The Changes and Trends in Telephone Household Coverage

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1.Introduction

For almost three decades telephone household surveys have increased in number and size. There has been a corresponding development of telephone sampling techniques that attempted to improve the cost effectiveness of telephone surveys. For example, the two-stage RDD sampling devised by Mitofsky (1970) and revised by Waksberg (1978) provided nearly complete coverage of both listed and unlisted telephone households while improving the ability to locate telephone households.

Furthermore, telephone household surveys advanced as fixed telephone household coverage (FTHC) increased. A number of studies examined the nature of telephone household noncoverage. Collins (1987) dealt with non-coverage problem by non-ownership of the telephone in several countries such as the United States (US) and the United Kingdom (UK). Trewin and Lee (1988) made international comparisons of telephone household coverage around the world. Thornberry and Massey (1988) examined to the issue of telephone household non-coverage bias in the US.

In recent years, the growth of mobile service sector raised a potential threat to the improved coverage of telephone household surveys. Mobile service provides customers advantages in convenience, rather than price, compared to fixed line service. In many countries at present, there has been a decrease in fixed line coverage of households as pre-paid and other types of mobile service. For example, Kussela and Vikki (1999) found that FTHC in Finland has seriously decreased during last decade due to an increase of households that use mobile service as an alternative to fixed line. Nathan (2001) observed that this trend has been recently occurrng in several European countries such as UK, Israel, and Germany. Steeh and Cannon (2000) examined mobile telephone ownership in the state of Georgia in the US, and expressed concerns about a similar trend arising in the US. Kim and Lepkowski (2002) investigated the effects of increased mobile service on fixed line service, and concluded that there is a trend globally of decreased coverage of fixed line telephone households due to an increase in mobile only households.

In this paper, we examine the relationship between fixed line and mobile service penetration rates in 12 countries, and attempt to link penetration rate to FTHC. Hierarchical multivariate linear models (Raudenbush, Bryk, Cheong, and Congdon, 2000) are used to analyze the relationship between FTHC and mobile penetration rates at a country level.

2. Changes in telephone penetration rates and FHTC

In telecommunication services main telephone lines (MTL) are telephone lines connecting the subscriber's terminal equipment to the public switched network. Mobile telephone service (MTS) refers to users of portable telephones subscribing to a public mobile telephone service.

There are two corresponding telephone penetration rates for telecommunication service: the fixed telephone penetration rate (FPR) and mobile telephone penetration rate (MPR), respectively:

$$FPR = (\text{Number of MTL}/\text{Population Size}) \times 100$$

$$MPR = (\text{Number of MTS}/\text{Population Size}) \times 100.$$

That is, FPR is the number of MTL per 100 persons for a country, and MPR is the number of MTS per 100 persons.

The telephone penetration ratio (TPR) is the ratio of these two rates, and compares the extent of subscription between the two telephone services:

$$MPR / FPR = \text{number of MTS} / \text{number of MTL}$$

Thus, if TPR > 1 in a country, MTS has overtaken MTL. The year when a country first sees TPR > 1 is referred to as the cross-over point.

Figure 1 shows trends in TPR for nine European countries and Figure 2 for three non-

European countries for the period 1994 through 2001 (International Telecommunication Union, 2001b, 2002). The trends are steadily increasing in all countries, but the level of the TPR is higher in Europe.

Figure 1. Telephone penetration ratio (TPR) in nine selected European countries

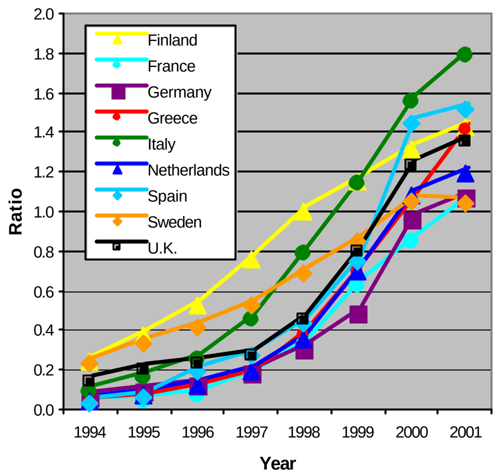
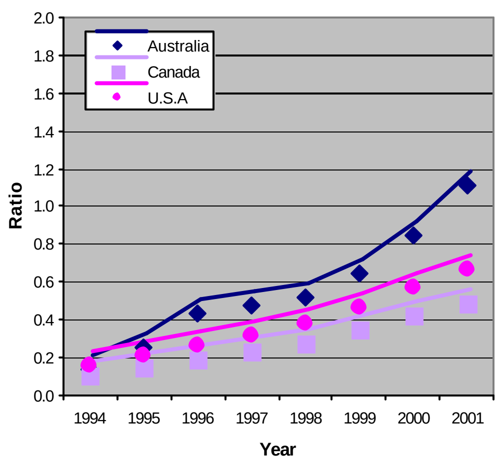


