Telecommunications Policy 35 (2011) 141–155

Contents lists available at ScienceDirect

Telecommunications Policy

URL: www.elsevierbusinessandmanagement.com/locate/telpol

Access to and penetration of ICT in rural Thailand

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A R T I C L E I N F O

Available online 19 January 2011

Keywords:
ICT
Thailand
Developing country
Universal service
Penetration
Telecommunication
Regression tree
Two-Stage Least Square
Factor analysis

A B S T R A C T

This paper presents an econometric study of information and communication technology (ICT) in all 70,000 rural villages in Thailand, where the ICT considered consists of fixed-line telephone service, mobile telephone service, public telephones, computers, and Internet service. The results may provide information that helps policymakers decide where to put limited resources to promote ICT, and helps profit-seeking ICT companies target regions that maximize revenues. The study found that education is far more important than income in predicting the percentage of households who adopt ICT services, and that some unexpected variables such as the penetration of pickup trucks are useful predictors as well. Even in areas where fixed-line phone service is available, 70% of households with computers choose not to become Internet subscribers, although many presumably have enough money and technical knowledge. By separating availability from penetration of ICT, the study found that they can have different predictors, which means that researchers who do not separate them may get misleading results. There is no evidence showing mobile telephone service as a substitute for fixed-line telephone service. Also, public telephone service had little or no impact as a substitute for fixed-line or mobile telephone service, so phone companies need not fear that deployment of more public telephones will decrease their subscribership. Finally, there appears to be significant unmet demand for telephone service in rural Thailand where the infrastructure does not yet exist.

1. Introduction

Many countries wish to adopt a policy to make information and communication technology (ICT) available, affordable, and usable to all segments of their population; such as a policy that subsidizes the deployment of public telephones. Policymakers want information to help them decide where to put limited resources to promote ICT. Also, profit-seeking ICT companies want to know what regions to target to maximize revenues, and whether or not other kinds of ICT companies represent a threat or an opportunity; for instance whether mobile telephone service competes with fixed-line telephone service.

Some regions have low penetrations of ICT products or services because people choose not to use a given type of ICT, while other regions have low penetrations because providers do not make the products or services as widely available in these regions. Other studies have tried to determine what factors are highly correlated with the penetration of ICT without considering how many households in the region have access to ICT if they want it. This study breaks up "access to" (availability of) ICT from "penetration of" ICT in those areas where the service is available. As a result, it is possible to observe that some factors are correlated with ICT penetration because they are indicative of choices made by individuals and

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0308-5961/$ - see front matter
doi:10.1016/j.telpol.2010.12.010

households, while other factors are correlated because they are indicative of choice made by service-providers to build out infrastructure.

The goal of this study is to provide information that helps both profit-seeking ICT companies and policymakers to answer these questions:

(1) What villages should profit-seeking companies offer ICT service to?
(2) What public policies are useful in expanding penetration of ICT service?
(3) To what extent do different kinds of ICT substitute for or complement each other?

This study analyses village-level data of rural Thailand in 2004, with variables associated with each village related to ICT penetration, geographic, and demographic information. The ICT considered consists of fixed-line telephone service, mobile telephone service, public telephones, computers, and Internet service. Linear and logistic regression models, regression trees, and factor analysis are used to study relationships between penetration of each type of ICT, access to each type of ICT, and a variety of demographic and geographic indicators. The study applies Two-Stage Least Squares regression (2SLS) to assess the extent to which different kinds of ICT substitute for or complement each other. Finally, the propensity scores technique is applied to predict penetration of ICT that could be achieved in the villages that do not currently have access, if the infrastructure were built out.

Section 2 discusses studies about predictors of ICT penetration, and substitution effects between mobile and fixed-line telephone. Background information about ICT in Thailand is presented in Section 3. The data set and research methodology are discussed in Section 4. After presenting results in Section 5, the policy implications for both profit-seeking ICT companies and policymakers are discussed in Section 6.

2. Literature review

Section 2.1 discusses various demographic and geographic predictors of ICT penetration in many studies. Section 2.2 discusses studies that investigate whether mobile and fixed-line telephone services are complements or substitutes.

2.1. Predictors of ICT

The ICT considered in this study is fixed-line telephone service, mobile telephone service, public telephones, computers, and Internet service. Studies about determinants or predictors of ICT penetration are conducted at different levels; countries or regional, and individuals or households level. This section gives a brief overview of predictors of each kind of ICT in different levels of study.

Fixed-line telephone service: Income has been found in many studies, using both household and national level data, as an important factor in predicting penetration of fixed-line telephone service. Torero and Braun (2006) surveyed rural households of China and found that annual household income is a predictor of fixed-line telephone penetration. Household income is suggested in Hudson (2006) as an indicator of willingness to pay for the service in developing countries. Using cross-country analysis, Torero and Braun (2006) and Norris (2001) found that a nation's per capita Gross Domestic Product (GDP) is an important predictor of fixed-line telephone penetration. Additionally, Torero and Braun (2006) found the education level of the household head, economic development of the area, and distance from household to the main road to be other predictors of fixed-line telephone penetration.

Mobile and public telephone service: Income is also a predictor of mobile and public telephone penetration. Using national level data, Norris (2001) and Torero and Braun (2006) found that a nation's GDP per capita is a good predictor of nationwide penetration of mobile telephone service. Based on data from 46 developed and developing countries, Kauffman and Techatassanasoontorn (2005) applied different diffusion models and found that Gross National Product (GNP) and telecommunications infrastructure are determinants of mobile telephones penetration. In rural households of Peru and Ghana, the study from Torero and Braun (2006) found that usage of public telephones can be predicted by education level of the household head, household income, and distance from a household to the public telephone.

Computers and Internet service: Using household and national level data, many studies commonly found that education, income, and age are important predictors of computer and Internet penetration. At the household level, the National Telecommunications and Information Administration (NTIA, 2001) found that household income, education level, and age of the household head are useful predictors of computer and Internet penetration in the US. A study from the Organization for Economic Cooperation and Development (OECD, 2000) and Norris (2001) concluded that penetration of computers is predicted by income, education, and age in OECD countries. At the national level, Torero and Braun (2006) and Hargittai (1999) found that per capita GDP is a useful predictor of computers and Internet penetration. Other studies also found gender (Pew, 1999), household size (OECD, 2000), and penetration of televisions and radios (Norris, 2001) as useful predictors of computer and Internet penetration.

2.2. Substitution and complement between fixed-line and mobile telephone services

Numerous studies have tried to assess the extent to which mobile telephone service and traditional fixed-line telephone service are substitutes or complements. A report from the International Telecommunications Union (ITU, 1999) concluded that mobile telephone is a complement to fixed-line telephone service in developed countries, but a substitute service in developing countries.

