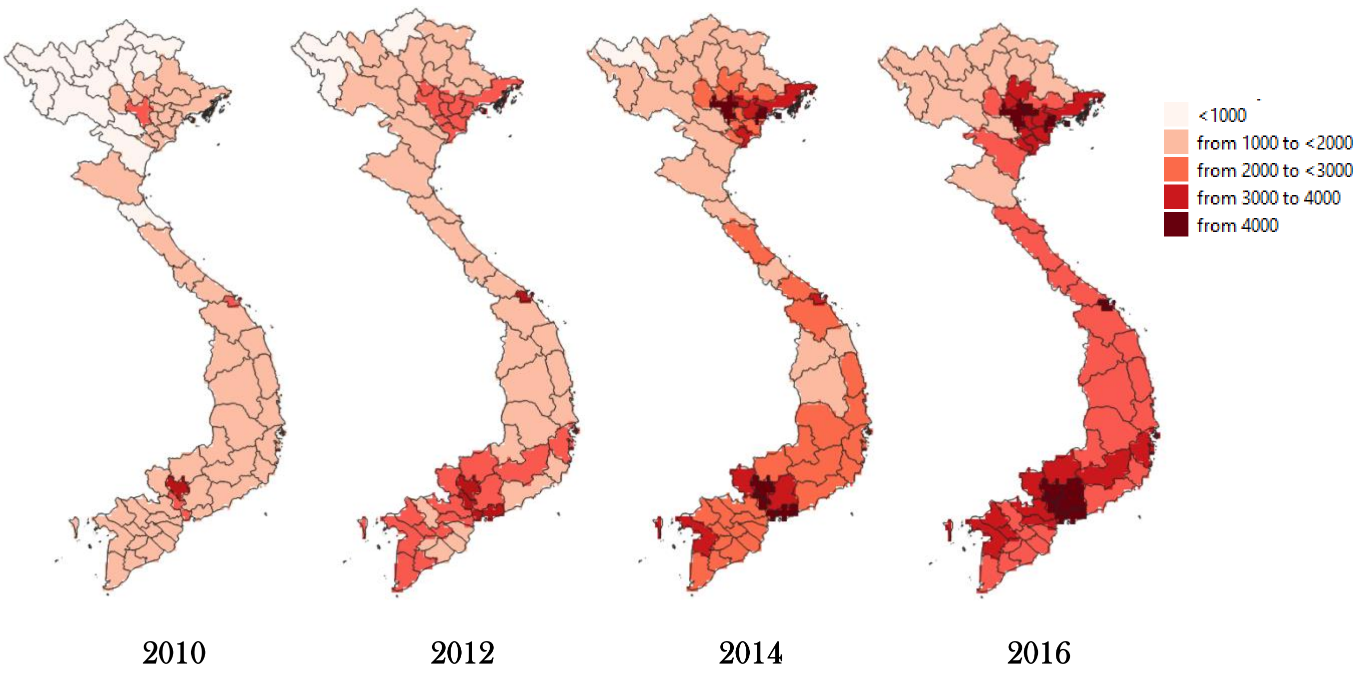
### 2.1. Vietnam's development achievements since 1980s

Aside from mass cheap access to the Internet, Vietnam has achieved notable success in poverty alleviation, universal electricity access, universal primary education through "*small-scale and rural infrastructure development [as] a key feature of Vietnam's inclusive developmen*t" (X. T. Nguyen & Dapice, 2009) over the past decades. The country reached lower-middle income country status in 2010 with annual GDP per capita of 1,673 USD (current value) (WDI data). Since then the country's income level has risen significantly over time (see figure 2 in the appendix).

Since the Reform (Doi Moi) towards the "socialist-oriented market economy" in 1986, Vietnam has liberalized the market and conducted multiple institutional reforms. The country became a member of WTO in 2007 and has participated in various bilateral and multilateral free trade agreements (FTAs) with the regional partners, the US, and Europe (see table 1 in the appendix for more information about Vietnam's FTA since 1975). Vietnam's recent growth has been mainly based on manufacturing, construction, tourism, and business services, with telecommunications equipment, textiles and garments, and computers, electronics & integrated circuits as the top three export sectors, providing millions of jobs and supplementing traditional industries and exports of oil and mining, agriculture, fisheries and aquaculture (Cameron & Pham, 2018). Combined with a growing market of 95 million people in 2018 from 60 million in 1986, Vietnam became Southeast Asia's hub for foreign investment and manufacturing, notably being the largest clothing and the second largest electronics exporter (after Singapore) in the region (WEF, 2018; World Bank, 2016). The social sector also plays an important role, with international NGOs providing around $300 million annually (European Union, 2014). Vietnamese citizens abroad also sent back over $8 billion in remittances each year, which is approximately the same size as FDI and twice of ODA (European Union, 2014).

Household income levels have increased over the years for all 63 provinces and centrally-run cities[1] (henceforth provinces), though there remains some gaps between north-central-south regions and between provinces, as can be seen in figure 1 below.

**Figure 1. Regional disparities in provincial monthly real income per capita 2010 – 2016 (in thousand VND)**




Source: authors', income data from VHLSS

Geographically three quarters of country's land is covered by mountains and plateaus (D. M. Nguyen, 2010) (see figure 3 in the appendix). Spatial inequality between urban-rural, mountainous or central highlands areas and the rest of the country remains a concern (European Union, 2014; X. T. Nguyen & Dapice, 2009; World Bank, 2019b).

### 2.2. Mobile Internet infrastructure and usage in Vietnam 2010-2016

Among developing countries, Vietnam's smartphone penetration rates have been among the top 10, reaching 71% of the total population in 2017 (Appota, 2018), following China and followed by Indonesia and Mexico (figure 4 in the appendix). Percentages of individuals using the internet has surpassed the upper-middle income country average since 2017 (WDI).

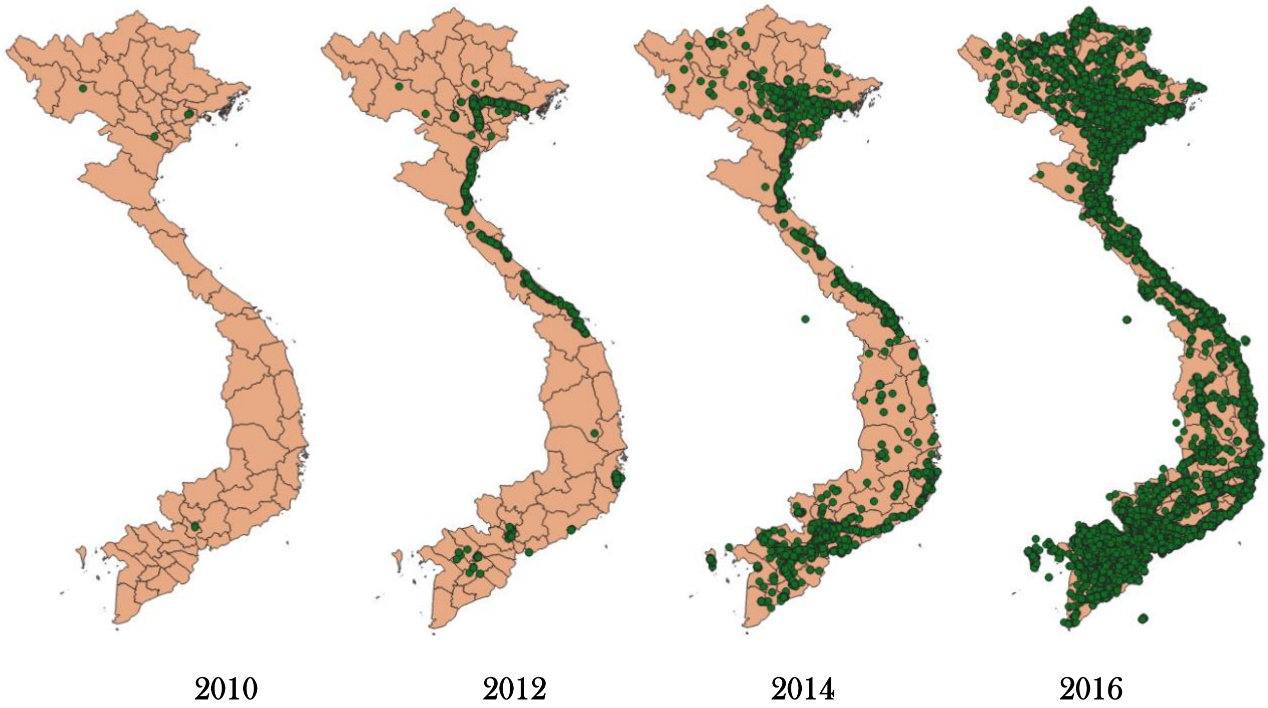
[1] Including 58 provinces and 5 centrally-run cities (Ha Noi, Hai Phong, Da Nang, Ho Chi Minh City, and Can Tho)

Mobile Internet users account for the majority of Internet users in Vietnam (Appota, 2018); with 68% of the population getting online via smartphone (SP) more often than desktops/laptop or PC (Appota, 2018)[2]. In 2017 smartphone penetration rates were 84% for key cities and 68% for rural areas (Appota, 2018), suggesting a small but real digital divide between urban and rural.

3G cell towers providing mobile internet signals have increased exponentially since 2010-2016 (figure 2 below). The average number of 3G cell towers per province has risen from 0.11 in 2010 to 1,838 in 2018; or from near zero to 0.8 cell tower per thousand population per province over 2010 – 2016. Coverage has become almost universal, with the exception of several areas in the northeast and northwest mountainous and central highlands regions. The 3G and smartphone package prices have reduced significantly. Telecoms companies together with mobile virtual network operators (MVNOs) and retailers have offered bundling services, driving both smartphone and mobile internet prices down (Google et al., 2019; momo.vn, 2021; Tinhte, 2019).

[2] with another 16% using SP and PC equally while 9% use PC/tablet more often than SP

Figure 2. Map of new 3G cell towers' signals collected 2010 – 2016




Source: authors', 3G cells data from OpenCellID[3]

Smartphones users access the digital world mainly through apps, which can be classified into two main types: 1) general apps that are often available by default (apps that are built in by smartphone producers and/or telecoms providers and applicable to most demographics)[4] (DeFazio, 2021; Roggio, 2021); and 2) specialized apps for specific demographic users groups, which are often downloaded by the users themselves like education (e.g. online blackboard for formal education systems or Coursera/Udemy for a specific skills or certificates), or healthcare and e-government, to name a few. These platforms can offer interactive 3D graphics and high-resolution videos that are downloadable for offline usages.

In Vietnam, the activities that smartphone users do the most often weekly are 1) watching videos; 2) social networking; 3) using search engines; 4) playing games; 5) looking for product information; and 6) purchasing products and services (Appota, 2018). For daily use, besides the aforementioned activities, people also check mail, view maps, e-banking, read book, and check health (Appota, 2018). Regarding online commerce, online shoppers in Vietnam in 2017 were estimated to be over

[3] a collaborative community project run by Unwired Labs, a geolocation service provider

[4] such as maps that help consumers locate places and businesses (as well as their opening hours and customer reviews) or suggest the best routes to destinations for riders/ drivers; utility apps like calculator, video/voice recording, weather forecasts; translation apps for cross-culture communication and search; search engines like Google; and social media e.g., Facebook in the context of Vietnam for both communication and information search where more and more businesses (both formal and informal) have added their presence in the online platform for marketing and ecommerce purposes

35 million people, with 72% of total visits on e-commerce websites and 53% of purchases being made using mobile phones (Appota, 2018). Additionally, there is a growing trend for purchases made in social media, i.e., 83% shopped in Facebook in 2017 from 67% in 2016 (Appota, 2018; Google et al., 2021). Rural areas account for 39% of e-commerce shoppers while HCMC alone contributes 38% and Ha Noi 17% (Appota, 2018). There are still some issues in the app ecosystem including trust, scamming, content availability and quality (Appota, 2018) but the market is growing, nevertheless.

