Assessing the Access: The significance of Internet penetration on economic output in Thailand

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การแพร่ระบาดของโควิด-19 และการใช้เทคโนโลยีดิจิทัลในอุตสาหกรรมได้เน้นย้ำถึงความสำคัญของการเข้าถึงอินเทอร์เน็ตในประเทศไทย ครัวเรือนที่ไม่สามารถเข้าถึงอินเทอร์เน็ตในช่วงการแพร่ระบาดของโควิด-19 หมดโอกาสในการศึกษาและการทำงาน ความเหลื่อมล้ำทางเทคโนโลยีดิจิทัลจึงเป็นปัญหาสำคัญที่ต้องแก้ในช่วงเวลานี้ ดังนั้น จึงเป็นเรื่องสำคัญที่จะต้องศึกษาว่าอัตราการเข้าถึงอินเทอร์เน็ตในจังหวัดต่างๆ ของประเทศไทยนั้นส่งผลต่อผลผลิตทางเศรษฐกิจผ่านผลิตภาพอย่างไร จมีผลอย่างไรต่อการเติบโตของผลิตภัณฑ์จังหวัดต่อหัว ปัจจัยอื่นๆ ที่นำมาพิจารณาในงานวิจัยชิ้นนี้ ได้แก่ สัดส่วนของผู้ใช้คอมพิวเตอร์ สัดส่วนของผู้ใช้โทรศัพท์มือถือ ทุนมนุษย์ และความล่าช้าจากของการเข้าถึงอินเทอร์เน็ต จากการสำรวจข้อมูลปี 2019 ใน 76 จังหวัดและ 1 เขตปกครองพิเศษ ถ้าหากอัตราการเข้าถึงอินเทอร์เน็ตเพิ่มขึ้นร้อยละ 1 ทำให้ผลิตภัณฑ์จังหวัดต่อหัวของจัเพิ่มขึ้นร้อยละ 3.1

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The COVID-19 pandemic and the digitalization of industries have emphasized the importance of Internet access in Thailand. Thai households that could not access the Internet during the COVID-19 pandemic were left behind in both education and employment. The digital divide has never become any more apparent during this moment. As such it is important to study how the Internet penetration rate, the proportion of Internet users relative to the entire population, across Thai provinces affects their economic output through productivity. The effects of the rate of Internet penetration on the growth of Gross Provincial Product will be studied. Other factors that are considered in this study include the proportion of computer users, the proportion of mobile phone users, human capital, and the time-lag effects of Internet penetration. Observing 2019 data across 76 provinces and 1 special administrative region, a 1-point increase in the rate of Internet penetration in a Thai province causes its GPP per capita to increase by 3.1%.

Field of Study:	Business and Managerial Economics	Student's Signature ....
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Introduction

In 2020, the rapid spread of the coronavirus disease 2019 or COVID-19 across the globe severely affected the world economy. Restrictions on social gatherings and travel created challenges for firms in terms as they struggled to keep their workplaces safe from the virus. Even as Thailand managed to limit the spread of the virus in 2020, the slowdown in global demand has created economic losses for Thai firms. According to the "Impact Assessment of COVID-19 on Thai Industrial Sector" by the United Nations Industrial Development (UNIDO) in June 2020, at least 90% of all Thai firms were expected to experience "extreme revenue loss", as a consequence of a severe reduction in orders and a severe shortage in inputs (United Nations Thailand, 2020). It was clear that firms would need to adapt and would need to receive urgent support in order to limit economic losses.

One recommendation that UNIDO suggested to Thai firms was to invest in advanced IR 4.0 Technology. Due to a reduction in the number of workers as a result of the pandemic, firms could digitalize their manufacturing operations in order to better adapt to changing environment. Such technologies include drones, robotics, blockchain, Internet of Things (IoT), Big Data, Artificial Intelligence (AI), and 3D-printing. In fact, 59% of the 320 Thai firms surveyed by UNIDO responded that they would utilize advanced equipment and technology in order to compensate for worker shortages at their workplaces (United Nations Thailand, 2020). It was clear that new automated technological processes were needed in order to counteract the reduction in labor and maintain productivity.

However, the COVID-19 pandemic has exposed another issue: the digital divide. Workers who could not access the Internet for remote work could not perform their tasks that were now assigned online. In developed countries, a high proportion of internet users allowed for a smoother transition for firms when social restrictions were put into place. Conversely, there is a significant part of the population in developing countries that cannot access or utilize the Internet effectively. This meant that many workers in developing countries were more likely to face unemployment or a reduction in wages as firms would not be able to maintain their operations through the Internet. Thus, the digital divide will worsen income inequality as a result of the COVID-19 pandemic.

At the same time, the Thai government has pursued the Thailand 4.0 economic model to improve the country's competitiveness in high technology industries. The Thai government will promote and support the "10 future industries", which includes the the First S-curve and the New S-curve (Royal Thai Embassy, 2021). The First S-curve industries included agriculture and biotechnology, food for the future, medical tourism, next-generation automotives, and smart electronics. The New S-curve industries aviation and logistics, biofuels and biochemicals, digital technology, medical hub, and robotics (Royal Thai Embassy, 2021). In order to improve the productivity of these industries so that they can compete at the international level, Thailand will have to make large investments in Internet Communication Technology (ICT). These industries will require integrated telecommunication and software systems in order to improve efficiency and create value-added for the goods and services in these 10 future industries.

Given the current economic situation in Thailand, how should the government approach the issues of the digital divide and new industry development in the country? To what extent can Thai citizens access the Internet and utilize this technology to benefit their livelihood? Digitalization will continue to change and shape society in the future, but economical and educational disparities will also prevent disadvantaged groups from advancing forward with this technological phenomenon. Perhaps the most straightforward question is: How does Internet penetration in Thailand affect the country's economic output?