Consistent with ITU (1999), Vagliasindi, Guney, and Taubman (2006) found using country level data from developing countries across Eastern Europe and the Former Soviet Union that mobile telephone is a substitute for fixed-line telephone service. However, using national level data of 23 developing African countries, Hamilton (2003) found that mobile telephone is a complement to fixed-line telephone service. Even in studies of many developed countries, results are different from ITU (1999). Using provincial level data of Korea, Sung, Kim, and Lee (2000) found evidence that mobile and fixed-line telephone services are substitutes. They reached this conclusion because of the positive correlation between the decision to subscribe to a mobile telephone service and the disconnection of fixed-line telephone service. Rodini, Ward, and Woroch (2003) and Ward and Woroch (2004) both analyzed household level data of the US and found that the two telephone service are substitutes. However, Phonenix Center (2004) analyzed the same data set as Rodini et al. (2003) and found the opposite result that mobile telephone service is not a competitor of fixed-line telephone service. Through many studies, the extent to which mobile and fixed-line telephones are complements or substitutes is inconclusive.

3. Background of ICT in Thailand

3.1. Telecommunication sectors

There were 3 providers of fixed-line telephone service in 2004. The TOT Public Company (originally Telephone Organization of Thailand), a government-owned incumbent, provided service throughout the country. After the privatization attempts during 2002–2006, TOT is currently a profit-seeking company that is partially owned by the government. The other two private companies, Thai Telephone and Telecommunication Public Company (TT&T) and True Corporation Public Company (TRUE), provided service in rural and Bangkok metropolitan areas, respectively.

The providers of fixed-line telephone service also provide public telephone service through payphone booths. TOT is the main provider of this service throughout the country while TT&T and TRUE are granted licenses to provide the service in some parts of the country. In rural Thailand, only TOT and TT&T are competing in fixed-line telephone and public telephone services.

The mobile telephone sector has many providers and intense competition. The providers were usually granted licenses to provide service throughout the country. In 2004, there were about 5 mobile providers in the market; all are privately owned. About 2–3 providers claimed to have coverage areas throughout the country and then competed in all those areas.

There were more than 10 Internet service providers throughout the country. Most Internet users relied on a dial-up connection via fixed-line telephone service. TOT offered free Internet dial-up connections, users paid only local telephone call charges for 2 hours online service, through its fixed-line telephone lines in every province.

As part of several rural development projects in the past, public telephones were installed in rural areas of Thailand by TOT and TT&T even in areas that were not expected to be profitable. On the other hand, providers of fixed-line telephone and mobile telephone services were attempting to maximize profit. Sellers of computer products were also profit-seeking companies. Except for TOT which provided free Internet services to its fixed-line telephone subscribers, other Internet Service Providers (ISPs) were also attempting to maximize profit.

3.2. Price and penetration of ICT

In 2004, there were 7 million subscribers of fixed-line telephone service, 17 million subscribers of mobile telephone service, 12 million computer users, and 7 million Internet users. While 2/3 of the Thai population lives in rural areas, the penetration of ICT is far lower than urban areas, as shown in Table 1. For example, the urban areas have nearly 3 times higher penetration of Internet than rural areas.

Although the price of a given ICT service may differ across providers, each provider applies an identical price scheme throughout the country. For example, TOT and TRUE offer different packages of fixed-line telephones to subscribers. However, the price of fixed-line telephone service offered by TOT is the same in all regions of Thailand. For this reason, regional differences in penetration reflect regional differences in demand.

Table 1
Penetration of ICT in Thailand 2004.
Source: The National Electronics and Computer Technology Center (NECTEC, 2004).

ICT	Urban	Rural	Total	Unit
Fixed line telephone			10.10	Numbers/100 inhabitants
Mobile telephone	41.91	21.48	28.24	Numbers/100 inhabitants
Public telephone	0.17	0.13	0.30	Million booths
Computer	33.20	15.56	21.40	Users/100 inhabitants
Internet	21.44	7.19	11.89	Users/100 inhabitants

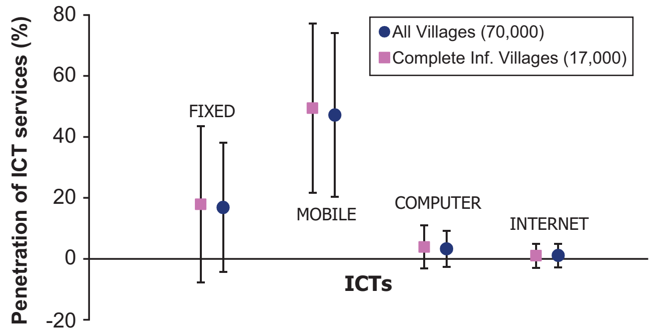

Fig. 1. Comparison of ICT penetration between all villages (70,000) and complete information villages (17,000). *Note*: The error bars show 1 standard deviation from mean values.

The actual prices of ICT service in 2004 are as follows. In both fixed-line and mobile telephone service, the calling party pays all charges. Subscribers of fixed-line telephone service pay monthly subscription charges and each local call costs 3 Thai bahts (THB) with unlimited calling time.[1] Mobile phone subscribers have a choice of either prepaid or postpaid service. The charge for a local call on a public telephone is 1THB for 3 minutes. A desktop computer costs about $250. Users can connect to the Internet using a prepaid Internet package, which costs about 10THB for 1 hour of dial-up connection (not including the telephone connection charge). Compared to the US, ICT services in Thailand cost a higher fraction of per capita GDP.

4. Research methodology

4.1. Data set and variables of interest

All results presented in this study are based on a census of Thailand's rural villages conducted by survey in 2004. This survey of all villages in rural areas was conducted by the National Statistical Office of Thailand (NSO, 2004).[2] The total number of surveyed villages is about 70,000, which accounts for 11 million out of 16 million households of Thailand. The villages not surveyed are located in urban metropolitan areas such as Bangkok.[3] The survey form was distributed to every district and subsequently to every village under the district supervision. The form was to be filled out by either the head of each village, or the staffs at the district level for the district that contains this village. 20% of the surveys were filled out by the head of village and 80% were filled out by district staffs. The fact that the survey form was filled out by people who do not necessary have perfect knowledge on all the survey's hundreds questions should add some noise to the resulting data.

For each rural village, more than 200 variables representing geographic, demographic, and other characteristics were surveyed. This included data about availability and penetration of ICT services. This study analyzes penetration of 5 ICT services: fixed-line telephone, mobile telephone, public telephone, computer, and Internet connection. While the penetration of public telephone service is measured by the number of payphone booths per 1000 people, penetrations of other ICT were defined as percentage of households in a village with such ICT services. This study also addresses the availability of telephone services by defining three binary variables representing the existence in a village of fixed line, mobile, and public telephone.

Out of all 70,000 villages in rural Thailand, only 17,000 villages have no missing information. This study used the listwise deletion technique (Little & Rubin, 1987) to exclude observations with missing values. This has little impact on results, provided that the villages with complete information are not significantly different statistically from the entire set of villages, which is the case for the data set used in this study. For example, the mean ICT penetration is statistically similar in all 70,000 villages and the 17,000 villages with complete information, as illustrated in Fig. 1. Table 2 shows that the coefficients of correlation between variables in both data sets are nearly identical in magnitude, sign, and statistical significance.