### 2.3. Preliminary evidence of households' income and employment improvement following mobile Internet arrival

The app economy or sharing economy (AlphaBeta, 2021; IMF, 2018; OECD, 2020; P. Wang, 2020) has created 29,000 jobs in 2015 for app developers[5] in Vietnam, up from zero as of 2007 before the iPhone arrival (Mandel, 2015). The numbers have risen to 42,500 jobs in 2017 (Arnold & Taş, 2019). These quantities do not include additional jobs created for sales employees, project managers, or database analysts. The demands for these jobs come from companies of different sizes who develop apps for clients or for themselves; or foreign IT outsourcing companies with offices in Vietnam; multinational companies setting up supply chains for app development in Vietnam; or companies developing apps for their consumers' use under their brands; and media, finance, and retail companies. The demand for new mobile apps is expected to continue to grow in the future (Mandel, 2015), and this is combined with the Internet of Things applications in almost all industries[6].

The app economy has also led to the rise of ride hailing services (transport, food delivery), e-commerce, and online travel (accommodation bookings, vacation rentals) - which slowed down during Covid19 but is recovering now, creating jobs for freelancers and increasing sales for small retailers (Google et al., 2019). The global freelance jobs listing platform Upwork already has listings for Vietnam-based positions or for Vietnamese[7], besides many other platforms, both local and international, also post information for both formal and freelance jobs (Sinicki, 2021; P. Wang, 2020).

In Vietnam, the Internet economy reached 12 billion USD in 2019[8] with e-commerce being one of the key drivers (Google et al., 2019). Home-grown online marketplaces (e.g., Tiki, Sendo) have

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[5] Data extracted from the job search engine Indeed with the number of job postings containing terms 'iOS' or 'Android' at http://vn.indeed.com

[6] from agriculture to healthcare and manufacture where farmers, nurses and doctors, managers will use app(s) to aid their production, manage patient care, control factories, and so on.

[7] https://www.upwork.com/freelance-jobs/vietnamese/

[8] Near 5% of the country total's GDP in 2019 (current USD values)

grown and now compete with regional players (e.g., Lazada, Shopee) (Google et al., 2019). Ride hailing and food delivery services i.e., Grab, Grab Food, NOW, etc., have created jobs for motorcycle or scooter riders and car drivers (Google et al., 2019), and promoted sales for local small or micro enterprises at the same time. With additional training e.g., internet user skills, benefits can be further enhanced and extended[9] (Danviet, 2020). Rising funding and startups e.g., logistics startups that utilize optimization technologies, have also created additional jobs for both high and low education groups[10] (Google et al., 2019).

Beyond this suggestive evidence, we next provide quantitative analysis of income effects.

## 3. Data sources and descriptive statistics

We collected both open-sourced administrative and geo-referenced data for the period of 2010-2016 for the main analysis and 2004-2008 for the pre-trend analysis tests. Our primary geographical unit of analysis is 63 provinces. The choice is mainly driven by the availability of income data from the national statistics office's open sources. For robustness tests, we also aggregate data to grid cell level of 0.5x0.5 degree (or 55.55x55.55 km).

### 3.1. Vietnam Household Living Standard Survey (VHLSS), Population and Housing Census (PHC), and Statistical Yearbooks

Data on provinces' average household per capita income, employment rates are sourced from the reports of the Vietnam Household Living Standard Survey (VHLSS) results published by the General Statistics Office of Vietnam (GSO)[11] (GSO, 2016a, 2019a); and from the Population and Housing Census (PHC) reports for 2009 and 2019 (GSO, 2010, 2020a). VHLSS has been conducted biannually since the early 1990s and designed to be representative at provincial, regional, and national level while PHC is designed to be representative at the district level and above[12] (Benjamin et al., 2017; Tarp, 2017). Formal wages data are collected from GSO's Statistical Yearbooks (GSO, 2016b, 2019b).

[9] For example, farmers who participated in a training project conducted by Google and the Farmers' Association between 2017 and 2019, targeting government officials and association members, were trained in information access and internet skills for improving both their production and daily lives. As a result of this training, these farmers have established fanpages on social media platforms such as Facebook and Zalo (Vietnamese leading message app equivalent to WhatsApp) to promote and market their fruit and cattle products.

[10] Truck drivers for example can use mapping service app on their phone for driving and messenger app for communicating family during long-haul journeys.

[11] specifically 2018 report which has data coverage for 2008-2016 and 2014 report for 2004-2014

[12] The administrative levels in Vietnam, in descending order, are: national, regional, provincial, district, and commune. For data before 2008 (before Ha Tay province was merged into Ha Noi capital), the data for Ha Tay and Ha Noi are calculated by averaging two provinces' data.

Provincial average household real income has risen significantly from 1,334 in 2010 to 2,816 thousand VND in 2016, with the largest differences between Lai Chau province, whose income per capita increased from 587 to 1,319 thousand VND, and Binh Duong province from 3,002 to 5,131 thousand VND during 2010 – 2016.

On income sources components, wages accounted for the majority of household real income (41% on average), followed by agriculture (27%) and non-agriculture (22%), though non-agriculture sources since 2014 have taken over agriculture to be the second largest component of income (see figure 5-6 in the appendix for trends in income sources and quintiles). Average formal wages have increased from 3,432 to 6,152 thousand VND during 2010 – 2016, approximately six times higher than average wages (including both formal and informal).

Overall employment rates[13] averaged at 58.4%; with Bac Kan province having the highest rate of 71.3% in 2014 while Da Nang city, the third largest city after HCMC and Ha Noi in economic size, has the lowest employment rate among all provinces in 2010 with 47.3%. Trained employment rates[14] (for employees who had formal education or on-the-job training) has increased from 13% to 18.2% during 2010-2018 (for visualization, see figure 7 in the appendix).

### 3.2. Data on Mobile Internet

Data on mobile coverage is extracted from OpenCellID, a source which has been used for studies of the internet, mobile coverage, and socioeconomic development (Hodler & Raschky, 2017; Viollaz & Winkler, 2020)[15]. For Vietnam, OpenCellID data covers three types of mobile technologies 2G (GSM), 3G (UMTS, first data collected in 2010) and 4G (LTE, first in 2014). The databases offer information on cell towers' longitude and latitude,[16] date and time signal collected

[13] Employment rates are calculated for surveyed individuals who are from 15 years old and has done any (not illegal) job from 1 hour to produce goods or service during the time of survey, including also paid trainees, internships, self-employed, students, retirees https://www.gso.gov.vn/du-lieu-dac-ta/2019/12/htcttk-cap-tinh-so-lao-dong-co-viec-lam-trong-nen-kinh-te/

[14] An employed person is considered trained employee if satisfies either of the two conditions: 1) trained at a formal school or centers under the national education system for at least 3 months and have graduated and received certificates/ qualifications including vocational training, college, university and postgraduates; 2) not trained at a formal school but self-educated or receive on-the-job training so that s/he has skills equivalent to the same formal training https://www.gso.gov.vn/du-lieu-dac-ta/2019/12/htcttk-cap-tinh-ty-le-lao-dong-da-qua-dao-tao/

[15] The database was used instead of GSMA source due to data availability for Vietnam. The authors contacted a representative from Collins Bartholomew - GSMA's partner for mobile coverage database but received response that data for Vietnam has been missing for many years as local telecommunications companies do not submit their data.

[16] Averaged longitude and latitude were provided when more than one signal was received.

which we then converted into province and year data (Viollaz & Winkler, 2020). Due to limited 4G data collected, we use only 3G data.[17]

In September 2009, the licenses to supply 3G services were offered to four companies including Vietnam Telecom Services Company (VinaPhone), Vietnam Mobile Telecom Services Company (MobiFone), Viettel Military Industry and Telecoms Group (Viettel), and Hanoi Telecoms Electricity Joint Stock Company. A total of 30,334 stations were built within 18 months with over 8 million 3G user accounts (Nhandan.vn, 2011).

3G cell towers coverage has risen significantly between 2010 and 2016 (see table 2 in the appendix). Over this period, 3G stations covered almost the entire country with an average of 504 towers/province, or 0.22 towers per thousand population, reaching the farthermost destinations from the north to south. Heterogeneity between provinces still exists, from almost zero for most provinces and cities in 2010 to 4.3 towers per thousand population for HCMC and to 0.12 for Dien Bien and Bac Giang provinces in 2016. Distance to the nearest cell towers have been reduced significantly (see figure 8 in the appendix).

### 3.3. Other variables

Data on elevation is taken from USGS's GTOPO30 mountain elevation (USGS, 2018). The highest point in Vietnam is the Fan Si Peak with elevation of 3,143m,[18] located in Lao Cai province, while provinces along the coastlines are just above sea level. The national average elevation is 255.2m, Lai Chau province has the highest provincial average elevation of 1,019m and Mekong Delta provinces have the lowest elevation of 1m.

Terrain slope data of 0.5-degree resolution is obtained from Verdin et al. (2011). Geo-referenced data on terrain ruggedness at 1×1 km grid-square levels is provided by Carter (2018).[19] Data on lightning strikes is collected from NASA's Global Hydrology Resource Center. This database provides a 0.1x0.1 degree[20] gridded composite of total lightning bulk production, expressed as a

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[17] For the 4G network, data from OpenCellID for Vietnam mostly cover urban areas only, either because current 4G users are from urban areas, or contributors who send their signals to OpenCellID via cell tracking apps are in urban residence, but mostly the second case because 4G signals have been provided across the country both urban and rural by major service providers. The price difference between the two types of signal in the local market is negligible compared to the benefits (significantly faster speed, stable network, ranges of services: video calling) and most smartphones (which have been purchased and exchanged for new ones at frequent cycles) can support the 4G signal.

[18] https://www.britannica.com/place/Fan-Si-Peak

[19] https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/WXUZBN

[20] 0.1x0.1 degree is equivalent to 11.132x11.132km. This smaller grid is used instead of 0.5x0.5 as in Manacorda & Tesei (2020) to fit the communes' average areas in Vietnam.

flash rate density (flash rate per squared kilometers per year). More details on specific data sources and processing can be found on table 3 in the Appendix.

Data description of key variables can be seen in the table below. A scatterplot demonstrating the correlation between the dependent and the main independent variable can be seen in figure 9 in the appendix.

**Table 1. Summary statistics of key variables**

| Variable | Obs | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|---|
| Real household income (thousand VND) | 252 | 2147.207 | 926.689 | 586.638 | 5131.138 |
| Log real household income | 252 | 7.580 | .433 | 6.374 | 8.543 |
| 3G cell towers | 252 | 504.202 | 2847.527 | 0 | 36167 |
| 3G cell towers per thousand pop | 252 | .215 | .516 | 0 | 4.265 |
| Log 3G cell towers per thousand pop | 252 | .145 | .275 | 0 | 1.661 |
| Weighted 3G cell towers | 252 | 17.578 | 68.910 | 0 | 823.723 |
| Log weighted 3G cell towers | 252 | 1.224 | 1.569 | 0 | 6.715 |
| Distance to nearest 3G cell tower (meters) | 252 | 60950.79 | 96732.8 | 34.065 | 531947.8 |
| Log distance to nearest 3G cell tower | 252 | 9.827 | 1.801 | 3.528 | 13.184 |
| Elevation X time trend | 252 | 893.158 | 1090.144 | 2 | 5097.213 |
| Employed ratio | 252 | 58.437 | 3.778 | 47.3 | 71.3 |
| Trained employment ratio | 252 | 15.537 | 6.791 | 5.1 | 42.7 |

## 4. Empirical strategy

To identify the causal effects of mobile internet, it is required that 3G internet allocation is exogenous to the dependent variable over the period 2010-2016. From the demand side perspective, internet adoption or usage is more likely to be endogenous to household income (reverse causality of higher income leading to higher mobile BB adoption) compared to coverage or availability from supply side (Kolko, 2012). Telecoms companies may decide to construct cell towers in places with more market potential i.e., provinces' aggregate GDP, GNI or per capital values. To address this endogeneity concern, following contemporary literature we used an instrumental variable (IV) approach combined with province fixed effects (FE-IV) (Donati, 2019; Ivus & Boland, 2015; Manacorda & Tesei, 2020; Ndubuisi et al., (2021); Tang et al., 2022a; P. Wang, 2020). Based on extant literature and data availability, we identified that in Vietnam higher elevation results in lower coverage due to higher costs of construction and maintenance of cell towers. This is because areas on the mountains usually have narrow lanes built on cliffs, which causes higher transportation costs of cell towers; additionally, these areas experience unstable electricity and power outages more often,[21] as well as higher risks of flash flooding and landslides. We also use slope as robustness for the FEIV approach and identified similar results.