Internet penetration rate is defined as the proportion of internet users of a country's total population, measured as a percentage (Miniwatts Marketing Group, 2021). However, the definition of an "Internet User" may vary across sources. According to National Statistical Office Thailand (NSO), an Internet User is defined as an individual who has accessed the Internet through an electronic device in the past

3 months (National Statistical Office Thailand, 2021). Given this definition, the Internet penetration rate according to the 2020 Household Survey on the Use of Information and Communication Technology conducted by the NSO was at 77.8% or approximately 49.7 million users, which was a significant increase from 2016 at 47.5% (National Statistical Office Thailand, 2021). When considering the frequency of use, 89.3% of Internet users use the Internet everyday (National Statistical Office Thailand, 2021). However, there is still 22.2% of the population who are not Internet users. If Internet penetration rate does affect economic output, the government should pursue policies that improve Internet access for this group, as they will most vulnerable to digitalization and the crippling economic effects of the COVID-19 pandemic.

This paper will measure the relationship between internet penetration rate and economic output at the provincial level in order to measure the overall effect of Internet penetration rate on Thailand's economic output.

Literature Review

ICT and Economic Output

As a form of technological progress, ICT has an effect on increasing the Total Factor Productivity (TFP). TFP is defined as the "ratio of aggregate output to aggregate input" (Hernandez, Faith, Martin, & Ramalingam, 2016), or "the portion of output not explained by the amount of inputs used in production" and "is determined by how efficiently and intensely the inputs are utilized in production" (Comin, 2010). Growth in TFP can be measured using the Solow residual given in the following equation:

$$g_Y - \alpha * g_K - (1 - \alpha) g_L$$

As defined by Diego Comin, g_Y is the growth rate of aggregate output, g_K is the growth rate of aggregate capital, g_L is the growth rate of aggregate labor, and alpha is the capital share (Comin, 2010). Robert Solow indicates that only growth in

TFP can increase long-run growth in income per capita, given constant returns to scale in capital and labor for a perfectly competitive economy (Comin, 2010). This suggests that technological advancement is key in increasing income per capita, and that endogenous innovation increases TFP (Comin, 2010).

Looking at the literature on the effect ICT has on economic output, there is a general trend that increasing access to ICT has led to an observable increase in output. Vu et al. (2020) reviewed 208 papers published between 1991 and 2019 that discussed the relationship between ICT and economic growth. The results of their literature survey indicate that the scale of ICT on economic growth and the causal effect of ICT on productivity tend to increase over time and are statistically significant. 89 out of 117 papers that used the regression analysis method found significant evidence on the effect of ICT on economic growth while 20 papers had mixed results (Vu, Hanafizadeh, & Bohlin, 2020). The report by Hernandez et al. (2016) on the impact of ICT on economic indicators also found a positive correlation between ICT investment, ICT infrastructure, and ICT adoption on economic growth and productivity, although issues of endogeneity and simultaneous and reverse causality weakened the analysis of this relationship (Hernandez, Faith, Martin, & Ramalingam, 2016).

It is important to recognize that there are many variables that can affect economic output, consequently undermining the effects of ICT. Vu et al. suggested that in papers that indicated mixed results, the role of ICT was more ambiguous towards economic output. One paper that they reviewed suggested that ICT had a strong effect on international trade, which is an important factor for economic growth (Vu, Hanafizadeh, & Bohlin, 2020). This is an important factor to consider as the trend of globalization continues across the world. The shift towards an integrated world economy will compel firms to utilize ICT in order to expand their production and markets.

Similarly, there has been advances in ICT since its introduction in the late 20th century. Dial-up internet that was common in the past is now steadily replaced by broadband internet and mobile internet. Such changes can mark In addition, the mechanisms of how ICT can promote economic growth and key events of technological changes (such as switching mobile phone speeds from 3G to 4G) are not observed or assessed using quantitative data (Hernandez, Faith, Martin, & Ramalingam, 2016). In New Zealand, Grimes et al. observed that firms that switched from dial-up internet to broadband internet were more likely to use the Internet to enter new export markets and purchase goods and services online (Grimes, Ren, & Stevens, 2012), which suggests the importance of ICT in facilitate world trade. However, the ability to trade internationally with relative ease will also cause domestic production to increase in order to capture foreign markets.

As such, the rapid growth of international trade will have to be accounted for when looking at the effects of internet penetration on economic output; countries can show high growth in output even if their ICT infrastructure is not as developed due to factors such as high inflow foreign direct investment, increased domestic consumption, government infrastructure, greater access to export markets, etc. In addition, the mechanisms of how ICT can promote economic growth and key events of technological changes (such as switching mobile phone speeds from 3G to 4G) are not observed or assessed using quantitative data (Hernandez, Faith, Martin, & Ramalingam, 2016), and thus the internet penetration effect on output can also be overestimated if not accounting the level of ICT in the country.

Another aspect to consider is the level of economic development of countries. Assuming no significant progress in ICT in the near future, less developed countries have more potential to increase their productivity. Vu et al. observed a large difference in the effect of ICT across countries, and that the benefits of ICT were smaller for developing countries. However, the effects of ICT penetration on productivity was inconsistent among countries, regions, and industries. One paper reviewed by Vu et al. pointed out that there are large differences in the effect of ICT across countries, and that the benefits of ICT were smaller for developing countries (Vu, Hanafizadeh, & Bohlin, 2020). Moreover, Herandez et al. found strong ICT penetration effects on GDP growth for specific countries like Ecuador and China, but statistically insignificant results for other countries like the Philippines or Senegal (Hernandez, Faith, Martin, & Ramalingam, 2016).

Similarly, Dedrick, Gurbaxani, & Kraemer (2003) reviewed firm and industry level literature and data to find whether or nor investment in IT increased productivity. Their review indicated that studies from the 1980s, there showed little correlation between IT investment and productivity. However, during the 1990s firms started to associate IT investments with high gross marginal product or "excess returns", even if their link to profitability was not clear (Dedrick, Gurbaxani, & Kraemer, 2003). The rate of upskilling for workers was the fastest in industries that used computers intensively, indicating a higher demand for high-skilled workers adept at using ICT.