The Thailand Department of Labor has categorized provinces into 14 different groups reflecting their economic development to determine the minimum daily wage. Survey data is supplemented with the variable CITY_DEV, which reflects the province's economic development. CITY_DEV is an ordinal variable ranging from 1 to 14; 1 is the least developed and 14 is the most. Table 3 presents statistics of selected villages. On average, about 18% and 52% of households in the village have fixed-line and mobile telephone, respectively.

Table 4 shows the availability and penetration of ICT in the selected data set. Fixed-line telephone and public telephone is available in nearly 75% of the areas while mobile telephone is widely available in more than 98% of the villages.[4] Internet

[1] The estimated currency conversion in 2004 was 40THB = 1USD.

[2] "Village", the lowest level of hierarchical administration of Thailand's governance, is usually a group of 100–500 households in the same geographical region.

[3] According to the Urbanization Act of Thailand 1953, an "urban area" is any area with high population and population density. The designations have been updated over time. "Rural areas" are those areas that are not urban.

[4] In order to decide if fixed-line or mobile telephone is available in a specific village, the study observes if there is any household in the village subscribing to the services. The telephone service is assumed to be unavailable in the village if no household in the village subscribing to it.

Table 2
Example of comparison between the correlation matrix of all villages (70,000) and complete information villages (17,000).

	(A) 70,000 villages					(B) 17,000 villages					Difference=|A–B|				
	FIXED	MOBILE	PAYPHONE	COMPUTER	INTERNET	FIXED	MOBILE	PAYPHONE	COMPUTER	INTERNET	FIXED	MOBILE	PAYPHONE	COMPUTER	INTERNET
FIXED	1					1					0				
MOBILE	**0.38**	1				**0.37**	1				0.01	0			
PAYPHONE	0.05	0.02	1			0.03	0.02	1			0.02	0.00	0		
COMPUTER	**0.42**	**0.27**	0.05	1		**0.39**	**0.24**	0.05	1		0.03	0.04	0.00	0	
INTERNET	**0.37**	**0.21**	−0.01	**0.74**	1	**0.32**	0.16	0.02	**0.73**	1	0.05	0.04	0.02	0.01	0
AGE	**0.26**	**0.20**	0.03	0.17	0.13	**0.27**	0.16	−0.01	0.15	0.10	0.01	0.04	0.04	0.02	0.03
EDU_COLLEGE	**0.27**	**0.19**	0.02	**0.25**	**0.20**	**0.36**	**0.23**	0.00	**0.37**	**0.29**	0.08	0.04	0.01	0.11	0.09
INCOME	**0.19**	**0.23**	0.05	0.17	0.15	**0.21**	**0.25**	0.01	0.18	0.14	0.01	0.02	0.04	0.00	0.01
POP_DENT	0.18	0.07	−0.01	0.14	0.12	**0.26**	0.11	−0.01	**0.21**	0.19	0.07	0.04	0.00	0.08	0.07
DISTANCE	−**0.22**	−**0.20**	0.01	−0.15	−0.12	−**0.26**	−**0.21**	−0.02	−0.16	−0.12	0.04	0.01	0.03	0.01	0.01
CITY_DEV	**0.35**	**0.24**	0.01	0.18	0.18	**0.39**	**0.27**	0.00	**0.22**	0.19	0.05	0.03	0.01	0.04	0.01

Note: All coefficients of correlation are statistically significant at alpha=0.05.

Table 3
Descriptive statistics (per village) of various variables in complete information villages (17,000 villages).

	Variable	Definition	Mean	Std. dev.
1	FIXED	Percentage of households with fixed line telephone	17.94	25.57
2	MOBILE	Percentage of households with mobile telephone	52.24	27.73
3	PAYPHONE	Number of public telephone (booth per 1000 population)	4.03	12.36
4	COMPUTER	Percentage of households with computer	3.92	7.06
5	INTERNET	Percentage of households with Internet connection	1.05	3.93
6	AGE	Mean age of population (years)	22.66	2.62
7	EDU_COLLEGE	Mean percentage of population with education beyond high school	5.89	6.01
8	INCOME	Mean annual households income of population ($1000)	2.10	1.71
9	POP_DENT	Population density (person per 1600 m^2)	0.40	0.78
10	DISTANCE	Distance of village from the nearest city (kilometers)	46.41	39.14
11	CITY_DEV	Development level of a province that contains the village	4.76	3.27
12	TRUCK	Number of pickup truck (per 100 households)	18.91	21.15
13	TV	Percentage of households with television	90.98	14.91
14	RADIO	Percentage of households with radio	62.92	32.25
15	AGRICULTURE	Existence of agriculture as one of the three most common careers	0.96	0.19
		Total number of villages in the data set	16,837	

Table 4
Availability and penetration of ICT in complete information villages (17,000 villages).

Descriptive statistic of ICT in general (Dec 17, 2007)					
Variable	Service availability		Service penetration		Penetration (only area having service)
	% Villages	# Villages	% HH	# HH	% HH
FIXED	74.76	12,587	17.94	400,000	24.00
MOBILE	98.37	16,562	52.24	1,250,000	53.11
PAYPHONE	76.37	12,859	4.03 booth/1,000 people		5.28 booth/1000 people
COMPUTER	All villages		3.92	75,000	3.92
INTERNET	Same as FIXED		1.05	25,000	1.36
TV	99.85	16,811	90.98	2,200,000	91.11
RADIO	98.40	16,562	62.92	1,500,000	63.94
ELEC	99.23	16,686	95.99	2,300,000	96.74
Total	100.00	16,837	100.00	2,400,000	100.00

connection is available in any place with fixed-line telephones. Generally, the ICT penetration is higher when considering only the areas where such service is available, for instance penetration of fixed-line telephone is 24% in areas where service is available, as compared to just 18% averaged over all surveyed villages.

In this study, the market penetration of fixed-line telephone, mobile telephone, computer, Internet, and the penetration of public telephone are transformed when they are used as a dependent variable of the regression model. Because these variables are market penetrations (percentage between 0 and 100), the study performs the odd-ratio transformation:

$$x' = \ln[(x+c)/(100-(x-c))]$$

while x' and x is the transformed and original variable, respectively, and c is a small constant. The sensitivity analysis of using different c values has been conducted, using values of c from 0.0000001 to 0.1. Results of the study are robust with different c values. As a result, a constant 0.01 will be used.