On the relevance requirement of the instrument, past literature has used elevation or terrain characteristics as instruments for cell tower coverage in developing countries, including Buys et al. (2009); Klonner & Nolen (2010)) for 2G signal before 2010; and Donati (2019); Tang et al. (2022) for 3G signal or broadband internet in the later period. For Vietnam specifically, Yoon (2015) used terrain slope as an instrument for rural electrification to analyze its effects on household incomes during 2004-2006. In their analysis higher slope causes less electrification (proxied by nightlight intensity) with similar arguments of higher installation costs of the transmission network due to higher cable length if the line passes through a mountain. Our instrument approach, adapted from Ivus & Boland (2015); Manacorda & Tesei (2020) with local characteristics, can explain the differences in 3G coverage between provinces via elevation heterogeneity while the linear time trend account for the changes over time within provinces. The first-stage results with F-statistic significantly above 10 (presented in section 5) corroborated the relevance condition.

For the exogeneity requirement, elevation can be used as an instrument under the assumption that its correlation with provinces' economic development is only indirect via mobile broadband coverage. In section 5.2 and 5.3 of the paper we present multiple tests in support of our identification assumptions. We show that the instrument is not correlated with income over the period 2004-2008 (pre-treatment); and that leading values of income (placebo test) and the instrument are not associated.

### 4.1. Model specification

With the availability of socioeconomic panel data, the main equation used to estimate mobile internet's effect on income is:

$$\boldsymbol{ln(\bar{y}_{jt}) = \beta_0 + \beta_1 ln(Cov_{jt}) + \beta_2 X_{jt} + f_j + f_t + \varepsilon_{jt}} \ \mathbf{(1)}$$

where $\bar{y}_{jt}$ is average monthly household per capita income of province j in year t; $Cov_{jt}$ is the mobile signal coverage of province j at year t (measured by logarithm of the number of 3G cells per thousand population per province); $X_{jt}$ refers to a set of control variables measured at the province level (e.g. population density, FDI values); $f_j$ for province fixed effects which can control for different trends in market outcomes across geographical units (e.g., distances to the nearest

[21] We also confirm this with several engineers who have worked at local telecoms companies building cell towers.

coastlines, or local tradition or culture); $\boldsymbol{f_t}$ for time fixed effects (e.g., a general increase in tech-savvy culture); and $\boldsymbol{\varepsilon_{jt}}$ denotes is the idiosyncratic error term.

Our first-stage estimation equation is:

$$\boldsymbol{ln(Cov_{jt}) = \delta_0 + \delta_1 Z_{jt} + \beta_2 X_{jt} + f_j + f_t + \eta_{jt}} \ (\mathbf{2})$$

where $\boldsymbol{Z_{jt} = mount_j * t}$; with $\boldsymbol{mount_j}$ as the average elevation of province j, $\boldsymbol{t}$ captures the generalized increase in mobile phone coverage across the country during 2010-2016[22]; $\boldsymbol{f_j}$ and $\boldsymbol{f_t}$ denotes province and time fixed effects respectively similarly to the second-stage equation; $\boldsymbol{\eta_{jt}}$ as the idiosyncratic error term.

Our base models are FEIV without any time-variant control variables due to potential collinearity and measurement issues of these variables. We nevertheless tested models with several control variables i.e., population density, FDI registered values, temperature, rainfall (following extant literature on factors influencing regional economic activities on Vietnam and other countries of relatively similar socioeconomic characteristics (Driffield & Jones, 2013; A. N. Nguyen & Nguyen, 2007; C. V. Nguyen et al., 2021; H. H. Nguyen, 2019; H. Q. Nguyen, 2017; Vu et al., 2008; Yang et al., 2015; Zang, 2019), and the results remain robust (next section 5.1).

## 5. Empirical results

In this section we present our main regression results; tests of identification assumption; heterogeneity analyses; and a battery of robustness tests.

### 5.1. Main results

The main outcomes of different models are presented in Table 2. We adopted multiple estimation methods of fixed effects (FE) and fixed effects – instrumental variable (FE-IV) with different combinations of year and province fixed effects and weighting schemes. Columns (1) to (4) adopted the FE method, (5) to (6) FE-IV. Columns (1) to (6) all have province FE, while columns (3) to (6) all have year FE. The even columns have province's population as weights, while odd columns do not. The dependent variable in all regressions is the log provincial average household per capita income; the main independent variable is log number of 3G cell towers per thousand population per province.

From the table it can be seen that mobile broadband coverage has positive effects on household income across different estimation methods. The effect size from the FE-IV estimation with weights

[22] with t equals 1, 2, 3, 4 for the year 2010, 2012, 2014, 2016 respectively.

in the column (6) suggests that a ten percent increase in the number of 3G cell towers per thousand population per province will cause approximately 0.4 percentage points increase in household income per month, or 4.8 percentage points per year. In the IV models the first-stage results show that the effects of elevation on mobile internet coverage is negative and highly significant, with F-statistics satisfying the relevance requirement, being above 10. We also run models with time-variant controls and an alternative instrument, and the results remain robust in terms of effect sizes and significance levels for models with controls and qualitatively the same for models with the average slope of the terrain as the instrument (see table 4 in the appendix).

Table 2. Monthly household income and mobile broadband

| Log HH income | (1) | (2) | (3) | (4) | (5) | | (6) | |
|---|---|---|---|---|---|---|---|---|
| 3G Internet | 0.152*** | 0.136*** | 0.0200** | 0.0107 | 0.0449*** | | 0.0387** | |
| | (0.00606) | (0.0140) | (0.00800) | (0.0110) | (0.0172) | | (0.0165) | |
| 1st-stage | | | | | | -.000732*** | | -.00105*** |
| | | | | | | (.000136) | | (.000239) |
| Province FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | No | No | Yes | Yes | Yes | Yes | Yes | Yes |
| Weights | No | Yes | No | Yes | No | No | Yes | Yes |
| F-stat | | | | | | 29.213 | | 19.565 |
| N | 252 | 252 | 252 | 252 | 252 | 252 | 252 | 252 |
| R-squared | 0.581 | 0.614 | 0.967 | 0.969 | 0.985 | 0.899 | 0.985 | 0.884 |
| Adjusted R-squared | 0.579 | 0.612 | 0.967 | 0.969 | 0.979 | 0.863 | 0.980 | 0.843 |
| rmse | 0.187 | 0.183 | 0.0526 | 0.0521 | 0.0539 | 0.580 | 0.0551 | 0.742 |

*Notes:* Columns (1) to (4) adopted FE method, (5) and (6) FE-IV. Columns (1) to (6) all have province FE, while columns (3) to (6) all have year FE. Columns (5) and (6) used elevation multiplied with linear time trend as instrumental variable. The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.010$

In the next sub-section 5.2., we present tests of the identification assumptions for the instrument used in the FEIV models in table 2.

### 5.2. Probing the instrument

We conduct multiple tests to examine the exogeneity of the instruments as follows.

First, we run province and year FE models for the period 2004-2008 to test if the instrument is correlated with the dependent variable and find no statistically significant correlation at conventional levels (see table 5 in the appendix), suggesting the exogeneity of the instrument.

Second, we found that the (placebo) lead values of income do not correlate with the instrument in province and year FE models with or without time-varying control variables, and with or without weights (see table 6 in the appendix).

As an additional check, we found that the instrument is not correlated with the residuals from the main regressions with or without time-variant control variables, as can be seen from table 7 in the appendix, indicating the instrument's exogeneity with the dependent variable.

### 5.3. Robustness tests

In this subsection several robustness tests are carried out to corroborate the results of the main model.

We start by running the same models for a sample without Ha Noi, the capital, and HCMC, the largest economic center, and find that the regression results remain robust across models, with effect sizes and statistical significance levels slightly increased (see table 8 in the appendix).

Next we use distances to the nearest cell tower as the independent variable rather than cell tower counts. As can be seen in the table 9 in the appendix, distances to the nearest 3G cell towers have statistically significant negative impacts on income level, suggesting that the further away from a 3G cell tower, the smaller the effect of mobile internet on household income.

Thirdly, following Manacorda & Tesei (2020) we run the same models using 0.5x0.5 grid cells as the unit of analysis. The gird level of 0.5x0.5 cell level produced 62 units of analysis (the country's total land area is 310,070 $km^2$) that have approximate average area with provinces. We detect similar positive significant results as can be seen in table 10 the appendix.

Fourthly, we use an event study approach following Caldarola et al. (2022). As figure 10 in the appendix shows, there are positive results of mobile internet coverage treatment[23] with similar effect sizes in the first year of adoption. This is in line with our main regression results in section 5.1

[23] under the threshold of 0.2 3G cells per thousand population, or 1 cell per five thousand people

above. The results in the appendix also demonstrate the increasing effect sizes over time, which are all statistically significant with the exception of the one-year lead effect in the weighted model. This result indicates the potential long-term impacts of mobile technologies, aligning with evidence from Bahia et al. (2020) and Caldarola et al. (2022). The pre-trend assumption is also confirmed by the insignificant effects on the (placebo) lags before treatment.

Fifth, we used FEIV-Lewbel method that exploits variation from the second moments of the first stage regression (equation 2)'s error distribution to create instrument following Deuflhard et al. (2019); and Ndubuisi et al. (2021), and identified similar significant results (table 11 in the appendix). The Hansen's J results are insignificant at the 5% level, which fails to reject the null hypothesis of exogeneity of the generated instrument (Baum et al., 2012).

Finally, we also tried a control function approach, following J. Wang et al. (2022) and Pinzon (2020), and similar results are also identified in models with or without controls, and with or without weights (see table 12 in the appendix).

After providing multiple robustness tests for our main results, we now turn to examine the possibility of heterogeneous impacts of the technology.

### 5.4. Heterogeneity analyses

Previous literature has offered evidence that broadband technologies (including mobile broadband) have heterogeneous impacts on sub-groups of the population in terms both of geography and of socioeconomic conditions.

Rural areas in particular have received significant attention arising from the fact that internet technologies can help geographically isolated areas access urban as well as international markets. Whitacre et al. (2014) identified positive significant increases in household income growth for rural areas in the US during 2001 – 2010 following broadband adoption. Similarly, Ivus & Boland (2015) provided evidence of wage and employment growth for rural areas in Canada in 1997-2011 following broadband deployment, particularly for service industries (i.e., idea-producing industries like IT, finance) that have been able to overcome geographical barriers hampering rural growth. Not on broadband technologies specifically but Zang (2019) provide some evidence of increasing rural residents' income over time thanks to computer penetration (using the government's village broadband connection program as an instrument) in China during 2003 – 2013. In Vietnam Kaila & Tarp (2019) found that Internet access (through a commune's internet access point) has significantly promoted rural agricultural production during 2008 – 2012 (6.8% increase in total agricultural output), thanks to improved information about agriculture through government-run and private online information platforms, with effect sizes stronger for younger households and for less-developed northern provinces.

While mobile broadband is only a part of broadband spectrum (including fixed broadband), its widespread adoption by individuals in both business and personal environments may offer additional and more nuanced impacts for specific groups and regions. This subsection presents the heterogeneous analysis for urban-rural dichotomy and for different income quintile groups thanks to available data collection.

### 5.4.1. Urban – rural differences

GSO's Statistical yearbooks have data about urban population for provinces in which urban population is "*the population of the territorial units to which the State is defined urban areas.*" (GSO, 2016: 72).[24] The regression results (table 13 on the appendix) show stronger effect sizes for rural areas than for urban areas. This outcome may be indicative of the more inclusive technological change impact of mobile internet compared to other technologies for (previously) disadvantaged regions like rural or remote areas. The specific mechanisms behind the stronger effects for rural areas are discussed in section 6. The insignificant results for urban may be due to the smaller number of observations and/or less variation in independent variable.

### 5.4.2. Different effects between income quintiles

The VHLSS reports by Vietnam's GSO provide information about provincial income distribution by quintile groups. Total monthly household per capital income is dissected into five quintile groups. We conduct the same analyses with FE-IV methods for each quintile group for all provinces, resulting in five regressions for five quintile analyses.

As can be seen in table 14 on the appendix, mobile broadband offers the strongest positive effects for quintiles 2 and quint 3 of income, followed by quintile 1. Quintiles 4 and 5 feel no significant effect.