At the industry level, Dedrick et al. found that although labor productivity has increased in IT intensive industries than non-IT intensive industries, both manufacturing and service industries have seen a general increase in labor productivity during the 1990s (Dedrick, Gurbaxani, & Kraemer, 2003). The increase in multifactor productivity growth in the IT sector was caused by innovations in the semiconductor and computer industries. At the national level, Dedrick et al. found that the sudden increase in IT investment during the mid and late 1990s aligned with a rapid increase in labor productivity growth, although they pointed that IT investments have been accumulated for over 30 years (Dedrick, Gurbaxani, & Kraemer, 2003). In conclusion, although the ICT on economic output are observed in the long-run as according to the Solow model,

Effectiveness of ICT at increasing productivity

ICT is increasingly becoming an important tool for transmitting information. In their analysis, Palvalin et al. (2013) found that ICT reduced time for users to search and access higher quality information and made real-time communication and information sharing more efficient (Palvalin, Lonnqvist, & Vuolle, 2013). This allowed users to make better decisions and make fewer errors as they were able to receive any new information almost instantaneously. Similarly, Hernandez et al.

summarized that broadband internet supported efficient two-way communication, reduced transaction costs, improved access to third-party information for firms (Hernandez, Faith, Martin, & Ramalingam, 2016). Additionally, the network effect of ICT further amplifies the benefits of information transmission between users and work processes as more workers and tasks are connected to each other. Through the network effect, a higher Internet penetration rate can potentially increase the productivity of firms.

Palvalin et al. revealed that it was not difficult to measure the impact on of ICT on the productivity of knowledge-based tasks, contrary to what the literature review indicated. They studied the effects of ICT in the firm “TeliaSonera” and found that respondents experienced benefits in increased efficiency, decreased waiting time, and greater satisfaction with ICT (Palvalin, Lonnqvist, & Vuolle, 2013). Palvalin et al. noted that ICT improved the efficiency for “non-value-adding tasks” in order for workers to allocate more time for more important tasks. In addition, ICT also benefits workers by reducing the amount of time spent on these unimportant tasks. On the other hand, respondents also did not experience a decrease in IT-helpdesk contacts, which the company representatives assumed that it was due to the respondent still adapting to the new technology (Palvalin, Lonnqvist, & Vuolle, 2013).

Despite this, ICT appears to have a “lagged” effect on productivity, caused by several different factors. Mack & Faggian noted the so-called “productivity paradox” during 1980-1990, when productivity growth was slow despite the introduction of ICT for a period of time (Mack & Faggian, 2013). Although this may seem to contradict what the Solow Model presented, the positive effects of ICT on economic growth were still observed in the long-run. Several papers reviewed by Vu et al. also emphasize that the effects of computerization are only fully realized in the long run (Vu, Hanafizadeh, & Bohlin, 2020). However, Mack & Faggian reflected those lagged effects of IT investment on productivity attributed to a period where ICT was not widely included in accounting measures and price indices while Vu et al. argued that ICT only when it reached a critical mass would it have a significant impact economic growth.

This suggests two main challenges that firms face to increase productivity: accessibility and application. The workplace must not only have access to ICT but must also work how to best utilize it. According to the NSO's 2020 Household Survey on the Use of Information and Communication Technology, 92.0% of Thai Internet users connected to the Internet to partake in social network activities, but only 2.9% of users used the Internet to edit online documents and spreadsheets (National Statistical Office Thailand, 2021). As such, there can be a considerable lag in productivity for a given area after ICT has been made accessible as ICT knowledge must be disseminated to users in order to operate the technology effectively. Considering the rapid growth of Thai Internet penetration mentioned in the introduction, this is an important factor to consider. The lagged effect of Internet productivity also suggests that time series data should be used in order to measure various factors that affect productivity over time, as changes may not be observed in just cross-sectional data.

Although the Solow model indicates technological advancement as the key to increasing economic growth, the importance of human capital should not be underestimated. Mack & Faggian (2013) explored the relationship between broadband provision and productivity in US counties, and the level of variability due to differences in human capital among counties. Using data on broadband provision in 1999 and time series data on productivity between 2000 and 2007 across 3,046 counties, Mack & Faggian created a regression model to record the lagged effects of broadband provision on productivity. Results showed that when controlling for college-level education attainment and high-skilled occupations, broadband provision was positively correlated with productivity, but when not controlling for these factors, broadband provision was negatively correlated with productivity (Mack & Faggian, 2013).

Mack & Faggian attempted to explain these results by noting the increasing wage disparity between high-skilled and low-skilled workers caused by the introduction of ICT and a substitution of workers by ICT (Mack & Faggian, 2013). Another explanation was that the benefits of broadband internet were not fully realized in 1999 when data for broadband provision was retrieved. Firms in that period may have lacked sufficient knowledge and understanding to utilize ICT in comparison to the early-mid 2000s. Mack & Faggian noted that if the negative sign between broadband provision and productivity is attributed to difference in worker skill levels rather than high startup costs of providing broadband internet, broadband provision may be a detriment or limiting to productivity (Mack & Faggian, 2013).

Likewise, Hernandez et al. (2016) suggested that increased ICT penetration may have displaced jobs in the short-run and medium-run due to automation, while workers who did not upskill to meet the requirements of ICT faced higher income inequality and lower productivity (Hernandez, Faith, Martin, & Ramalingam, 2016). Although these effects on employment and living standards were not observed in papers, Hernandez et al. recommended that more research be done on this topic, especially for developing countries so that job creation, skills training, and other policies can be implemented accordingly.

The implication that human capital can inhibit the effects of ICT on productivity suggests that ICT policies should also focus on training and educating ICT users once the infrastructure and connection has been established. In fact, the NSO reported that 55.4% of non-Internet users responded that not knowing how to use the Internet was a large factor of why they were not an Internet user (National Statistical Office Thailand, 2021). Governments and firms should invest in training programs to ensure that citizens and employees can perform tasks efficiently. Otherwise, areas with less developed human capital may not see the full effects of ICT, thus widening the gap in economic output between areas with more skilled labor and areas with less skill labor. Human capital should be an important factor when contemplating the effective of ICT on productivity.