4.2. Identification of important predictors

One goal of this study is to identify a small set of village characteristics that are most important in predicting use of ICT, where "use of ICT" could mean access to or penetration of any given type of ICT. For example, if a company or policy-maker wanted to estimate how many homes would subscribe to the Internet in a given area if the service became available, these would be the most useful characteristics to examine. This study compares the predictive power of all available variables to identify the best predictors, and then shows how the best set of predictors differs from one type of ICT to another. Many researchers use statistical significance as an indicator of importance, but they are not the same. The importance of a variable does not depend on how many times it is sampled, but statistical significance does. In this study, because the data set is large, hundreds of variables are correlated with ICT use at a statistically significant level, and they cannot all be among the most important.

There is no universally accepted definition of an important predictor, so one will be defined for this paper, based on the following observations. First, an important predictor should be strongly correlated with the dependent variable, which in this case is some measure of the use of ICT. However, a strong correlation alone is insufficient. For example, if the two variables with the strongest correlations are also correlated with each other, then predictions made with these two variables might be far worse than predictions with one of these variables and with some other variable. Thus, to be an important predictor, a variable should also appear within one or more of the small sets of variables that are best for predicting the dependent variable, where this predictive power can be measured by the R^2 of regression models. Finally, if a set of n variables has high predictive value, then adding a fairly useless variable will yield a set of $n+1$ which also has high predictive value. Thus, when defining an important predictor, one must also consider whether removing it from a set of other variables significantly decreases R^2 of the set.

Specifically a variable meets the definition of "important" if and only if its correlation with ICT is higher than 0.2, and it appears in at least one "important multivariate set". A multivariate set meets the definition of important if and only if its R^2 is in the top-3 among other sets using the same number of predictors and no variable in the set can be removed without decreasing its R^2 by at least 10%. The numerical thresholds used in this study are somewhat arbitrary, but setting specific thresholds makes it possible to quantitatively and qualitatively separate the few variables with the greatest impact.

For example, from the correlation matrix, average annual household income [INCOME] and fraction of population with college education [EDU_COLLEGE] are both correlated with fixed-line telephone penetration [FIXED]. With the discussed definition of importance, EDU_COLLEGE is an important predictor of FIXED while INCOME is not. While INCOME is also a predictor of FIXED, it is EDU_COLLEGE that enables the best predictions possible with this data set, and INCOME is valuable primarily because it is correlated with EDU_COLLEGE. The definition of important predictor is partially a function of which data is available. INCOME could become an important predictor of FIXED if data about EDU_COLLEGE is not available.

Information about age, education, and income were categorically collected in different ranges of values indicating distributions of population and household. For example, income of village is collected as number of households having annual household income in different ranges. Because part of the research questions focuses on comparing the predictive power of different predictors, the study chooses to represent these categorical data as a "single" variable, i.e. there would be only 1 variable representing education level of people in each village.

Based on the past literature, one expects to see correlation between penetration of ICT and demographic/geographic characteristics of the village. This study hypothesizes that income and education characteristics are highly correlated with and will be important predictors of ICT penetration (NTIA, 2001; Torero & Braun, 2006). It is also hypothesized that age and distance to the city will be important predictors of ICT (Norris, 2001; Torero & Braun, 2006). Similar to many studies of developing countries as discussed in literature review section, this study hypothesizes that mobile and fixed-line telephone service share the same pool of customers and eventually become substitutes for each other (Rodini et al., 2003; Ward & Woroch, 2004).

5. Results

Results of the study are elaborated in 5 sections. Section 5.1 discusses choosing single variables; each represents information about age, education, and income. Section 5.2 describes how regression models, regression trees and factor analysis are used to study the relationship between penetration of each type of ICT, access to each type of ICT, and a variety of demographic and geographic indicators. Section 5.3 applies Two-Stage Least Squares (2SLS) to explore whether different kinds of ICT substitute for or complement each other. Using the propensity scores technique, Section 5.4 predicts ICT penetration that could be achieved in villages that do not currently have access, if the infrastructure were built out.

5.1. *Choosing "single" categorical variable*

As discussed in Section 4.2, a single variable representing categorical data can be calculated in many ways; for instance information about the age of population can be represented by average age, fraction of people whose age exceeds a certain number (i.e. age higher than 20 years), or even fraction of people within a specific range of age (i.e. age between 15 and 25 years). This study defines the best single-variable to be the one with the highest correlation with ICT compared to other single variables. The study found mean age [AGE], fraction of population with education beyond high school [EDU_COLLEGE], and mean annual household income [INCOME] to be the best single-variables for age, education, and income, respectively.

5.2. *Important predictors of ICT*

The important predictors (as defined in Section 4.2) of access to and penetration of ICT are identified in Table 5 using logistic and linear regression. Access to fixed-line, mobile, and public telephone along with penetrations of fixed-line, mobile, public telephone, computer, and Internet in areas that each ICT is available are studied.

The important predictors are ranked in importance, where a variable is the most important predictor in a multivariate set if and only if the R^2 of this set decreases most when the variable is removed. For example, among all identified important predictors of fixed-line telephone penetration [FIXED], the penetration of pickup truck [TRUCK] is the most important and it is positively correlated with FIXED.

Table 5
Important predictors of ICT.

	Penetration of					Access to		
	FIXED	MOBILE	PAYPHONE	COMPUTER	INTERNET	Bin_FIXED	Bin_MOBILE	Bin_PAYPHONE
1. EDU_COLLEGE	3+			1+	1+	2+		
2. POP_DENT	5+			3+		1+		
3. CITY_DEV	2+	3+						
4. DISTANCE	4–					3–		
5. TRUCK	1+	2+		2+	2+			
6. TV		1+						
7. AGRICULTURE					3–			
8. RADIO		4+						
9. INCOME		5+						

Note: The signs show direction of relationship with ICT and numbers show ranking of predictive power.

5.2.1. Penetration of ICT

The fraction of population with education beyond high school [EDU_COLLEGE] is an important predictor of fixed-line [FIXED], computer [COMPUTER], and Internet penetration [INTERNET]. The results are consistent with this study's hypothesis and other studies (Norris, 2001; NTIA, 2001; OECD, 2000; Torero & Braun, 2006). This could mean that a village with a more educated population uses more ICT, or that higher use of ICT somehow leads to a more educated population, or that there are uncontrolled factors related to both education and ICT penetration. While this numerical result alone cannot precisely indicate which possibility is correct, the most likely is that an educated population uses more ICT. Using this information, fixed-line telephone and computer providers might market their products and promotions in areas where universities or colleges are located (high population with post high school education).

Contrary to the hypothesis in Section 2 and what was found by several studies (Hudson, 2006; NTIA, 2001), income is not an important predictor of ICT penetration, except the penetration of mobile telephone [MOBILE]. In part, this is because income is correlated with education and education seems to matter more in the prediction of ICT penetration. While affordability may still be a factor, this implies that subsidizing the cost of ICT services (e.g. fixed-line telephone or Internet) may not result in as large an increase of ICT penetration as policymakers might expect.