For the second quintile group, ten percent increase of number of 3G towers per thousand population per province will cause around 0.9 percentage points rise in household income per month, or 10.8% per year, twice the average effect size of the whole population in the main regression result. The effects are about two thirds (of the second quintile group's) for the third quintile group. For the poorest group, ten percent increase of number of 3G towers per thousand population per province will cause 0.6 percent rise in household income per month, or 7.2% per

[24] Urban classifications are decided by Prime Minister, Minster of Ministry of Construction, or Chair of Provincial People's Committee based on regional and national urban development programs

year. This inclusive impact is also identified in developed country contexts like the US for example according to Zuo's (2021) study that finds significant effects of subsidized (in-home wireline) internet during 2012-2015 for low-income groups using triple diff-in-diff method (incorporating geographic, individual eligibility, and temporal differences). Wang (2020) in their research also for US market detect heterogenous effects for different income groups, specifically the largest earnings increase is for the 40th to 50th percentile groups, followed by the 20th percentile group of the earnings distribution.

## 6. Mechanisms of impacts

The literature has identified multiple mechanisms through which mobile internet might affect income level. Caldarola et al. (2023) in Rwanda has identified positive effects on education (secondary and tertiary level) for the population of 5-25 years old; migration (to areas with internet coverage) for employment in skilled occupations and in modern sectors (manufacturing, services); and increases in exports (for both manufacturing and services enterprises) and productivity (sales per employees, mainly driven by the service sector).

Arnold & Taş (2019)'s qualitative and anecdotal evidences shows that Rich Interaction Apps (RIAs)[25] that offer *"full internet experience"* (p.17) lower the entry barriers for entrepreneurs in Vietnam, creating employment opportunities in retails, tourism, trade of goods and services. Through the use of RIAs micro, small, and medium sized enterprises (MSMEs) have been able to communicate with providers to get better information about products, to pay cashlessly, and improve their business efficiency. There is also evidence that female entrepreneurs, including "mumpreneurs", seem to benefit more (Hoang Anh et al., 2016; T. H. Nguyen, 2017; Zhu et al., 2015).

Regarding education and labour market skills, emerging literature has provided some evidence of the effect of smartphone use on learners' (foreign) language skills, self-confidence, autonomy, skill knowledge and performances, and reinforcing learned knowledge thanks to personalized learning, demonstration videos e.g., for medical training, optimal two-way teacher-student communications, and anytime anywhere learning across countries by literature review studies (Kacetl & Klímová, 2019), qualitative interviews (Damuri et al., 2018; T. T. T. Nguyen & Yukawa, 2019), and randomized controlled trials (Chuang et al., 2018). The use of smartphones seems to offer additional benefits especially for learning in informal environments (outside school), and is considered as complementary to formal schooling. Yet contemporary literature has found mixed

[25] such as Facebook Messenger, Zalo, Mocha, iMessage, KakaoTalk, LINE, Signal, Skype, Snapchat, Threema, Viber, WeChat and WhatsApp

results on educational achievements, and it remains to be seen that whether and to what extent the mobile devices usage can effectively complement and/or replace which aspects of formal education. There are also other mechanisms such as increased revenues for tourism sectors (Le & Tran 2023); increased efficiency in the health sector, as well as people's health more generally thanks to more low-cost information and searching (Arnold & Taş, 2019; Damuri et al., 2018).

### 6.1. Employment and mobile internet

Vietnam GSO's online portal[26] provides data on employment and trained employment rate for provinces across years. By running the same FE-IV regression models with employment rates as dependent variables, we identified positive significant impacts on trained employment rates but not on overall employment rates (table below). Regarding trained employment, ten percent increase of number of 3G cell towers per thousand population per province will lead to approximate 0.127 percent points rise in trained employment rate.

[26] https://www.gso.gov.vn/lao-dong/

Table 3. Employment rate and Trained employment rate and mobile broadband

| Employment | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | Employed ratio | | Trained employment ratio | |
| 3G Internet | -1.500*** | -1.181*** | 1.269*** | 1.062** |
| | (0.422) | (0.321) | (0.473) | (0.431) |
| Province FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| Weights | No | Yes | No | Yes |
| F-stat | 29.213 | 19.564 | 29.213 | 19.564 |
| Observations | 252 | 252 | 252 | 252 |
| R-squared | 0.875 | 0.899 | 0.941 | 0.968 |
| Adjusted R-squared | 0.830 | 0.863 | 0.920 | 0.957 |
| rmse | 1.336 | 1.268 | 1.642 | 1.611 |

*Notes:* All models adopt FE-IV methods with elevation multiplied with linear time trend as instrumental variable, with both province and year FE. Columns 1 and 2 have overall employment rates as dependent variable; while columns 3 and 4 have trained employment rates as dependent variable. The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * p<0.10, ** p<0.05, *** p<0.010

This particular result can be understood by the increase in labor demand for skilled workers including software engineers for the digital economy and sales or project management, thanks to stable flows of graduates (usually tertiary level) who now can have more job opportunities and are able to find jobs that match better their degrees or expertise, but not necessarily because of the increase in education attainment in the context of Vietnam. Nevertheless, there may be increases in enrolment and degree attainment for specific programs e.g., for IT, business, but not for other programs, and at national level but not provincial level as major changes in enrolment and graduation patterns are more likely to occur in major universities in Ha Noi, HCMC, or regional but not all provincial universities.

The negative effect signs of overall employment may be because of the data collection or measurement issues due to the potentially significantly under-reported informal self-employment (GSO, 2020b). On the other hand, this however might be due to the fact that the decrease in the number of low-skilled workers was not offset by the rise in the number of high-skilled workers.

### 6.2. Wages and mobile internet

On income sources components, formal wages have the highest positive effect sizes with strong significance level while self-employment from non-agricultural activities and other sources have no statistically significant signs (table 4 below). Agriculture-based income sources have some positive effects though only weakly significance.

With regards to formal wages, the earlier section of preliminary evidence showed that the app economy has created a significant number of jobs for app developers and sales, project management staff; and these positions required formal education and training for high-skilled labor. This may also explain the significant effects for groups of income quintile 3 as evidenced in the heterogeneity analysis.

Non-agriculture self-employment in Vietnam are often of high-income quintile groups (group 4 or 5) (UNDP & VASS, 2016), and this justify the insignificant effects for quintile 4 and 5.

Table 4. Income sources and mobile broadband

| Log Household income | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Wages | | Formal wages | | Agriculture | | Non-agriculture | | Others | |
| **3G Internet** | 0.0250 | 0.0198 | 0.0944*** | 0.0662*** | 0.0583* | 0.0688* | -0.0953* | -0.0511 | -0.0953* | -0.0511 |
| | (0.0234) | (0.0204) | (0.0281) | (0.0234) | (0.0313) | (0.0380) | (0.0525) | (0.0341) | (0.0525) | (0.0341) |
| **Province FE** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Year FE** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Weights** | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes |
| **F-stat** | 29.213 | 19.564 | 29.213 | 19.564 | 29.213 | 19.564 | 29.213 | 19.564 | 29.213 | 19.564 |
| **Observations** | 252 | 252 | 252 | 252 | 252 | 252 | 252 | 252 | 252 | 252 |
| **R-squared** | 0.983 | 0.986 | 0.889 | 0.911 | 0.949 | 0.971 | 0.942 | 0.959 | 0.942 | 0.959 |
| **Adjusted R-squared** | 0.976 | 0.981 | 0.849 | 0.879 | 0.931 | 0.961 | 0.922 | 0.944 | 0.922 | 0.944 |
| **rmse** | 0.0718 | 0.0705 | 0.0983 | 0.0918 | 0.133 | 0.151 | 0.154 | 0.124 | 0.154 | 0.124 |

*Notes:* All models adopt FE-IV method with elevation multiplied with time trend as the instrument. The dependent variables are log household income from wages, log household income from formal wages, log household income from agriculture, log household income from non-agricultural activities, and log household income from other sources, respectively from columns left to right. The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * p<0.10, ** p<0.05, *** p<0.010

Regarding agriculture-based income sources, while Kaila & Tarp (2019) found strong effect sizes of Internet access on agricultural production in Vietnam during 2008-2012, the weakly significant effects we identified in our paper may be due to 1) significantly smaller sample sizes; and/or 2) the channel of fertilizer usage thanks to information search detected by Kaila & Tarp in the previous period for example may not be the same in the later period due to saturation effects of fertilizer uses. Positive effects for agricultural income sources may explain the strong effect sizes for income quintile groups 1 and 2 nevertheless.

In sum, the stronger results for trained employment rates and formal wages indicate the structural change pattern towards formal sectors in the country. The stronger effect sizes for rural areas particularly may present that i) new formal businesses have been established (can be in both rural and urban areas) and/or formalization of household or informal businesses, especially service-based ones ranging from retail to tourism (Arnold & Taş, 2019) in rural area; and ii) rising productivity of these sectors by increased sales and/or reduced business costs like marketing and training. The insignificant effects of total employed rates and informal wages can be due to underreported survey data issues as the VHLSS's survey not being designed specifically for the informal sector (GSO, 2020b).

Rural households, who typically have multiple income streams[27] (World Bank, 2019a), may stand to benefit more from mobile digitalization. First, due to the lowered expenses associated with doing business from distance thanks to mobile communication, mobile banking, online marketing, more businesses can be established in rural areas, possibly serving nationwide or urban market. Second, with reduced costs and/or increased efficiency of transportation and logistics, business costs will also be reduced while sales can be promoted. We identified positive significant outcomes of mobile internet and transportation volumes for both passenger and freight services (see table 15 in the appendix). Third, e-commerce platforms and social media can help rural citizens to market and sell their products online. Fourth, remittances and social transfers have been increased through more (im)migration (thanks to more information and cheap communication) and monetary flows (via mobile banking with lower fees and more user-friendly utilities).

We have no data on informal wages, self-employment or entrepreneurship, (im)migration and remittances, which needs further study. These may benefit both rural areas and urban areas though still with stronger effects for rural regions.

## 7. Concluding remarks

[27] often three of out six comprising of (i) household farming; (ii) agricultural wages; (iii) non-agricultural wages; (iv) household business; (v) remittances; and (vi) transfers.

Our results offer evidence of mobile internet's positive effects on household income over the first decade following the arrival of the first smartphone in a developing country context. In Vietnam in the last decade the technologies have produced more inclusive impacts for the lower-income groups and for rural areas. These groups in particular have skipped PCs and used smartphones as the only device to integrate into the digital world.

Our paper contributes further evidence for M4D particularly for developing countries. Compared to Hubler & Hartjie (2016), we offer new evidence of stronger effect sizes and additional impact mechanisms of the new smartphone generations which have better quality and more functionalities with a growing app ecosystem. Compared to Bahia et al. (2020), we show that mobile internet can offer a pathway for improvement on livelihoods (income, employment) and productivity (wages), not only on welfare (consumption).

Future micro data collection can be done to disentangle the heterogeneous effects for subgroups of population e.g., in terms of age (Caldarola et al., 2022; Kaila & Tarp, 2019) or gender (Hoang Anh et al., 2016; T. H. Nguyen, 2017; Zhu et al., 2015); and to dissect micro mechanisms of impacts including i) information (about job search, migration or immigration); ii) communications (including social media platforms) that help promote entrepreneurship, informal economy, e-commerce, remittances (via social contact/ group) (Google et al., 2021); iii) digital/ platform economy including e-commerce (i.e., Shopee, Lazada, Tiki), the "sharing economy" (Uber/ Grab), e-banking (almost all banks), remittances, social transfers, charities (Google et al., 2019); iv) learning, education, innovation e.g. mobile apps including videos, AR/VR with downloaded content (requires no internet); and v) 4G and 5G instead of 3G as many 3G cell towers has been closed off since 2021 in many regions (Arnold & Taş, 2019; Viettel, 2022).

Future research can offer evidence on nuanced mechanisms regarding usages (both quantity, quality and skills) rather than just coverage or adoption as well as regarding emerging ecosystem with new content and functionalities that can offer further connectedness, engagement, and innovation.