However, the relationship between ICT and human capital may be difficult assess due to globalization. Inflow foreign direct investment is likely to encourage the development of domestic human capital, while simultaneously introducing ICT into the workplace. Using data from the Conference Board Total Economy dataset on GDP growth and average labor productivity growth from 1977 to 2017, Vu et al.

found that GDP and average labor productivity rates were higher for the years 1997-2017 than the years 1977-2017, in which the former coincided with the spread of ICT across the world (Vu, Hanafizadeh, & Bohlin, 2020). Vu et al. thus recommended that future research should focus on how digital technologies affect what indicators of economic growth, despite the presence of confounding variables such as human capital, and whether ICT proliferation provide more benefits for developing countries than developed countries despite lower levels of human capital.

Nevertheless, even if an Internet user were to develop the necessary skills, they may also need the right tools and equipment to work efficiently. Evidently, an Internet User will require an electronic device that can be connected to the Internet. Firms can provide and invest in these equipments and devices, but to what extent should the households invest in these devices? The COVID-19 pandemic has shown that households needed these devices to work remotely. As mobile phone technology gets closer with computer technology, how does possessing these devices complement Internet use, and does the type of device have an impact on a user's productivity?

Using the 2020 Household ICT Survey, 94.8% of households used a mobile phone (feature phone and smart phone) compared to only 26.4% for computers (personal computer, laptop, and tablet) (National Statistical Office Thailand, 2021). This stark difference in device usage may be important to consider as not every activity performed on a mobile phone can be as productive as a computer. Dr. Saowaruj Rattanakhamfu from Thailand Development Research Institute suggests that although the government had provided SIM cards to university students in order to access the Internet, they should also provide computers to students without them, as students from poor households would not be able to afford computers to study online, as mobile phones are not as effective for writing and learning online (Rattanakhamfu, 2020).

Mobile phones and computers may be complementary goods to Internet consumption, but they are also not substitute goods of each other. Given the discrepancies in phone usage and computer usage, this implies that a significant portion of the Thai population uses only their phones to access the Internet. This further implies that computer literacy may not necessarily be high, and that Thai workers may need additional training and knowledge to operate computer machines and programs connected to the Internet.

Another factor to study is the level of technology. Grimes, Ren, & Stevens (2012) studied the level of internet access in firms on productivity by using micro-survey and longitudinal financial data of approximately 6,000 New Zealand firms. The study focuses the change on productivity of firms switching from dial-up/no internet access to broadband access. Grimes et al. found that variables that help increase broadband adoption include urbanization, quality of local ICT, firm's general management capabilities, firm-specific ICT knowledge, sector-specific ICT knowledge, foreign-owned firms, and R&D activity. Using an estimated average treatment effect for firms that switched to broadband internet, Grimes et al. found that productivity increased by 7-10% for all firms (Grimes, Ren, & Stevens, 2012). Given the current situation in Thailand, level of technology may revolve around the use of 5G networks for users.

Methodology

According to Vu et al., the two main models used to measure the relationship between ICT and economic output is a regression analysis and growth accounting (Vu, Hanafizadeh, & Bohlin, 2020). Regression analysis estimates the relationship between the independent variable and dependent variable, while growth accounting measures the impact of various variables to economic growth in order to indirectly calculate the rate of technological progress in the country's economy. Growth accounting observes the growth rates in capital, labor, and output over time in order to estimate the change in productivity through technological progress. Since this paper discusses ICT, it seems more appropriate to use the growth accounting method, but this method may be limited for several reasons.

As this paper studies Internet penetration rate and not the effect of technological progress, using growth accounting to measure its effect on economic output may not be entirely appropriate, even though an increase in Internet users should theoretically lead to higher productivity for workers, which would be observable using this method. Consequently, using regression analysis to determine the relationship between Internet penetration rate and economic output may be worthy of note.

Vu et al. reviewed the models used in 208 papers in their analysis. They discovered that 117 papers used regression analysis while only 46 papers used growth accounting (Vu, Hanafizadeh, & Bohlin, 2020). Moreover, 19 out of the 46 papers that used growth accounting used United States data in their analysis (Vu, Hanafizadeh, & Bohlin, 2020). Vu et al. suggests that using this method may be difficult to replicate outside of the United States without quality longitudinal data (Vu, Hanafizadeh, & Bohlin, 2020).

Considering the limited scope of this paper, it will be difficult to obtain and analyze longitudinal data for all the variables in Thailand's provinces. Complex calculations may be needed to measure growth in capital and labor based on current data available. In addition, it may be difficult to measure some variables using past data as the creation of new Thai provinces from existing provinces in the past 30 years may make data difficult to retrieve. Given the circumstances, it may be more convenient to just observe a single year, even though the literature review suggests lagged effects in ICT on economic output. This is an important limitation to consider for the results.

Given these reasons, this paper with therefore using regression analysis to measure the relationship of Internet penetration rate on economic output at the national level by using Thai provinces as data points. Using the information from the literature review, the economic model for this regression analysis will be as follows:

Model 1:

$$lnY_t = \beta_0 + \beta_1 IP_t + \beta_2 CU_t + \beta_3 IC_t + \beta_4 CE_t + \varepsilon$$

- Y_t = Gross Provincial Product per capita (THB) for t year

- IP_t = Internet penetration rate (percentage) for t year
- CU_t = Proportion of computer users (percentage) for t year
- IC_t = Contribution of industrial sector to GPP (percentage) for t year
- CE_t = Proportion of workers with college education attainment (percentage) for t year

Gross Provincial Product (GPP) per capita will be the dependent variable that will be used to observe the level of economic output per person for the province. Given that the explanatory variables will be measured as a proportion, it may be useful to measure economic output per person using a natural logarithmic function in order to measure the degree of response in a change of the explanatory response. In other words, a 1-point increase in the Internet penetration rate will cause GPP per capita to increase by a specified percentage points according to the linear regression analysis. Internet penetration rate will be the main regressor that will be used to measure internet penetration as is defined as the proportion of internet users of a country's total population. Proportion of computer users will be used to control for the use of computers that may affect a worker's productivity alongside the Internet. Computer users are used instead of mobile phone users as Thailand currently has an extremely high proportion of mobile phone users. It will be more difficult to measure the effects of mobile phone usage as proportions maybe more similar between provinces.