Interestingly, the number of pickup trucks per 100 households [TRUCK] is among the most important predictors of ICT penetration. To the best of knowledge from reviewed literatures, this has never been identified as a predictor of ICT penetration before. As a traditional vehicle in rural Thailand, people use trucks to travel outside the village. Although there is insufficient information to conclusively prove causality, this study hypothesizes that people who travel outside a village are also more likely to use ICT to communicate outside the village. Further research with additional data is encouraged to test this hypothesis.

Another surprising result is that the penetration of television [TV] and radio [RADIO] are among the most important predictors of MOBILE, although not for other ICT services. Further research may be needed to explain this.

Among several main occupations of people in rural Thailand (such as agriculture, labor, small business), the only occupation that is important in determining penetration of ICT in the study is agriculture. A binary variable representing agriculture as one of the three main occupations of population [AGRICULTURE] is one of important predictors of INTERNET with negative relationship. Even when correcting for other factors, the 4% non-agricultural villages still experience higher penetration of Internet than their counterparts.[5]

While causality can go either way, the correlations between the important predictors and ICT penetration more likely mean that change in demographic and geographic characteristics of the village leads to change in ICT penetration, and not the other way around. This implies that the important predictors of ICT penetration indicate the demographic and geographic characteristics of those individuals who would want to subscribe. There are similarities in the characteristics of those who are more likely to subscribe to fixed and mobile service, i.e. they are both in villages with higher levels of development and more trucks, but there are also important differences. While penetration of fixed-line telephone service is higher in areas with high education and population density that are located near the city, the penetration of mobile telephones telephone service is higher in areas with high penetration of television, radio, and high income. While it is not definitive, this is consistent with the hypothesis that when both services are available, the respective service-providers may be drawing from different pools of customers.

The number of public telephone booth per 1000 people [PAYPHONE] has no important predictor in the study. If the number of telephone booths in each village is a proxy variable indicating the usage of public telephones, then this is a useful result. For example, it would indicate that factors such as household income are not significant when predicting usage, as one might expect. However, it is unclear whether payphone penetration is a sufficiently good proxy for usage, particularly given

[5] 96% of the villages have agriculture as one of their three main occupations, shown in Table 2.

that the decision regarding the number of payphones per village may not have been made to maximize profit when TOT was a government-run monopoly.

As hypothesized, the distance to the city is an important predictor of fixed-line telephone penetration. Contrary to the hypothesis in Section 2 and what was found in many studies (Norris, 2001; NTIA, 2001; OECD, 2000), the average age of a population is not an important predictor of the penetration of any type of ICT.

It should be noted that the list of predictors of ICT penetration considered in this survey is large but not exhaustive, so there may be some important predictors that are not listed in Table 5. For example, the authors have shown in other work (Tengtrakul & Peha, 2010) that greater levels of computer and Internet penetration in the home can be expected in those cities that have made computers and Internet available in schools, especially primary schools.

5.2.2. *Access to ICT*

Important predictors of access to ICT (whether each ICT service is available in the area) help explain how ICT providers chose to build out their infrastructure in the past. In theory, the correlations between important predictors and access to ICT shown in the regression models could mean that these demographic and geographic characteristics affect the decisions of ICT providers to build out their infrastructure, or the availability of ICT causes changes in characteristics of the village, or that there are uncontrolled factors related to both village's characteristics and the access to ICT. The paper assumes the former; it is clear that ICT providers can and do use such information to increase profits.

Access to mobile telephone [Bin_MOBILE] has no important predictor, perhaps because mobile phones are already available in more than 98% of the villages, as shown in Table 4. The access to public telephone [Bin_PAYPHONE] also has no important predictor. It appears that no factor including income is a good predictor of where public telephones will be available. Again, this may be because in the past, public telephones were deployed based on motivations other than profit.

Only access to fixed-line telephone [Bin_FIXED] has important predictors. By separating availability from the penetration of ICT, it is possible to see that population density [POP_DENT] is the most important predictor of access to fixed-line telephone while it is less important when predicting penetration of fixed-line telephone. This is to be expected based on the engineering-economics. When fixed-line telephone providers made the decision to invest in the infrastructure for the first time, areas with high population density were most likely to be selected because they potentially have lower costs (per subscriber) of providing the service. Although the numerical results are also consistent with the hypothesis that access to infrastructure leads to increased population, the former effect is likely to be much larger. Interestingly TRUCK and CITY_DEV, which are most important in predicting penetration of fixed-line telephone, are not indicative of choices made by the providers to build out infrastructure.

As described in Section 1, many researchers have used a similar regression analysis to predict ICT penetration, but they examined large geographic areas in which some but not all households have access to ICT. Because the predictors for penetration of ICT and access to ICT can differ, as shown in Table 5, a failure to separate the two may yield misleading results.

5.2.3. *Regression tree*

While important predictors of ICT are identified in Table 5 using linear and logistic regression models, the relationships between ICT and observed variables are not all linear. The regression tree helps explore such possible non-linear relationships. De'ath and Fabricius (2000) explains the regression tree as a binary tree that repeatedly splits data into more homogenous groups based on combinations of explanatory variables. Each group is categorized by the value of a dependent variable, the number of observations in the group, and the values of the explanatory variables that define the split. Fig. 2 illustrates how regression tree works. At each split (nonterminal node) the data is partitioned into two mutually exclusive groups, each of which is as homogeneous as possible. The maximum homogeneity of data in each node is achieved by minimizing sum of squared deviations from a mean of the dependent variable in the node. Each nonterminal node is in a rounded rectangular shape and labeled with an explanatory variable, its value that determines the split, and the split condition. The numbers of data that meet and miss the split condition are shown on the left and right branch of the node, respectively. The splits continue on each group separately until stopped by a user-defined condition, such as when data in a node is less than 10 observations. The leaves (terminal node) are in rectangular shape and labeled by the mean value of the dependent variable computed from observations in the node.

The overall effectiveness, optimality, and reliability of the tree are examined by a tree pruning technique called "V-fold cross-validation". Pruning a tree is done by first growing the tree as large as possible (or until a user-defined condition is met), and then pruning back each terminal node to its parent node from the bottom of the tree to the root node. The effectiveness of a tree is calculated as its prediction errors or sum of squared differences of the observations and predictions. Breimen, Friedman, Stone, and Olshen (1984) showed that for each tree size (number of leaves), there is a unique smallest tree that minimizes prediction errors. As a result, for each regression tree, one can prune back and find a sequence of trees, each of which is the best of its size. The V-fold cross-validation divides data into 'V' mutually exclusive subsets; each subset is as equal in size as possible. A subset is then omitted while the remaining subsets are used to construct a regression tree with different tree sizes. The constructed tree of each size is used to predict a dependent variable of the omitted subset and compute its prediction errors. Then, the process continues by omitting a next subset of data, using the remaining subset to construct trees with different sizes, and calculating prediction errors of the omitted subset. Eventually, an estimated error rate for each size of tree is a sum of prediction errors over all subsets. Even though the best tree can simply be the tree with the smallest estimated error rate, Breimen et al. (1984) suggested that the "1-SE rule" should be applied. While a standard error of estimation for each

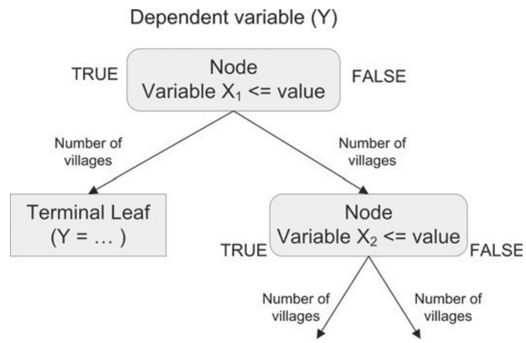

Fig. 2. Example of how regression tree works.
Source: Modified from Green (2008).