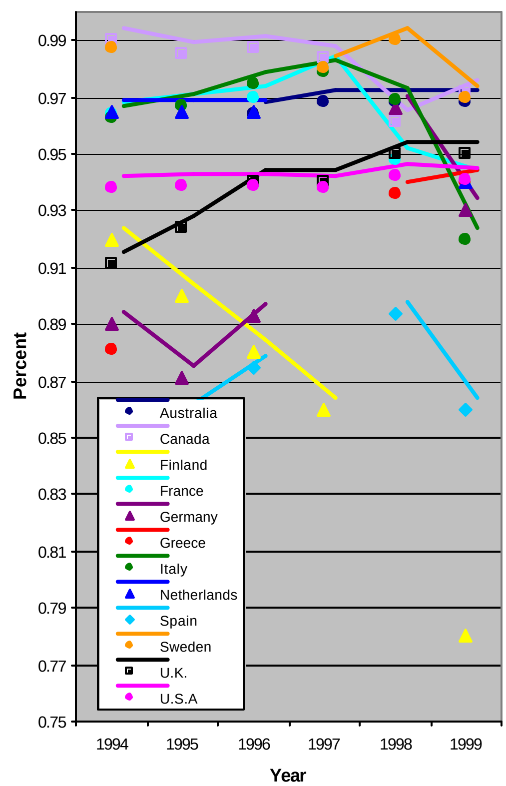
Figure 2. Telephone penetration ratio (TPR) in three selected non-European countries



Among European countries, TPR increases almost linearly in Finland and exponential in other countries. The cross-over point occurs in most of these European in 2001. In non-European countries, the TPR is still less than 1, and the effect of obviously increasing mobile service is comparatively. However, Australia has reached the cross-over point, following the trend in European countries observed in Figure 1.

While these trends are of general interest, from the telephone survey viewpoint, the primary question is whether they have any relationship to FTHC. While FPR and MPR data are available routinely year by year for many countries, data on FTHC are less complete. The trend data for FTHC for the 12 selected European and non-European countries is not as complete, with data available for most of these countries only through 1999 (see Figure 3). Even then, there are several gaps in the time series for individual countries. (The data are taken from the Australian Communications Authority (1999), a communication from the European Commission (1998), the European Commission (1999), the Federal Statistical Office Germany (2000), the International Telecommunications Union (2001a, 2001b), Kuusela and Vikki (1999), the Spanish Statistical Institute (2000), and the Swedish Institute for Transport and Communications Analysis (2001)).

Figure 3. Fixed telephone household coverage (FTHC) in all selected 12 countries



Some countries, such as Canada, France, the UK, and the US provide FTHC every year through regular household surveys. Other countries do not estimate FTHC regularly. From the incomplete data in Figure 3, and other data, we can verify that FTHC in most countries was decreasing or steady since 1994. There is no clear increasing trend in any of these countries. Most striking is the FTHC trend in Finland, which decreased from 92 percent in 1994 to 78 percent in 1999.

3. Hierarchical multivariate linear models for FTHC

Figures 1-3 show a set of trends at the country level that imply increasing TPR, and reaching the cross-over point, predict decreasing FTHC. We consider an application of the hierarchical multivariate linear model (HMLM), through growth curve models, to these data to examine the relationship between these two trends.

The HMLM allows, through a simple growth curve model, models of within-country variation across repeated observations of FTHC at level 1, and of between country variation on a number of country characteristics observations at level 2. Bryk and Raudenbush (1992) deal with hierarchical linear models (HLM) in the study of individual or person level change. This application treats the country as the individual unit.

Since not all countries have FTHC data from 1994 to 1999, the model must also permit the estimation of multivariate normal models from incomplete data. In practice, the EM algorithm for incomplete data (Dempster, Laird and Rubin (1977), Jennrich and Schluchter (1986)) has been incorporated into the HMLM. Raudenbush, Bryk, Cheong, and Congdon (2000) describe the application of the EM algorithm in the HMLM.

In the next section, models for FTHC using data over time are examined. The models were fit by HLM5.

3.1 Unrestricted model

An unrestricted HMLM has a within country variation level and a between country level. The Level-1 model for within-country variation across time is:

$$Y_{ti} = p_{0i} + \sum_{q=1}^{Q} p_{qi} X_{qti} + e_{ti} \qquad \textbf{(1.1)}$$

where Y_{ti} denotes the observed FTHC for country i at time t (t=1,2,…,T), and X_{qti}, (q=1,2,…,Q) represents the Level-1 predictor q for country i at time t. p_{qi} is the coefficient for the Level-1 predictor q.