Contribution of industrial sector to GPP is used to control for level of economic development. Given that GPP is related to the average income of a province, it may be difficult to determine level of economic development of a province as it may affect a citizen's ability to afford Internet subscriptions. Since the industrial sector on average produces higher value goods than the agricultural sector, and is the sector emphasized by the Thailand 4.0 Industry policy, this variable can be used to observe the level of economic development as more developed provinces are more likely to have larger contributions from the industrial sectors.

The proportion of citizens with college education attainment is used to control for human capital, as citizens of this group are most likely to have the knowledge and skills to use ICT effectively, or most likely to engage in activities that require ICT. College level attainment was selected based on the results by Mack & Faggian that discovered that those with a bachelor's degree were more likely to use ICT more productively. However, this does not mean that citizens with less than college-level education cannot receive additional education or training in order to use ICT effectively.

However, it would also be beneficial to study the effects of Internet penetration rate of prior years in order to measure the "lagged effects" between ICT implementation and productivity. In addition, the high mobile phone penetration at 94.8% of the Thai population when compared to only 26.4% for computer penetration in 2020 (National Statistical Office Thailand, 2021) can be studied to look at how mobile phone and Internet usage impacts productivity through mobile apps. As such, a second model would include the following variables:

Model 2:

$$lnY_t = \beta_0 + \beta_1 IP_t + \beta_2 CU_t + \beta_3 IC_t + \beta_4 CE_t + \beta_5 IP_{t-1} + MU_{t-1} + \varepsilon$$

- Y_t = Gross Provincial Product per capita (THB) for t year
- IP_t = Internet penetration rate (percentage) for t year
- CU_t = Proportion of computer users (percentage) for t year
- IC_t = Contribution of industrial sector to GPP (percentage) for t year
- CE_t = Proportion of workers with college education attainment (percentage) for t year
- IP_{t-1} = Internet penetration rate (percentage) for t-1 year
- MU_{t-1} = Proportion of mobile phone users (percentage) for t-1 year

Data

Data collected from the 76 provinces and 1 special administrative area in Thailand will be used for the linear regression analysis. Internet penetration rate, proportion of computer users, proportion of mobile phone users and proportion of workers with college education data will be retrieved from the National Statistical

Office Thailand (NSO). Internet penetration rate and proportion of computer users (of at least age 6) will be retrieved from the 2019 Information and Communication Technology Survey. Proportion of workers (at least age 15) with college education attainment from universities data will be retrieved form the 2019 Household Basic Information Survey. 2019 projected GPP per capita and contribution of industrial sector to GPP data will be retrieved from the 2019 Gross Regional and Provincial Product Table from the Office of the National Economic and Social Development Board (NESDB). Given that the latest public report for GPP only records real GPP up until the year 2018, the GPP for each province in 2019 is predicted based on data from previous years.

Although data for the 2021 survey exists, the data is much more limited due to a smaller selection of questions being surveyed as a result of the COVID-19 pandemic that limited travel in 2021. In addition, the pandemic created an exogenous shock where households and firms were encouraged to use the Internet for work, school, communication, etc., therefore increasing the Internet penetration rate, but simultaneously causing output to decrease due to labor shortages and supply shocks. As such, 2019 data will be used, as data was collected prior to the initial outbreak of the virus. However, data on mobile phone usage in Thai households (at least age 6) was not collected in 2019, therefore 2018 mobile phone usage to calculate the mobile phone penetration rate. This is the reason why the t-1 period was used for mobile phone penetration variable in Model 2.

Data for the 76 provinces and 1 special administrative region is further grouped into 7 regions as classified by the NESDB: Northeastern, Northern, Southern, Eastern, Western, Central, and Bangkok & Vicinities. Table 1 provides a descriptive summary of the 7 regions for all the variables outlined in Model 2.

	Internet Penetration Rate (%)								
Region	2018	2019	Growth in Internet Penetration Rate (2018-2019)	Proportion of Computer Users 2019 (%)	Proportion of Mobile Users 2018 (%)	Contribution of Industrial Sector to GPP (%)	Contribution of Agriculture Sector to GPP (%)	Proportion of College Level Workers (%)	GPP per capita 2019 (baht)
Northeastern	44.54	55.63	11.09	19.33	87.64	17.15	22.85	4.53	79,897
Northern	47.92	58.33	10.41	22.38	86.37	18.44	27.7	7.32	109,503
Southern	54.95	65.54	10.59	22.9	88.43	12.34	27.38	8.92	162,237
Eastern	59.55	69.15	9.60	22.79	90.18	41.21	19.75	8.03	395,695
Western	52.62	63.75	11.13	20.77	86.64	27.52	20.9	8.05	162,651
Central	55.43	64.56	9.13	22.48	88.02	41.52	14.25	8.56	219,583
Bangkok and Viciniti	69.07	77.19	8.12	29.62	93.42	41.76	1.77	17.58	352,508

Table 1 Provincial Data by Region

Bangkok & Vicinities region ranked the highest Internet penetration rates for both 2018 and 2019 (at 77.19% in 2019), the highest for proportion of computer users (29.62%) and mobile phone users (93.42%), the highest contribution of the industrial sector to GPP (41.76%), and the highest proportion of college educated workers (17.58%), and ranked second in average GPP per capita for all regions (352,508 baht). High levels of economic output and high use of ICT supports the fact that Bangkok and its surrounding areas make up the economic center of Thailand.