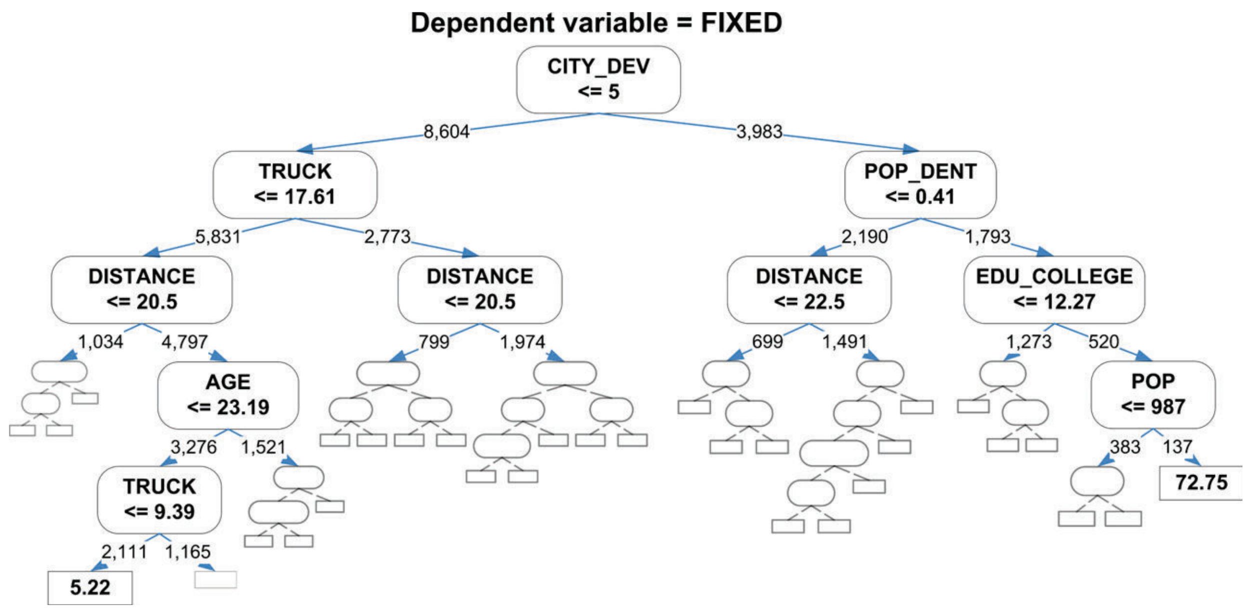

Fig. 3. Regression tree to predict penetration of fixed-line telephone. Only parts of the tree are elaborated.

tree size can be calculated, the optimal tree is the smallest tree of which its estimated error rate is within one standard error of the minimum. Statistical details of regression tree can be found in Breimen et al. (1984) and De'ath and Fabricius (2000).

This study applies regression tree to predict penetration of fixed-line telephone, mobile telephone, computer, and Internet service using demographic and geographic variables. Using the 10-fold cross-validation technique, an optimal tree of each ICT can be constructed.[6] The regression tree to predict penetration of fixed-line telephone is partially presented in Fig. 3. The regression tree technique can reveal predictors that only matter in some regions (branches of the tree), which is not possible using linear or logistic regression models. Examples of interesting results are followings:

- Total population of the village [POP] is a good predictor of fixed-line telephone penetration in villages with high development, but not in villages with low development.
- Penetration of radio and television [RADIO and TV] are good predictors of fixed-line telephone penetration only in villages with low development.
- Penetration of motorcycle [MOTORCYCLE] is a predictor of mobile-telephone penetration only in areas where penetration of pickup truck is low (specifically lower than 30). This result may be consistent with the hypothesis that those who travel more to other villages are more likely to use ICT to communicate with other villages. As hypothesized, the penetration of trucks may be a measure of how many people travel in those villages where the penetration is high. However in areas with few trucks, the penetration of motorcycles may be a useful indicator of the number of people who travel.

[6] In particular, the study stops splitting the tree when number of villages in the node is less than 100 villages. Then, the tree is pruned back to find the best tree of each tree size. Eventually, 10-fold cross-validation is applied with "1-SE" rule to find the proper tree.

Table 6
Factor analysis of predictors of ICT penetration retaining three factors.

Predictors of ICT penetration (Total variance explained: 46.1%)	Factor 1 "Cultural Opportunity"	Factor 2 "Urbanization"	Factor 3 "Wealth"
1. AGE	**0.654**	−0.075	0.040
2. DISTANCE	−**0.600**	−0.311	0.109
3. TV	**0.560**	−0.081	0.178
4. RADIO	**0.519**	0.084	0.327
5. EDU_COLLEGE	**0.438**	0.326	0.231
6. POP_DENT	0.074	**0.781**	0.014
7. AGRICULTURE	−0.014	−**0.741**	−0.118
8. TRUCK	0.169	−0.035	**0.674**
9. INCOME	0.095	0.023	**0.658**
10. CITY_DEV	0.042	0.358	**0.620**
Eigenvalues (percentage of variance explained)	2.372 (23.7%)	1.234 (12.3%)	1.001 (10.1%)

Note: Bolding indicates the clear factor loading on each factor.

Another useful aspect of regression trees is that they reveal characteristics of villages that experience low or high ICT penetration. Policymakers can use this information to help them apply public policy to expand penetration of ICT to such areas. The profit-seeking ICT providers can also use this information to help make decisions about where to provide ICT services.

5.2.4. Factor analysis

From preliminary examination of a correlation matrix between variables, predictors of ICT penetration in the study are correlated with each other. It is possible that variables are correlated because they are measuring the same unobserved factor. Factor analysis has been performed to explore the underlying pattern of collinearity among predictors of ICT penetration.