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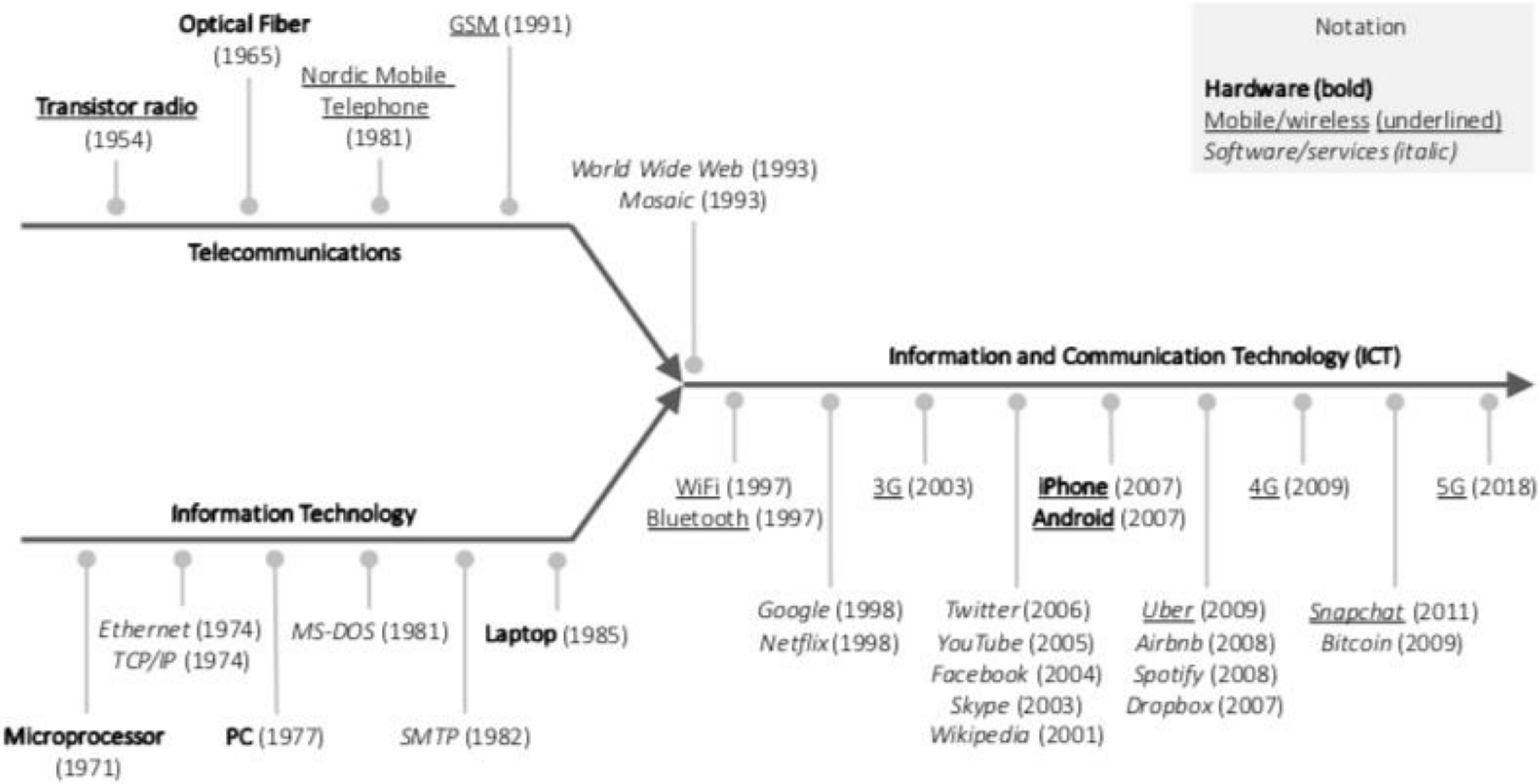
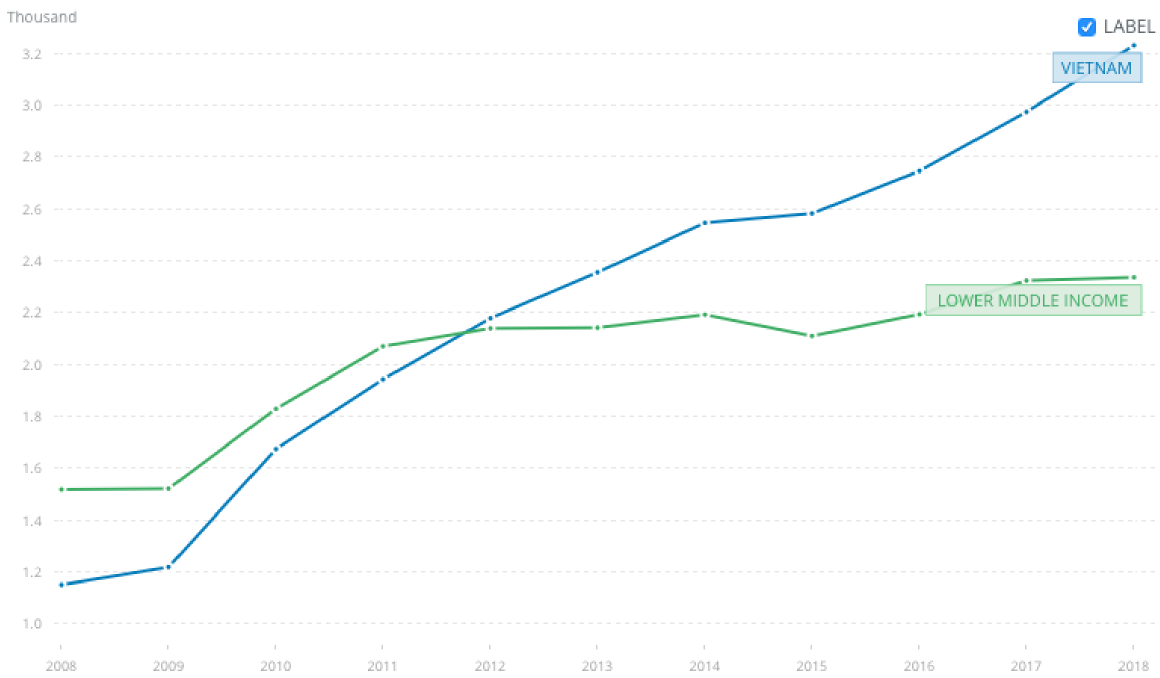
## APPENDIX

Figure 1. ICTs innovations timeline 1971-2018




Source: (Øverby & Audestad, 2018: 21)

**Figure 2. GDP per capita (current US$) - Vietnam, Lower middle income**




Source: WDI

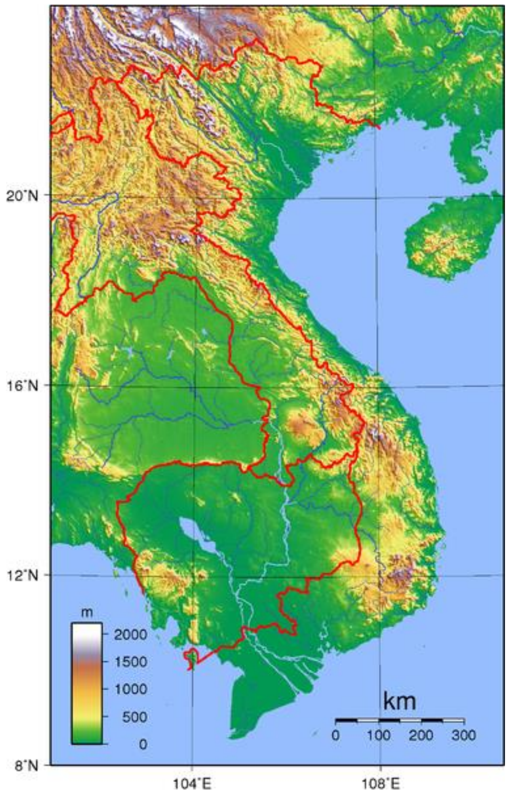
**Table 1. Vietnam's economic achievements since 1975**

| Timeline | Event |
|---|---|
| 1975 | Reunification of North-South following the end of Vietnam - America war |
| 1986 | The beginning of Reform process toward "socialist-oriented market economy" (Doi Moi) |
| 1995 | ASEAN FTA, WTO application |
| 2000 | Vietnam - US FTA signing |
| 2004 | ASEAN - PRC FTA |
| 2006 | ASEAN – KOR FTA |
| 2007 | WTO accession |
| 2008 | ASEAN – Japan FTA; Vietnam – Japan EPA |
| 2009 | ASEAN – India FTA; ASEAN – New Zealand – Australia (AANZ) FTA |
| 2012 | Vietnam – Chile FTA (commenced in January 2014) |
| 2014 | ASEAN – Hong Kong FTA started negotiation |
| 2015 | Europe – Vietnam FTA (EVFTA) completed negotiation; Vietnam – Israel FTA negotiation |
| 2018 | Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) signed |
| 2019 | CPTPP came into effective |
| 2020 | EVFTA came into effective |

Source: authors' synthesis from multiple sources[28]

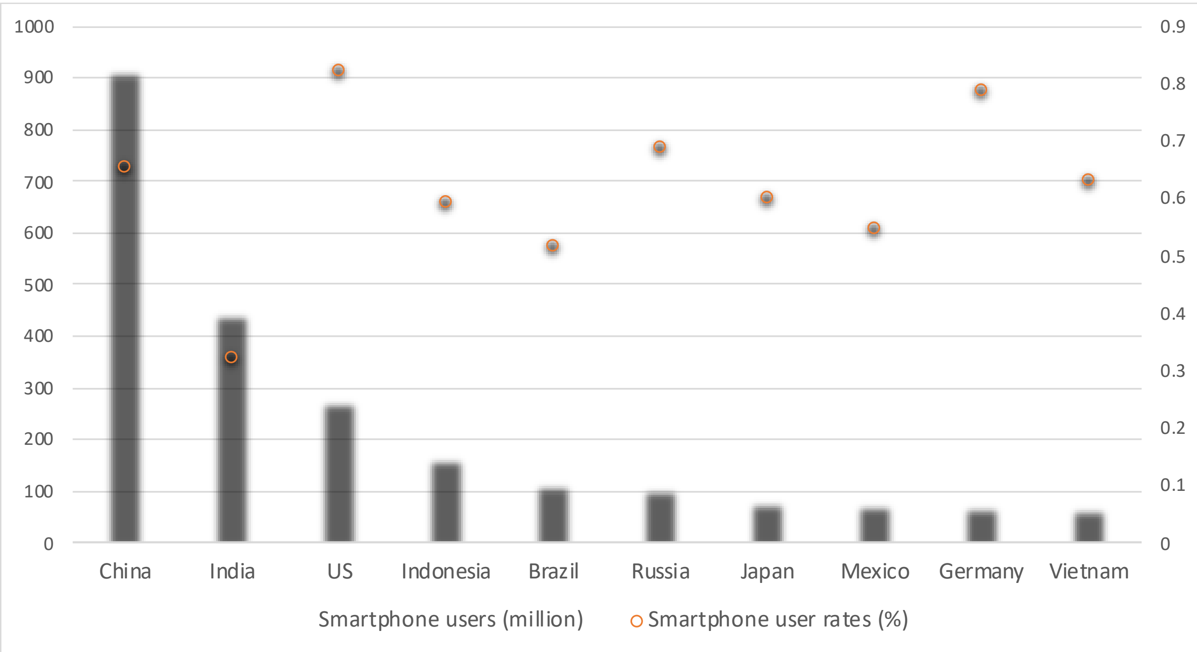
[28] https://www.weforum.org/agenda/2018/09/how-vietnam-became-an-economic-miracle/
https://aric.adb.org/blog/viet_nams_participation_in_free_trade_agreements_history_and_the_way_forward
https://www.asiabizconsult.com/en/news-briefs/278-free-trade-agreements-in-vietnam

**Figure 3. Vietnam's topography**




Source: Global Land One-km Base Elevation Project (GLOBE)[29]