The Eastern region ranks the highest for average GPP per capita for all regions (395,695 baht), ranked second in proportion of mobile phone users (88.43%) and industrial contribution of the industrial sector to GPP (41.52%) but ranks in the middle for all other variables. This data can be attributed to the Thailand 4.0 policy, which aims to promote the Eastern Economic Corridor (EEC), consisting of 3 provinces in the region: Rayong, Chon Buri, and Chachoengsao. These three provinces received attention for investment in manufacturing industries. A lower proportion of college educated workers may indicate training activities to create skilled workers relevant for the manufacturing industries, or an inward migration of skilled workers from outside the Eastern region.

The Northeastern region ranked last for most variables, having only a 55.63% Internet penetration rate in 2019, a regional average of 79,897 baht for GPP per capita, 4.53% for proportion of college educated workers, and 19.33% for proportion of computer users. It ranked second lowest for proportion of mobile phone users (87.64%) and contribution of industrial sector to GPP (17.15%). The data suggests that the Northeastern region was the most underdeveloped in ICT usage and economic output in Thailand. However, it also experienced the second largest increase in the proportion of Internet users from 2018 to 2019, and so has large opportunities for ICT.

The Northern region had the lowest proportion of mobile phone users (86.37%) while the Southern region had the lowest contribution of industrial sector to GPP (12.34%). The Northern region may have had the lowest proportion of mobile phone users due to its mountainous terrain, making mobile phone signals more difficult to intercept. The Southern region's more developed agricultural and service sectors (in particular the tourism industry) may explain why the industrial sector's contribution to GPP was low.

Looking at the top 5 provincial rankings for highest and lowest Internet penetration rates in the country in 2019 in Table 2 and Table 3, all the 5 provinces with the highest Internet penetration rates were from the highest GPP per capita quartile, while 5 provinces from the lowest and medium-low GPP per capita quartile ranked the lowest for Internet penetration rate. These tables suggest the disparity in economic output when observing Internet penetration rankings. The internet penetration rate for Bangkok (85.32%), the area with the highest penetration rate, is nearly two times higher than the internet penetration rate for Si Saket in the Northeastern region (43.87%), the province with the lowest penetration rate.

Top 5 provinces with the highest Internet penetration rate 2019			
Rank	**GPP per capita Quartile**	**Region**	**Penetration Rate**
1. Bangkok	High	Bangkok and Vicin.	85.32
2. Pathum Thani	High	Bangkok and Vicin.	85.09
3. Phuket	High	Southern	83.55
4. Samut Prakan	High	Bangkok and Vicin.	82.88
5. Chon Buri	High	Eastern	81.84

Table 2 Top 5 provinces with the highest Internet penetration rate 2019

Top 5 provinces with the lowest Internet penetration rate 2019			
Rank	**GPP per capita Quartile**	**Region**	**Penetration Rate**
1. Si Saket	Low	Northeastern	43.87
2. Narathiwat	Low	Southern	47.59
3. Mae Hong Son	Low	Northern	49.25
4. Loei	Medium-low	Northeastern	49.98
5. Amnat Charoen	Low	Northeastern	50.90

Table 3 Top 5 provinces with the lowest Internet penetration rate 2019

Conversely, the top 5 provincial rankings for highest and lowest change in Internet penetration rates from 2018 to 2019 in Table 4 and Table 5 show great improvements to Internet access in poorer provinces. All of provinces with the highest change in Internet penetration rates were from the lowest and medium-low GPP per capita quartile. Conversely, 4 out of the 5 provinces with the lowest change in Internet penetration rate were from the highest and medium-high GPP per capita quartile. Notably, the aforementioned Si Saket province had the smallest increase in Internet penetration, with an increase of 2.01% in the penetration rate. For comparison, the province with the highest change in Internet penetration was Ranong province in the Southern region, which had an increase of 20.42% in the penetration rate. This is despite the fact that both provinces are from the lowest GPP per capita quartile.

Top 5 provinces with the largest increase in Internet penetration rate 2018-2019			
Rank	**GPP per capita Quartile**	**Region**	**Change**
1. Ranong	Low	Southern	20.42
2. Sakon Nakhon	Low	Northeastern	19.50
3. Nan	Medium-low	Northern	19.41
4. Pattani	Low	Southern	17.58
5. Bueng Kan	Low	Northeastern	16.53

Table 4 Top 5 provinces with the largest increase in Internet penetration rate 2018-2019

Top 5 provinces with the smallest increase in Internet penetration rate 2018-2019			
Rank	**GPP per capita Quartile**	**Region**	**Change**
1. Si Saket	Low	Northeastern	2.01
2. Phuket	High	Southern	4.28
3. Songkhla	Medium-high	Southern	4.36
4. Ang Thong	Medium-high	Central	4.60
5. Nakhon Si Thammarat	Medium-high	Southern	4.69

Table 5 Top 5 provinces with the smallest increase in Internet penetration rate 2018-2019

Results

Linear regression analysis was conducted using the STATA statistical software. The results for the first model are shown Table 6. The F-statistic given by 4 variables and 72 degrees of freedom in the first model produces a value of 56.13, yielding a p-value equal to 0.0000. Given a 5% significance level, the null hypothesis that the explanatory variables have no effect on lnGPPpercapita can be rejected. For the coefficients, three out of the four explanatory variables were statistically significant at the 5% level: 2019 Internet penetration rate (IP_t) (0.000), proportion of college-level workers (0.005), and contribution of the industrial sector (0.000). Only proportion of computer users was not statistically significant (0.284). We can safely reject the null hypothesis that the coefficient for 2019 Internet penetration rate, Proportion of college-level workers, and Contribution of the industrial sector is not equal to zero.