The technique of factor analysis aims to find the minimum number of underlying factors, which explain the maximum amount of the overall covariance of the observed variables. Each factor is a linear combination of observed variables. The correlation between observed variables and factors are calculated (so-called factor loadings), and variables are assigned to the factor in which they are most correlated. Eventually each factor can be interpreted to explain observed variables loaded within it. For more details of the use of factor analysis, see Loehlin (2004).[7]

Table 6 presents the result of factor analysis when three underlying factors are extracted. These factors explain about 46% of overall covariance of the ICT penetration's predictors. Factor 1, highly loaded on AGE, DISTANCE, TV, RADIO, and EDU_COLLEGE may be called cultural opportunity. Factor 2, loaded on POP_DENT and AGRICULTURE is called urbanization. Factor 3 consists of TRUCK, INCOME, and CITY_DEV may account for general wealth of people in the area.

5.3. Substitution and complement between ICT

In this section, a Two-Stage Least Squares regression (2SLS) is applied to determine whether one type of ICT is a complement or substitute for another. This approach is more effective than simply using penetration of one ICT as a dependent variable and another as an explanatory variable, because with this latter approach, there is a danger that the explanatory ICT variable would not be independent of the error term, leading to misleading results. For details of the Two-Stage Least Squares regression techniques, see Wooldridge (2002).

Using only villages in which both services are available, Table 7 shows the relationship between penetration of fixed-line [FIXED] and mobile telephones [MOBILE]. In regression model 1 of the table, FIXED has been predicted using its important predictors; fraction of population with education beyond high school [EDU_COLLEGE], population density [POP_DENT], development level of the city [CITY_DEV], distance from village to the nearest city [DISTANCE], and penetration of pickup truck [TRUCK]. By applying 2SLS regression, penetration of mobile telephones is added as a predictor in model 2. The positive coefficient of MOBILE is evidence that the two services are not substitutes. Indeed the positive paired correlation between MOBILE and FIXED, from correlation matrix in Table 2, shows the possibility that they are complements. While it is possible these telephone services are in fact substitutes but there are uncontrolled factors that affect penetration of the services in ways that make them appear to be complements, the study included all of the services' important predictors in the regression models, making this explanation less plausible. The result is consistent when penetration of mobile telephone is predicted using penetration of fixed-line telephone. Thus, the results agree with what Hamilton (2003) found in developing African countries, but contradict this study's hypothesis and the conclusion of the ITU (1999) described in Section 2.

[7] In particular, the study performs exploratory factor analysis using principal components method of extraction and Varimax rotation. The factors are retained based on Kaiser's rule of eigenvalues and a scree plot.

Table 7
Regression models to study relationship between penetration of fixed-line and mobile telephone using Two-Stage Least Squares (2SLS).

Dependent variable=Penetration of fixed-line telephone [FIXED]		
Predictors	Model 1[a]	Model 2[a]
MOBILE		0.447 (0.447)
EDU_COLLEGE	0.871 (0.203)	0.674 (0.157)
POP_DENT	4.285 (0.138)	3.927 (0.126)
CITY_DEV	1.829 (0.237)	1.260 (0.163)
DISTANCE	−0.099 (−0.140)	−0.060 (−0.085)
TRUCK	0.350 (0.243)	0.183 (0.127)
N	12,498	12,498
Adjusted R^2	0.330	0.345

Note: All regression coefficients are statistically significant at alpha=0.05. Standardized coefficients are in parentheses.
[a] Only villages where both fixed-line and mobile telephone service are available are included.

Table 8
Regression models to study relationship between fixed-line and public telephone.

Dependent variable=Penetration of fixed-line telephone [FIXED]				
Predictors	Model 1[a]	Model 2[a]	Model 3[b]	Model 4[b]
Bin_PAYPHONE		−2.835 (−0.044)		
PAYPHONE				0.036 (0.017)
EDU_COLLEGE	0.872 (0.203)	0.873 (0.203)	0.876 (0.207)	0.876 (0.207)
POP_DENT	4.121 (0.135)	4.188 (0.137)	4.418 (0.153)	4.423 (0.153)
CITY_DEV	1.840 (0.238)	1.820 (0.236)	1.859 (0.239)	1.860 (0.239)
DISTANCE	−0.100 (−0.141)	−0.099 (−0.139)	−0.102 (−0.143)	−0.102 (−0.143)
TRUCK	0.350 (0.243)	0.346 (0.241)	0.347 (0.237)	0.346 (0.236)
N	12,587	12,587	9670	9670
Adjusted R^2	0.329	0.331	0.345	0.346

Note: All regression coefficients are statistically significant at alpha=0.05. Standardized coefficients are in the parentheses.
[a] Only villages where fixed-line telephone service is available, regardless of public telephone service, are included.
[b] Only villages where both fixed-line and public telephone service are available are included.

Regression models in Table 8 predict penetration of fixed-line telephone using its important predictors and variables representing (i) penetration of public telephone booth [PAYPHONE], and (ii) access to public telephone [Bin_PAYPHONE]. While the existence of one or more public telephones in a village slightly decreases the predicted penetration of fixed telephone service, an increase in the number of public telephone booths does not affect the predicted penetration of fixed telephone service (coefficients of Bin_PAYPHONE and PAYPHONE are −2.835 and 0.036, respectively). A public telephone may therefore be a slight substitute for fixed-line telephone service, but the effect is very weak. When predicting penetration of mobile telephone using its important predictors, PAYPHONE and Bin_PAYPHONE, the study also found that existence of public telephone can slightly decrease the penetration of mobile telephone, but an increase in the number of public telephone booths does not affect the predicted penetration of the mobile telephone service. Thus, it is concluded that deployment of payphones probably has only a slight impact on the penetration of fixed and mobile service, so profit-seeking companies can offer the service with little fear of undermining an existing revenue service.

5.4. *Predicted penetration of ICT*

This section predicts the penetration of ICT that would emerge in areas that never before had (i) fixed-line and (ii) public telephone service if the infrastructure became available. It is assumed in this analysis that the demographic and geographic characteristics of a village influence demand for ICT far more than the availability of ICT in a village could influence the demographic and geographic characteristics of that village. The propensity scores method (Rosenbaum & Rubin, 1983) is applied to predict penetration of ICT that could be achieved in the villages that do not currently have access, if the infrastructure were built out. The villages that lack access to ICT and are predicted their potential ICT penetration are called the "treatment group", and the villages where ICT penetration is known are called the "control group". The propensity score technique tries to match each village from the treatment group to a village in the control group that has similar demographic and geographic characteristics. The predicted ICT penetration of the village in the treatment group then equals penetration in the matched village. The characteristics of each village are represented as a "propensity score" which is a conditional

Table 9
Predicted ICT in areas where fixed-line and public telephone service is not available using Propensity Scores.

	FIXED			PAYPHONE		
	Areas w/service	Areas w/o service		Areas w/service	Areas w/o service	
	Observed	Observed	Predicted	Observed	Observed	Predicted
FIXED	24.00	0	12.98	17.25	20.51	19.99
MOBILE	54.79	44.69	44.59	51.65	54.15	54.43
COMPUTER	4.65	1.76	2.62	3.90	3.98	4.38
INTERNET	1.36	0.11	0.56	1.03	1.11	1.14
N (Villages)	12,587	4250	12,859	3978		

probability of a village being in a treatment group given the village's demographic and geographic variables. The propensity scores can be estimated using logistic regression model.[8] For more details of propensity scores technique, see Rosenbaum and Rubin (1983) and Dehejia and Wahba (2002).