**Figure 4. Smartphone users and penetration rates of several countries in May 2021**




Source: authors, data source from Statista

[29] https://www.ngdc.noaa.gov/mgg/topo/globe.html

**Figure 5. Household income components 2010 – 2016**

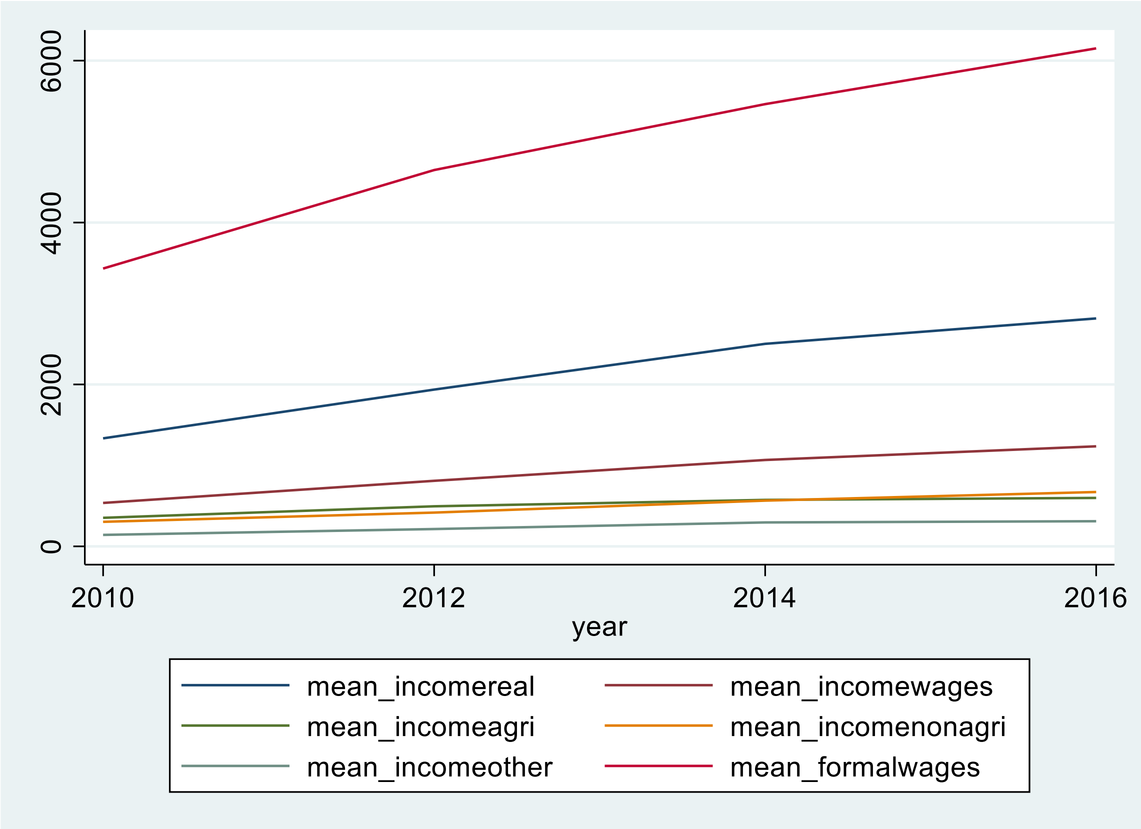



**Figure 6. Income quintiles 2010 - 2016**

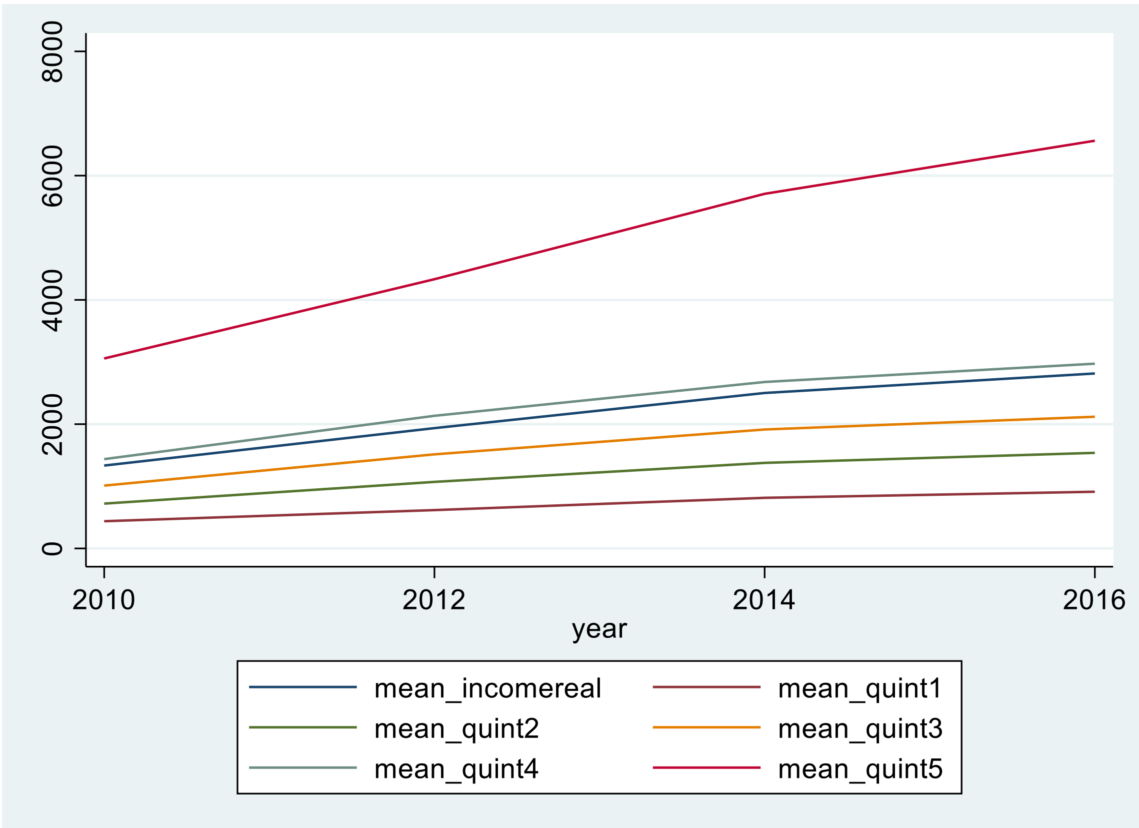


Figure 7. Employment and Trained employment ratio 2010 – 2016

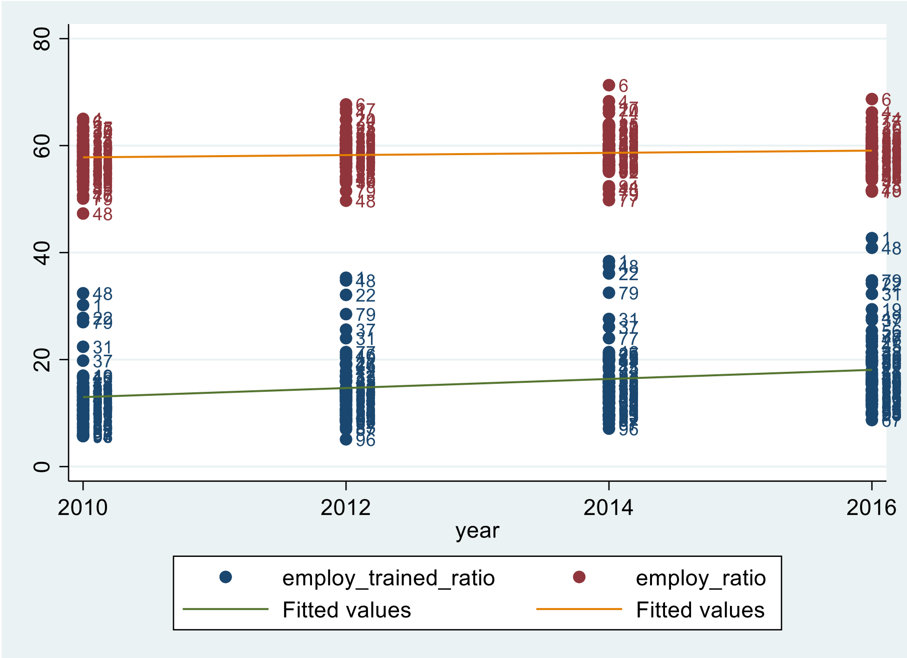



Table 2. 3G cell towers signals 2008-2020

| year | GSM/2G | UMTS/3G | LTE/4G | Total | Accumulation |
|---|---|---|---|---|---|
| **2008** | 87 | 0 | 0 | 87 | 89 |
| **2009** | 1,135 | 0 | 0 | 1,135 | 1,224 |
| **2010** | 38 | **7** | 0 | 45 | 1,269 |
| **2011** | 29 | 49 | 0 | 78 | 1,347 |
| **2012** | 551 | 1,346 | 0 | 1,897 | 3,244 |
| **2013** | 1,187 | 3,022 | 0 | 4,209 | 7,453 |
| **2014** | 9,576 | 5,520 | **1** | 15,097 | 22,550 |
| **2015** | 12,278 | 34,858 | 2 | 47,138 | 69,688 |
| **2016** | **33,557** | **71,817** | 118 | 105,492 | 175,180 |
| **2017** | 6,053 | 26,685 | **4,985** | 37,723 | 212,903 |
| **2018** | 16 | 346 | 701 | 1,063 | 213,966 |
| **2019** | 796 | 3,204 | 985 | 4,985 | 218,951 |
| **2020** | 4,838 | 355 | 83 | 5,277 | 224,228 |
| **Total** | 70,141 | **147,211** | 6,875 | 224,228 | |

Source: data source from OpenCellID

Figure 8. Distance from province's centroid to the nearest 3G station

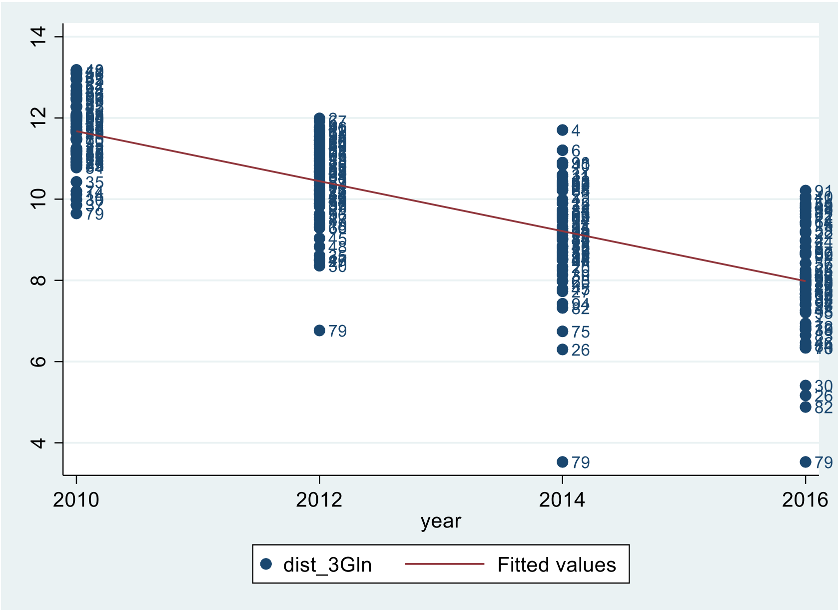



Table 3. Specific data sources and interpolation

| Variable | Content | Unit | Data source |
|---|---|---|---|
| **Income per capita** | Province's average Monthly Household income | thousand VND | VHLSS reports 2014, 2018 |
| **Mean school years** | Average number of school years | School years | |
| **Area** | Province's total area | km² | |
| **pop** | Province's total population | thousand | |
| **Employed rate** | Employment ratio (of 15yo older) % total pop | percent | Statistical year books 2010-2018 |
| **Trained employment rate** | Trained employed (of 15yo older) % population | percent | |
| **GDP** | Gross Regional Domestic Product of each province | Bil. VND current price | GSO's 2015-2018 reports of 63 provinces, cities |
| **GDP sectors** | Percentage share of agriculture, industry, and service | percent | |
| **Public spending** | Public expenditure on education, training and vocational training, social securities | Bil. VND | |
| **Public investment** | | Bil. VND | |
| **Private investment** | | Bil. VND | |
| **Internet sub** | Number of internet subscribers | thousand | |
| **FDI capital** | Province's accumulated FDI projects' registered values | Mill. USD | Statistical Year books |
| **PCI** | Provincial Competitiveness Index | 0-100 | VCCI |
| **3G BTS coverage** | Accumulated number of 3G BTS per thousand population | BTS | OpenCellID |
| **2G BTS coverage** | Accumulated number of 2G BTS per thousand population | BTS | |
| **Distance to HN/HCM** | Distance from province's centroid to HN or HCM | | |
| **Elevation** | Mountain elevation | Meters | USGS's GTOPO30 |