Source	SS	df	MS			
				Number of obs	=	77
				F(4, 72)	=	56.13
Model	24.1887337	4	6.04718342	Prob > F	=	0.0000
Residual	7.75736257	72	.107741147	R-squared	=	0.7572
				Adj R-squared	=	0.7437
Total	31.9460963	76	.420343372	Root MSE	=	.32824

lnGPPcap	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
InternetPenetrationRate2019	.0308605	.0066899	4.61	0.000	.0175244	.0441966
ProportionofComputerUsers201	-.0140326	.0129939	-1.08	0.284	-.0399355	.0118702
ProportionofCollegeLevelWork	.0427731	.0149212	2.87	0.005	.0130283	.072518
ContributionofIndustrialSecto	.0163028	.0022518	7.24	0.000	.0118139	.0207917
_cons	9.466519	.3373157	28.06	0.000	8.794092	10.13895

Table 6 Model 1 Linear Regression Statistics

The coefficients for the explanatory variables indicate that a 1-point increase in the 2019 Internet penetration rate will increase the GPP per capita by 3.1%, a 1-point increase in the Proportion of college workers will increase GPP per capita by 4.3%, and a 1-point increase in the Contribution of the industrial sector will increase GPP per capita by 1.6%. On the other hand, a 1-point increase in the Proportion of computer users will decrease GPP per capita by 1.4%. Given that the model has a high adjusted R-squared of 0.7437, the lnGPPpercapita values are considerably explained by the changes in the explanatory variables.

However, the results of the White Test for Model 1, as shown in Table 7, indicate a statistically significant value to reject the null hypothesis for homoskedasticity. This indicates that the variance of the residuals for lnGPPpercapita is different as the explanatory variables change. Therefore, heteroskedasticity in the first model may overstate the highly positive correlation of the first model. In addition, a statistically significant value indicating skewness for lnGPPpercapita values in Table 7 further weakens the effect of the explanatory variables due to outliers in the dataset.

```
White's test for Ho: homoskedasticity
         against Ha: unrestricted heteroskedasticity

         chi2(14)     =     33.66
         Prob > chi2  =    0.0023

Cameron & Trivedi's decomposition of IM-test
```

Source	chi2	df	p
Heteroskedasticity	33.66	14	0.0023
Skewness	10.47	4	0.0332
Kurtosis	2.22	1	0.1358
Total	46.35	19	0.0004

Table 7 Tests for Heteroskedasticity, Skewness, and Kurtosis in Model 1

When the additional two explanatory variables for the 2018 Internet penetration rate (IP_{t-1}) and 2018 Proportion of mobile phone users are added to create Model 2 as shown in Table 8, the statistical significance for the four explanatory variables in the first model were affected. Using the same 5% significance level, only two out of the six explanatory variables were statistically significant: the 2018 Internet penetration rate (0.005), and 2019 Contribution of the industrial sector (0.000). The 2019 Internet penetration rate (0.594), 2019 Proportion of computer users (0.258), 2018 Proportion of mobile phone users (0.537), and 2019 Proportion of college-level workers (0.123) were not statistically significant. The F-statistic given by 6 variables and 70 degrees of freedom in the first model produces a value of 42.37. This value still rejects the hypothesis that the explanatory variables have no effect on lnGPPpercapita.

Source	SS	df	MS			
				Number of obs	=	77
				F(6, 70)	=	42.37
Model	25.0486807	6	4.17478012	Prob > F	=	0.0000
Residual	6.89741556	70	.098534508	R-squared	=	0.7841
				Adj R-squared	=	0.7656
Total	31.9460963	76	.420343372	Root MSE	=	.3139

lnGPPcap	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
InternetPenetrationRate2019	.0057502	.0107274	0.54	0.594	-.015645	.0271454
InternetPenetrationRate2018	.0345674	.0118116	2.93	0.005	.0110099	.0581248
ProportionofComputerUsers201	-.0142303	.0124793	-1.14	0.258	-.0391195	.0106588
ProportionofMobilePhoneUsers	-.0075655	.0121818	-0.62	0.537	-.0318614	.0167304
ProportionofCollegeLevelWork	.0244029	.0156215	1.56	0.123	-.0067532	.055559
ContributionofIndustrialSecto	.0143531	.0022529	6.37	0.000	.0098597	.0188464
_cons	10.09556	.9759662	10.34	0.000	8.149055	12.04206

Table 8 Model 2 Linear Regression Statistics

The coefficients for the explanatory variables for related Internet penetration rate indicate that a 1-point increase in the 2019 Internet penetration rate will increase the GPP per capita by 0.5%, but a 1-point increase in the 2018 Internet penetration rate will increase GPP per capita by 3.5%. A 1-point increase in the 2019 Contribution of the industrial sector will only increase GPP per capita by 1.4% while a 1-point increase in the 2019 Proportion of college-level workers will increase GPP per capita by 2.4%. Conversely, a 1-point increase in the 2019 Proportion of computer users decreases GPP per capita by 1.4%, while a 1-point increase in the 2018 Proportion of mobile phone users decreases GPP per capita by 0.7%.

The adjusted R-squared value for Model 2 is 0.7656, which is slightly higher than the first model. The results calculated by the White Test for Model 2 in Table 9 now does not reject the null hypothesis for skewness, which suggests a normal distribution for the data given that kurtosis is not rejected. However, the null hypothesis for homoskedasticity still cannot be rejected, which still indicates issues of heteroskedasticity in the second model. The effects of the explanatory variables on lnGPPpercapita in the second model may still be overstated.

```
White's test for Ho: homoskedasticity
         against Ha: unrestricted heteroskedasticity

         chi2(27)     =     48.32
         Prob > chi2  =    0.0071

Cameron & Trivedi's decomposition of IM-test
```

Source	chi2	df	p
Heteroskedasticity	48.32	27	0.0071
Skewness	10.60	6	0.1017
Kurtosis	2.63	1	0.1049
Total	61.55	34	0.0026

Table 9 Tests for Heteroskedasticity, Skewness, and Kurtosis in Model 2

In Table 10, the pairwise correlations between all variables are observed. Looking at the correlations for the 2019 Internet penetration rate with all other explanatory variables, all the other variables are moderately or strongly correlated with the 2019 Internet penetration rate, even when disregarding the Internet penetration rate from the previous year. The R-squared values for the pairwise correlations for the 2019 penetration rate ranges from 0.3835 to 0.9273.