Table 9 shows observed and predicted penetration of fixed-line and public telephone service both in the areas with and without the services. From the 17,000 villages selected in this study, fixed-line telephone service is available in 13,000 villages with penetration of 24%. In areas without fixed-line telephone service, penetration of the service is predicted to be 13% of households if the service was available. Thus, there appears to be significant unmet demand for telephone service in Thailand where the infrastructure does not yet exist, but not surprisingly, the infrastructure had been deployed in areas that expect to have almost twice the penetration on average than those areas without service.

If public telephones were deployed in areas that never had a public telephone before, penetration of both fixed-line and mobile telephone service is predicted to just slightly change. Consistent with the results found in Section 5.3, existence of public telephone service does not have a large effect on penetration of other telephone services.

From Table 9, penetration of both computer and Internet penetration is predicted to increase if fixed-line infrastructure were available in areas that never had it. Given that one of the main reasons of purchasing a computer is to connect to the Internet if fixed-line telephone service is available in the area, these additional predicted households are assumed to use fixed-line telephone to connect computer to the Internet via dial-up connection.

However, in areas where fixed-line telephone service is available, 70% of households that have a computer use it as a standalone computer without connecting to the Internet (4.7% of households have computer but only 1.4% households connect to the Internet). Moreover, even in the areas where fixed-line telephone service is not available, 1.8% of households still have computers. The computers are used in other offline purposes besides connecting to the Internet. NSO (2004) reported that education is the main purpose of computer use in Thailand, which may indicate that educational uses of computers in Thailand today do not make much use of the Internet.

6. Discussion and policy implications

6.1. Results useful to profit-seeking companies

6.1.1. Villages where companies should focus

The important demographic and geographic predictors, identified in Table 5, allow this study to identify villages where ICT penetration is likely to be high, if that ICT is available. Profit-seeking providers may consider these factors as they decide where to extend infrastructure. Penetrations of pickup trucks and televisions are found to be important predictors that have not been previously reported. While the penetration of pickup trucks can be a representative of wealth, one can also hypothesize that people who travel outside their village are more likely to subscribe to ICT services to communicate with people outside their village.

At least for fixed-line telephone, computer and Internet, education has been shown to be more important than income. Income appears to be relatively unimportant because it is correlated with education, and it is education that is more important in predicting ICT penetration. Targeting these ICT services to areas with a more educated population may be a good alternative to targeting areas with high income.

By separating availability from penetration of ICT, the study found that they can have different predictors, which means that researchers who do not separate availability from penetration may get misleading results. For example, a population

[8] "Propensity score" of each village, $p(x_i)$, is calculated as the probability of a village ith being in the treatment group is as follows:

$$p(x_i) = \Pr(z_i = 1 | x_i)$$

where z_i=1(=0) if the ith village was assigned to treatment (or control) group. For example, villages without access to fixed-line telephone service are assigned to the treatment group while villages with access to the service are assigned to the control group. The x_i is a vector of observed demographic and geographic indicators of the ith village. The propensity matching scheme in this study is a "replacement matching using nearest neighbor" which allows each village in control group to be matched more than once by villages from the treatment group.

density is the best predictor of whether fixed-line telephone infrastructure has been built out in a given village in the past, but it is only the fifth best predictor of penetration of fixed-line telephone service in villages where this service is available. Thus, analysis that does not explicitly consider where the service is available would overestimate the importance of population density on the demand for fixed-line service. Many researchers have adopted this practice when comparing ICT penetration based on national statistics that do not consider the extent to which a service is available. Similarly, some researchers have been speculating about why demand in rural and urban areas in the US would be sufficiently different to explain the fact that the percentage of rural households that subscribe to broadband is a third lower than urban households; they forget that roughly a third of rural households in the US do not have access to broadband (Peha, 2008).

There are similarities in the characteristics of those who are more likely to subscribe to fixed and mobile service, i.e. they are both in villages with higher levels of development and more trucks, but there are also important differences. While penetration of fixed-line telephone service is higher in areas with high education and population density that are located near the city, the penetration of mobile telephones telephone service is higher in areas with high penetration of television, radio, and high income.

6.1.2. Other ICT, threat or opportunity

There is no evidence that mobile telephone service is a substitute for fixed-line telephone service. The different important predictors of the two services in Table 5 show that in areas where both services are available, the respective service-providers may be drawing from different pools of customers. Indeed, even when controlling for other factors, penetration of fixed-line and mobile telephones are positively correlated, shown in Table 7. As a result, mobile telephone service is concluded as a complement of fixed-line telephone service. The rapid growth of mobile telephone service is not a serious threat to fixed-line telephone providers, and providers of both telephone services can determine where to build infrastructure without serious concern about the other service.

There is at most a small substitution effect between public telephones and either fixed or mobile telephone service. Thus, providers of both services can install public telephones without concern that they might substantially reduce revenue from their core business.

6.2. Results useful to policymakers

6.2.1. Affordability vs. accessibility vs. education

The universal service policy in developing countries usually focuses on making ICT affordable, accessible, and usable, such as a policy to subsidize deployment of fixed-line, public telephone or Internet services. From the important predictors listed in Table 5, income is far less important than education in all ICT except mobile telephone service. This suggests that affordability may not be as great an impediment as some believe. For the importance of education to computer and Internet penetration, future research should determine whether it is because people learn skills to use computers and Internet through education,[9] or people with more education are simply more interested in using computers and Internet.

In areas where Internet service is available, about 70% of households that have computers choose not to connect to the Internet. Presumably, these households can afford and are educated enough to use the Internet, so there appear to be other impediments to the growth of Internet. There may not be enough local content that interest these rural households, or the available content is in foreign language.[10] Future research could be conducted to study these hypotheses.

6.2.2. Issues of payphones

Some universal service policies focus on providing public telephones to the rural population because public telephones can serve people who cannot afford other kinds of telephone services. Public telephones were not found to be a strong substitute for fixed or mobile telephone service. Thus, while the policy to promote deployment of more public telephones may have value, policymakers should not assume that these public telephones fulfill precisely the same needs as other telephone services.

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[9] Using in-person observations and interviews with a random Internet users, Hargittai (2003) found that education level is a predictor of users' computer skills (specifically Web searching skills). She concluded that training and support for Internet users are necessary in a policy aimed at getting people online or providing more Internet connections to geographic locations.

[10] Interestingly, Caselli and Coleman (2001) examined national-level data of developed and developing countries over the 1970 and 1990 timeframe, and found that English-language speaking skills of the population are not important to computer adoption.

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