**Figure 9. Scatterplot between the dependent and the main independent variable**

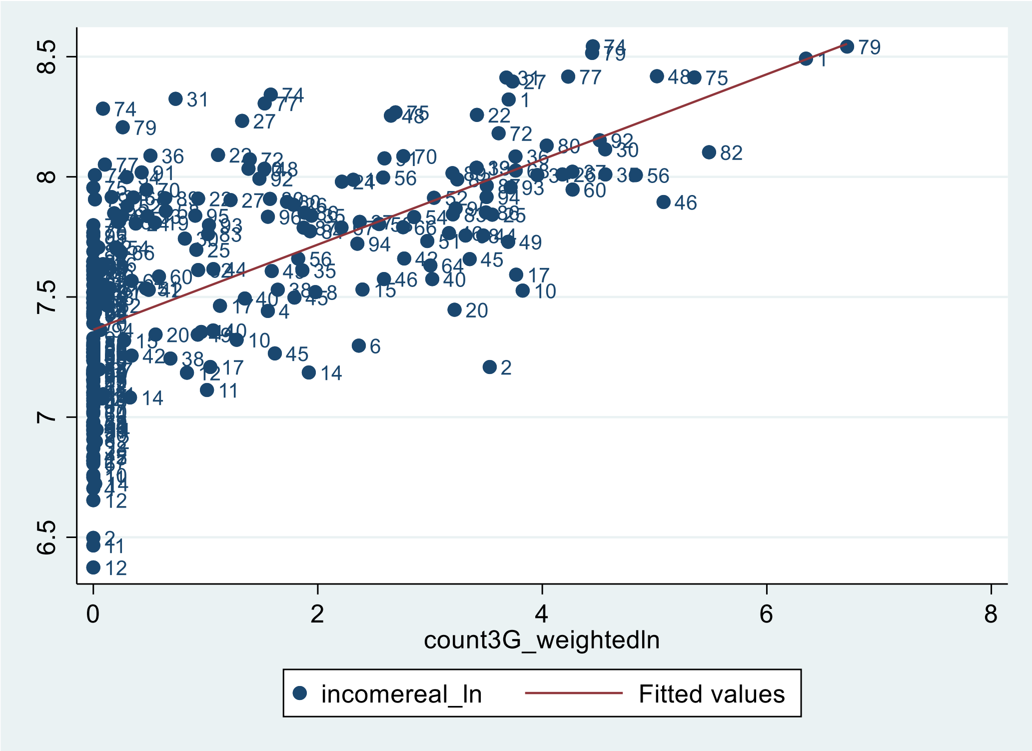


**Table 4. Models with time-variant control variables and alternative instrument**

| Log HH income | (1) | (2) | (3) | (4) | (5) | | (6) | | (7) | | (8) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3G Internet | 0.139*** | 0.128*** | 0.0150* | 0.0114 | 0.0407** | | 0.0442*** | | 0.0423* | | 0.0343* | |
| | (0.00855) | (0.0111) | (0.00802) | (0.0109) | (0.0175) | | (0.0167) | | (0.0216) | | (0.0183) | |
| 1st-stage | | | | | | -.000739*** | | -.0009*** | | -.0959*** | | -.145*** |
| | | | | | | (.00013) | | (.000162) | | (.0182) | | (.033) |
| Log pop den | 0.277 | 0.205 | 0.215 | 0.0175 | 0.140 | 2.933* | -0.234 | 6.816*** | | | | |
| | (0.554) | (0.422) | (0.159) | (0.267) | (0.132) | (1.527) | (0.228) | (2.632) | | | | |
| Log FDI | 0.130*** | 0.162*** | 0.0145 | 0.0206* | 0.0143 | -.128 | 0.0263*** | -.309*** | | | | |
| | (0.0329) | (0.0364) | (0.0120) | (0.0112) | (0.00962) | (.082) | (0.00929) | (.117) | | | | |
| Rainfall | -0.000268*** | -0.000280*** | -0.0000312* | -0.0000322* | -0.0000325** | -.000033 | -0.0000467*** | .000238 | | | | |
| | (0.0000456) | (0.0000446) | (0.0000159) | (0.0000172) | (0.0000128) | (.000155) | (0.0000164) | (.000211) | | | | |
| Temperature | -0.103*** | -0.135*** | 0.0123 | 0.00796 | 0.000967 | .332*** | -0.0168 | .622*** | | | | |
| | (0.0365) | (0.0445) | (0.0144) | (0.0168) | (0.0139) | | (0.0190) | (.221) | | | | |
| Province FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Weights | No | Yes | No | Yes | No | No | Yes | Yes | No | No | Yes | Yes |
| F-stat | | | | | | 31.341 | | 31.561 | | 27.93 | | 19.495 |
| Observations | 252 | 252 | 252 | 252 | 252 | 252 | 252 | 252 | 252 | 252 | 252 | 252 |
| R-squared | 0.686 | 0.731 | 0.969 | 0.970 | 0.985 | 0.909 | 0.986 | 0.913 | 0.985 | 0.895 | 0.986 | 0.883 |
| Adjusted R2 | 0.680 | 0.726 | 0.968 | 0.969 | 0.980 | 0.874 | 0.980 | 0.880 | 0.979 | 0.858 | 0.981 | 0.841 |
| rmse | 0.163 | 0.154 | 0.0514 | 0.0515 | 0.0522 | 0.557 | 0.0541 | 0.649 | 0.0535 | 0.591 | 0.0541 | 0.746 |

*Notes:* Columns (1) to (4) adopted FE method, (5) to (8) FE-IV. Columns (1) to 6) have control variables. Columns (5) and (6) used elevation as instrumental variable, columns (7) and (8) used slope; both interacted with linear time trend. Columns (1) to (8) all have province FE, while columns (3) to (8) all have year FE. The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.010$

Table 5. Correlation of the instrument (elevation) and Household income during 2004-2008

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Elevation X time trend | 0.0000317 | 0.0000539* | 0.0000348 | 0.0000577* |
| | (0.0000326) | (0.0000321) | (0.0000381) | (0.0000324) |
| Log pop den | | | -0.00716 | -0.346 |
| | | | (0.455) | (0.490) |
| Log FDI | | | 0.00428 | 0.00776 |
| | | | (0.0101) | (0.0124) |
| Constant | 5.999*** | 6.142*** | 6.019** | 8.181*** |
| | (0.0137) | (0.00758) | (2.534) | (2.953) |
| Year FE | Yes | Yes | Yes | Yes |
| Province FE | Yes | Yes | Yes | Yes |
| Observations | 189 | 189 | 189 | 189 |
| R-squared | 0.976 | 0.975 | 0.976 | 0.976 |
| Adjusted R-squared | 0.975 | 0.974 | 0.975 | 0.975 |
| rmse | 0.0468 | 0.0463 | 0.0470 | 0.0456 |

*Notes:* All models include province and year fixed effects. The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * p<0.10, ** p<0.05, *** p<0.010

Table 6. Placebo test – correlation of instrument (elevation) and lead values of income

| Log household Income | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Elevation X time trend | -0.0000115 | -0.0000365 | -0.00000986 | -0.0000283 |
| | (0.0000235) | (0.0000272) | (0.0000240) | (0.0000264) |
| Log den pop | | | 0.182*** | 0.122 |
| | | | (0.0646) | (0.161) |
| Rainfall | | | 0.0000224 | 0.0000325* |
| | | | (0.0000151) | (0.0000180) |
| Temperature | | | -0.01000 | -0.0220 |
| | | | (0.0126) | (0.0155) |
| Constant | 7.522*** | 7.659*** | 10.22*** | 14.00*** |
| | (0.0140) | (0.0120) | (3.814) | (4.742) |
| Year FE | Yes | Yes | Yes | Yes |
| Province FE | Yes | Yes | Yes | Yes |
| Observations | 189 | 189 | 189 | 189 |
| R-squared | 0.914 | 0.923 | 0.917 | 0.927 |
| Adjusted R-squared | 0.913 | 0.922 | 0.914 | 0.925 |
| rmse | 0.0481 | 0.0469 | 0.0475 | 0.0459 |

*Notes:* All models include province and year fixed effects. The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * p<0.10, ** p<0.05, *** p<0.010

Table 7. Correlations of the instrument (elevation) and the residuals of the main regressions

| Residuals | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| **Elevation X time trend** | -0.0000182 | -0.0000294 | -0.0000221 | -0.0000331 |
| | (0.0000161) | (0.0000230) | (0.0000162) | (0.0000225) |
| **Constant** | 0.00931 | 0.0106 | 0.0113 | 0.0119 |
| | (0.0105) | (0.00932) | (0.0100) | (0.00894) |
| **Year FE** | Yes | Yes | Yes | Yes |
| **Province FE** | Yes | Yes | Yes | Yes |
| **Observations** | 252 | 252 | 252 | 252 |
| **R-squared** | 0.013 | 0.023 | 0.019 | 0.030 |
| **Adjusted R-squared** | -0.003 | 0.007 | 0.003 | 0.014 |
| **rmse** | 0.0523 | 0.0515 | 0.0509 | 0.0509 |

*Notes:* All models include province and year fixed effects. Residuals in columns (1) and (2) are from the main regression models without any controls; in columns (3) and (4) are from models with control variables of population density, rainfall, and temperature. The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * p<0.10, ** p<0.05, *** p<0.010

## Table 8. Main regression results without Ha Noi and HCMC

| Log HH income | (1) | (2) | (3) | (4) | (5) | | (6) | |
|---|---|---|---|---|---|---|---|---|
| **3G Internet** | 0.158*** | 0.156*** | 0.0230*** | 0.0198** | 0.0509** | | 0.0754*** | |
| | (32.86) | (24.25) | (2.75) | (2.08) | (2.53) | | (3.16) | |
| **1st-stage** | | | | | | -.000638*** | | -.000561*** |
| | | | | | | (.000131) | | (.000135) |
| **Province FE** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Year FE** | No | No | Yes | Yes | Yes | Yes | Yes | Yes |
| **Weights** | No | Yes | No | Yes | No | No | Yes | Yes |
| **F-stat** | | | | | | 24.095 | | 17.372 |
| **N** | 244 | 244 | 244 | 244 | 244 | 244 | 244 | 244 |
| **R-sq** | 0.578 | 0.595 | 0.967 | 0.969 | 0.984 | 0.909 | 0.980 | 0.911 |
| **adj. R-sq** | 0.577 | 0.593 | 0.967 | 0.968 | 0.978 | 0.877 | 0.973 | 0.879 |
| **rmse** | 0.187 | 0.187 | 0.0526 | 0.0523 | 0.0539 | 0.523 | 0.0583 | 0.532 |

*Notes:* Columns (1) to (4) adopted FE method, (5) and (6) FE-IV. Columns (1) to (6) all have province FE, while columns (3) to (6) all have year FE. Columns (5) and (6) used elevation multiplied with linear time trend as instrumental variable. The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * p<0.10, ** p<0.05, *** p<0.010

**Table 9. Distances to the nearest BTS as independent variable**

| Log HH income | (1) | (2) | (3) | (4) | (5) | | (6) | |
|---|---|---|---|---|---|---|---|---|
| **Distance to cell** | -0.162*** | -0.156*** | -0.00488 | -0.000758 | -0.0775** | | -0.0611** | |
| | (0.00740) | (0.0140) | (0.00697) | (0.00774) | (0.0337) | | (0.0301) | |
| **1st-stage** | | | | | | .000424*** | | .000666*** |
| | | | | | | (.000156) | | |
| **Province FE** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Year FE** | No | No | Yes | Yes | Yes | Yes | Yes | Yes |
| **Weights** | No | Yes | No | Yes | No | No | Yes | Yes |
| **F-stat** | | | | | | 7.102 | | 8.154 |
| **Observations** | 252 | 252 | 252 | 252 | 252 | 252 | 252 | 252 |
| **R-squared** | 0.749 | 0.741 | 0.966 | 0.968 | 0.971 | 0.857 | 0.977 | 0.881 |
| **Adjusted R-squared** | 0.748 | 0.740 | 0.965 | 0.968 | 0.961 | 0.806 | 0.968 | 0.838 |
| **rmse** | 0.145 | 0.150 | 0.0537 | 0.0527 | 0.0731 | 0.792 | 0.0690 | 0.848 |