	lnGPPcap	Int~2019	Int~2018	Prop~201	Propor~s	Propor~k	Contri~o
lnGPPcap	1.0000						
Interne~2019	0.7500*	1.0000					
Interne~2018	0.7993*	0.9273*	1.0000				
Proporti~201	0.4402*	0.6550*	0.6622*	1.0000			
Proportion~s	0.4784*	0.5871*	0.6510*	0.3788*	1.0000		
Proportion~k	0.5654*	0.7005*	0.7583*	0.7680*	0.4785*	1.0000	
Contributi~o	0.6637*	0.3835*	0.4099*	0.0794	0.2259*	0.1112	1.0000

Table 10 Pairwise Correlation for all Variables

Discussion

An important discussion on the results is the policy implications for Internet penetration in Thailand. Examining the first model, the results show that a 1-point increase in the Internet penetration rate in a Thai province can increase its GPP per capita by 3.1%. The effects of the 2019 Internet penetration rate on the GPP per capita seems unusually high, given that studies from Hernandez et al. indicated that a 10-point increase in the Internet penetration rate led to an increase in GDP per capita growth varying from 0.9% to 3.2% (Hernandez, Faith, Martin, & Ramalingam, 2016). The issue of heteroskedasticity in the model also suggests that this effect of the rate of Internet penetration may be weaker than what is actually stated. Strong correlations among the explanatory variable also indicate

When accounting for the Internet penetration rate from the previous 2018 year, the effect of the Internet penetration rate from the 2019 year on GPP per capita growth is now ambiguous and may have no effect at all. Although Internet penetration may be a contributing factor to increasing the level of economic output in Thailand based on data, it is not clear whether the current year's Internet penetration rate is a contributing factor accounting for the previous year's Internet penetration rate. Regardless, there is some evidence that indicates that increasing the Internet penetration in a Thai province has a positive effect on its GPP per capita.

Conversely, the statistical significance of the previous year's Internet penetration rate suggests a lagged effect similar to what Mack & Faggian observed in their paper (Mack & Faggian, 2013). Policy implications suggest that sustained increases in Internet access from the past may have an effect on the economic output of Thai provinces. This may indicate that Internet access should be sustained across a period time as workers learn to apply the Internet in their work effectively. As such, continual investments in ICT infrastructure or access are important to improving economic output at the provincial level.

One striking observation was the statistical insignificance for the Proportion of computer users and the Proportion of mobile phone users in both models. This suggests that increasing access to computers and mobile phones had no effect on economic output, but medium levels of correlation between these two variables and the Internet Penetration do correspond to what Rattanakhamfu indicated in needing access to both Internet and computers to accomplish homework tasks (Rattanakhamfu, 2020). One explanation for these ambiguous effects on economic output may be that the work processes of Thai industries may not be digitalized enough where computer or mobile phone use contributes to productivity.

Another explanation is that computer or mobile phone use creates benign or negative effects. Computers and mobile phones may be primarily used for non-work-related activities which do not contribute to economic output, or that their usage reduces productivity as they decrease time spent on work-related activities, leading to problems such as procrastination. Another interpretation of the data is that similar proportions of computers users and mobile users across provinces made it more difficult to discern any observable relationship in comparison to the Internet penetration rates across provinces. Regardless, the policy implications from these results are to determine how to better integrate computers and mobile phone with Thai industries in order to make workers more productive.

Another surprising observation is that Proportion of college-level workers is statistically significant for Model 1, but not for Model 2. This is puzzling considering that if education is linked to human capital, the effects of additional years of schooling should make users more adept at using ICT, or more likely to engage in ICT activities as described by Mack & Faggian (Mack & Faggian, 2013). One explanation is that there a migration of highly educated workers from low GPP per capita provinces to high GPP per capita provinces in search of better economic opportunities may deprive low GPP per capita provinces of a skilled workforce and thus remain less productive. Perhaps including workers of different education attainments such as vocational education instead of only college-level university track workers may be more representative of the level of human capital in Thailand. If the results for Model 2 are to be used, perhaps there should be a focus on training workers with high school or vocational education attainment to use ICT productively in increasingly digitalized industries.

Contribution of the industrial sector indicates that industrialization yields higher economic output. High GPP per capita in a province may be determined by the level of industrial output as industrial goods yield higher prices. Although the most obvious policy implication would be to create more manufacturing in provinces, it may also be beneficial to consider high-technology industries that yield even higher good prices, as outlined by the Thailand 4.0 policy. Moreover, ICT could also be applied to benefit agricultural and service sectors through automated processes. However, a negative consequence would be the displacement of low-skilled workers for automation, which would create employment issues if training policies were not implemented simultaneously, as described by Hernandez et al.

One important drawback to consider when examining the results in Model 2 is to consider the projected 2019 GPP per capita values obtained from the NESDC. Since the projected values were calculated based on trends in previous years, the lagged effect of the 2018 Internet penetration rate may have been overstated, as the projected values are more likely to resemble trends from the 2018 GPP per capita data.

It is also not clear if there is reverse causality between growth in GPP per capita and the rate of Internet penetration. Citizens living in higher GPP per capita provinces are more likely to earn higher income, which increases their ability to purchase Internet services and their demand for Internet services. Thus, higher Internet penetration may be driven by higher demand for Internet services as a result of a more productive workforce. There are also non-economic factors such as leisure, which may raise the demand for Internet services by seeking entertainment.

Another drawback to the results is the data is not representative of the technological progress over time. Internet penetration over the past decade may have continuously increase, but its effect on the growth GPP per capita may not have been reflected over the same time period. For example, the COVID-19 pandemic would undermine the relationship between these two variables during this period of time as Internet penetration rose due to demand for remote work and communication, but GPP decreased due to supply shocks.

For future studies, it may be useful to look at the panel data for GPP per capita and Internet penetration rate for all Thai provinces over the past 10 years since the newest province was formed. The results will allow researchers to observe the trend of GPP per capita growth and Internet penetration growth in the medium-run and the long-run. Another study can be focused on the relationship between different education attainment groups, occupations and Internet access in Thailand to measure differences in ICT activity.

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