*Notes:* Columns (1) to (4) adopted FE method, (5) and (6) FE-IV. Columns (1) to (6) all have province FE, while columns (3) to (6) all have year FE. Columns (5) and (6) used elevation multiplied with linear time trend as instrumental variable. The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.010$

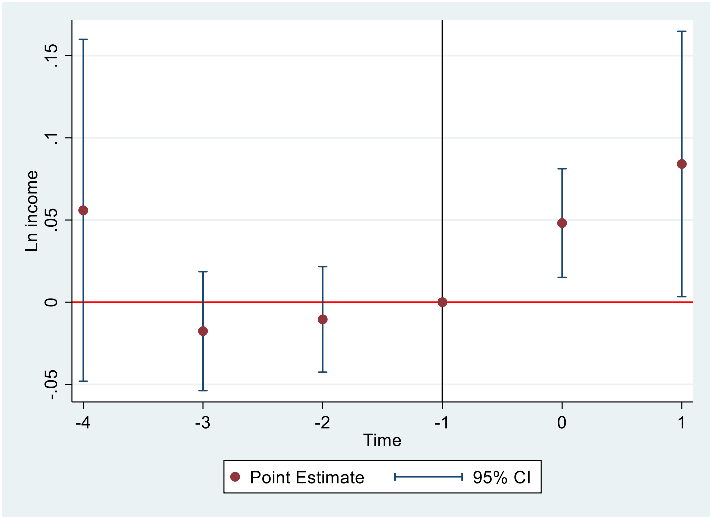
**Table 10. Household income and mobile broadband with grids as unit of analysis**

| Log HH income | (1) | (2) | (3) | (4) | (5) | | (6) | |
|---|---|---|---|---|---|---|---|---|
| **3G Internet** | 0.105*** | 0.0988*** | 0.00436 | 0.00907** | 0.0383*** | | 0.0235*** | |
| | (0.00298) | (0.00546) | (0.00358) | (0.00375) | (0.0122) | | (0.00740) | |
| **1st-stage** | | | | | | -.001139*** | | -.000658*** |
| | | | | | | (.000242) | | (.000185) |
| **Province FE** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Year FE** | No | No | Yes | Yes | Yes | Yes | Yes | Yes |
| **Weights** | No | Yes | No | Yes | No | No | Yes | Yes |
| **F-stat** | | | | | | 22.825 | | 12.981 |
| **Observations** | 236 | 236 | 236 | 236 | 236 | 236 | 236 | 236 |
| **R-squared** | 0.638 | 0.768 | 0.980 | 0.985 | 0.981 | 0.903 | 0.990 | 0.843 |
| **Adjusted R-squared** | 0.637 | 0.767 | 0.980 | 0.984 | 0.974 | 0.869 | 0.986 | 0.787 |
| **rmse** | 0.181 | 0.145 | 0.0425 | 0.0374 | 0.0570 | 1.139 | 0.0403 | 1.261 |

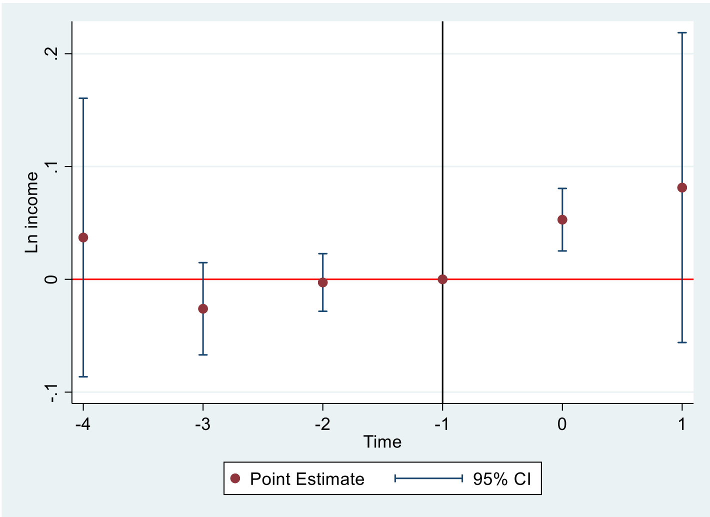
*Notes:* Columns (1) to (4) adopted FE method, (5) and (6) FE-IV. Columns (1) to (6) all have province FE, while columns (3) to (6) all have year FE. Columns (5) and (6) used elevation multiplied with linear time trend as instrumental variable. The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * p<0.10, ** p<0.05, *** p<0.010

**Figure 10. Event study approach**

**Unweighted model**




**Weighted model**




*Notes:* The event study design uses the first year in which a province hits 0.2 cells per thousand population, or 1 cell per five thousand people as treatment, corresponding to time 0 in the horizontal axis. The coefficients reported in the figure come from a model based on equation 1, including province and year fixed effects. Standard errors are clustered at the province level. Regression coefficients are reported together with their 95 per cent confidence interval (CI). The graphs have been created using the STATA command eventdd.

## Table 11. FEIV-Lewbel results

| Log HH income | (1) | (2) |
|---|---|---|
| 3G Internet | 0.0382* | 0.0361** |
| | (0.0201) | (0.0167) |
| Log pop den | 0.00109 | -0.0186 |
| | (0.0164) | (0.0163) |
| Mean schooling years | -0.00259 | -0.0351 |
| | (0.0295) | (0.0275) |
| FDI | 0.0149 | 0.0261** |
| | (0.0113) | (0.0110) |
| Rainfall | -0.0000332** | -0.0000436** |
| | (0.0000147) | (0.0000187) |
| Temperature | 0.00246 | -0.00958 |
| | (0.0162) | (0.0217) |
| Hansen J test | 3.536 | 3.976 |
| Hansen J p-value | 0.8964 | 0.8593 |
| Weights | No | Yes |
| Observations | 252 | 252 |
| R-squared | 0.967 | 0.968 |
| Adjusted R-squared | 0.954 | 0.955 |
| rmse | 0.0602 | 0.0605 |

*Notes:* The table reports IV estimates from regressions using both sets of generated instruments under the Lewbel method and external instruments (elevation X time trend). The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * p<0.10, ** p<0.05, *** p<0.010

## Table 12. Control function approach

| Log HH income | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| **3G Internet** | 0.0449** | 0.0387* | 0.0480** | 0.0558** |
| | (0.0221) | (0.0217) | (0.0233) | (0.0256) |
| **Residuals** | -0.0304 | -0.0334* | -0.0399 | -0.0517** |
| | (0.0235) | (0.0199) | (0.0251) | (0.0257) |
| **Pop density** | | | 0.129 | -0.334 |
| | | | (0.163) | (0.282) |
| **Temperature** | | | -0.00116 | -0.0246 |
| | | | (0.0147) | (0.0215) |
| **Rainfall** | | | -0.0000278* | -0.0000446*** |
| | | | (0.0000154) | (0.0000166) |
| **Province FE** | Yes | Yes | Yes | Yes |
| **Year FE** | Yes | Yes | Yes | Yes |
| **Weights** | No | Yes | No | Yes |
| **Observations** | 252 | 252 | 252 | 252 |
| **R-squared** | 0.968 | 0.970 | 0.970 | 0.971 |
| **Adjusted R-squared** | 0.967 | 0.969 | 0.969 | 0.970 |
| **rmse** | 0.0523 | 0.0515 | 0.0512 | 0.0511 |

*Notes:* Columns (1) and (2) are models without control variables, while columns (3) and (4) have. Residuals are from the first stage regressions of the endogenous variable and the instrument. The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * p<0.10, ** p<0.05, *** p<0.010

Table 13. Urban-Rural difference and 3G mobile internet

| Log HH income | (1) | | (2) | | (3) | | (4) | |
|---|---|---|---|---|---|---|---|---|
| | Rural | | | | Urban | | | |
| 3G Internet | 0.0530** | | 0.0887*** | | 0.0362* | | 0.0174 | |
| | (0.0267) | | (0.0301) | | (0.0216) | | (0.0183) | |
| 1st-stage | | -.000625*** | | -.000604*** | | -.000798*** | | -.00131*** |
| | | (.000158) | | (.000160) | | (.000299) | | (.000421) |
| Province FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Weights | No | No | Yes | Yes | No | No | Yes | Yes |
| F-stat | | 16.046 | | 14.554 | | 7.303 | | 9.967 |
| Observations | 143 | 143 | 143 | 143 | 109 | 109 | 109 | 109 |
| R-squared | 0.983 | 0.902 | 0.977 | 0.905 | 0.980 | 0.905 | 0.983 | 0.897 |
| Adjusted R-squared | 0.976 | 0.861 | 0.967 | 0.866 | 0.971 | 0.864 | 0.975 | 0.852 |
| rmse | 0.0517 | 0.502 | 0.0579 | 0.505 | 0.0547 | 0.653 | 0.0523 | 0.823 |

*Notes:* All models adopt FE-IV method with elevation multiplied with time trend as the instrument. The provinces population is divided into urban and rural population based on the threshold of percentage of people living in urban communities (i.e. ward, not commune). The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.010$

## Table 14. Income quintiles and 3G BTS

| Log HH income quintile | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Quintile 1 | | Quintile 2 | | Quintile 3 | | Quintile 4 | | Quintile 5 | |
| **3G Internet** | 0.0652*** | 0.0598*** | 0.119*** | 0.0930*** | 0.0996*** | 0.0691*** | 0.0217 | 0.0222 | 0.0234 | 0.0233 |
| | (0.0204) | (0.0186) | (0.0272) | (0.0244) | (0.0269) | (0.0241) | (0.0272) | (0.0199) | (0.0168) | (0.0157) |
| **Province FE** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Year FE** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Weights** | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes |
| **F-stat** | 29.213 | 19.564 | 29.213 | 19.564 | 29.213 | 19.564 | 29.213 | 19.564 | 29.213 | 19.564 |
| **Observations** | 252 | 252 | 252 | 252 | 252 | 252 | 252 | 252 | 252 | 252 |
| **R-squared** | 0.976 | 0.979 | 0.971 | 0.973 | 0.971 | 0.973 | 0.979 | 0.980 | 0.980 | 0.983 |
| **Adjusted R-squared** | 0.968 | 0.971 | 0.961 | 0.963 | 0.961 | 0.963 | 0.971 | 0.973 | 0.973 | 0.976 |
| **rmse** | 0.0675 | 0.0687 | 0.0800 | 0.0800 | 0.0781 | 0.0746 | 0.0620 | 0.0585 | 0.0610 | 0.0620 |

*Notes:* All models adopt FE-IV method with elevation multiplied with time trend as the instrument. Quintile 1 to 5 are income quintile groups of each province during 2010 – 2016. The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * p<0.10, ** p<0.05, *** p<0.010

## Table 15 Transportation volumes and 3G BTS

| Volumes | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | Passengers carried | | Passengers X distances | | Freight carried | | Freight X distances | |
| 3G Internet | 0.0420** | 0.0380*** | 1.405** | 0.625*** | 19.88* | 2.671 | 2.576* | 1.114** |
| | (0.0202) | (0.00854) | (0.668) | (0.201) | (11.00) | (2.447) | (1.509) | (0.503) |
| Province FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Weights | No | Yes | No | Yes | No | Yes | No | Yes |
| Observations | 252 | 252 | 252 | 252 | 252 | 252 | 252 | 252 |
| R-squared | 0.937 | 0.975 | 0.858 | 0.922 | 0.796 | 0.911 | 0.864 | 0.930 |
| Adjusted R-squared | 0.915 | 0.966 | 0.808 | 0.894 | 0.724 | 0.879 | 0.815 | 0.905 |
| rmse | 0.00598 | 0.00577 | 0.254 | 0.189 | 3.507 | 2.156 | 0.425 | 0.333 |

*Notes:* All models adopt FE-IV methods with elevation multiplied with linear time trend as instrumental variable, with both province and year FE. The dependent variables are number of passengers carried per capita per province for columns 1 and 2; number of passengers multiplied with travel distance per capita per province for columns 3 and 4; number of freights carried per capita per province for columns 5 and 6; and number of freights multiplied with travel distance per capita per province for columns 7 and 8. The even columns have province's population as weights, while odd columns do not. Standard errors clustered at province level in parentheses. * p<0.10, ** p<0.05, *** p<0.010

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