The Level-2 model addresses the variation in country predictors, $q = 1,2,\cdots,Q$:

$$p_{qi} = b_{qo} + \sum_{s=1}^{S_q} b_{qsi} W_{qsi} \qquad \textbf{(1.2)}$$

where W_{qsi} (s=1,2,…,S_q) denotes the Level-2 predictor s for country i, and b_{qsi} denotes the coefficient for the Level-2 predictor s. All random variation between countries for coefficients p_{qi} is absorbed into the error term in (1.1).

3.2 Simple quadratic growth model

In order to apply the unrestricted model to FTHC data in Figure 3, the following quadratic growth model is appropriate:

$$\begin{aligned} Y_{ti} &= p_{0i} + p_{1i}\left(\text{Year}_{ti} - L\right) \\ &+ p_{2i}\left(\text{Year}_{ti} - L\right)^2 + e_{ti} \end{aligned} \qquad \textbf{(1.3)}$$

where Y_{ti} denotes the observed FTHC for country i at time t (t=1,2,…,T), Year_{ti} is the year observed, and L denotes a centering year. In this instance, L = 1994 is the centering year.

As an initial model, we adopt the unconditional Level-2 model to allow identification of the Level-1 model prior to examining various level-2 models:

$$\begin{aligned} p_{0i} &= b_{0i} \\ p_{1i} &= b_{1i} \\ p_{2i} &= b_{2i} \end{aligned} \qquad \textbf{(1.4)}$$

Here, b_{0i} denotes the mean level of FTHC in 1994, b_{1i} denotes the FTHC growth rate from 1994 to 1999, and b_{2i} denotes the acceleration of the growth rate in FTHC in the same period.

Table 1 presents the results of the estimation of the unrestricted growth curve model. The 1994 mean FTHC and the mean growth rate are 91.5 percent and 2 percent, respectively. These coefficients alone indicate an increasing FTHC over the six year period 1994 to 1999. However, the mean acceleration rate indicates that the entire trajectory is decreasing over this period, as the growth rate slows 0.3 percent per year.

Table 1. Unrestricted growth curve model results

Fixed Effect	Coefficient	Std. Error	T-ratio	P-value
Mean FTHC, 1994 (b_{0i})	0.915	0.010	93.044	0.000
Growth Rate (b_{1i})	0.020	0.004	5.477	0.000
Acceleration (b_{2i})	-0.003	0.001	-6.038	0.000

The result in Table 1 can be summarized through a year-by-year estimation of the FTHC growth rate. In particular, the yearly growth rate is given as the first derivative of equation (1.3):

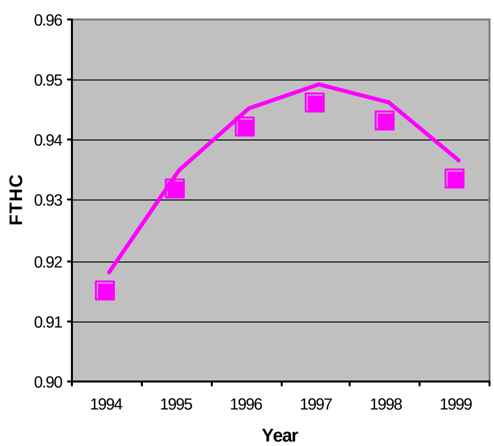
$$p_{1i} + 2p_{2i}\left(Year_{ti} - 1994\right) \qquad \textbf{(1.5)}$$

Table 2 presents the yearly growth rate values using the estimates of b_{1i} and b_{2i} in Table 1. Figure 4 presents the predicted growth curve under these yearly rates. The unrestricted quadratic growth model results in decreasing trends after 1997.

Table 2. Growth rate for each year under the unrestricted growth curve model

Year	Predicted Rate
1995	0.014
1996	0.007
1997	0.000
1998	-0.006
1999	-0.013

Figure 4. Predicted FTHC from the unrestricted growth curve model



3.3 Quadratic growth model for SYSTEM characteristics

The HMLM framework allows the introduction of country level characteristics into the quadratic growth curve model in equations (1.3) and (1.4). We introduce one predictor into the Level-2 model: SYSTEM, a dummy variable denoting the mobile system in each country. Countries may have a single mobile system throughout (SYSTEM = 1) , or they may have multiple mobile systems (SYSTEM = -1). In the European Union, there exists one mobile system, GSM, while other countries such as Australia, Canada, and the US, there are several mobile systems , including GSM as well as CDMA, TDMA, AMPS, and IDEN.

The level-2 model was modified as follows to account for SYSTEM differences between countries:

$$\begin{aligned} p_{0i} &= b_{00} + b_{01}\left(SYSTEM\right) \\ p_{1i} &= b_{10} + b_{11}\left(SYSTEM\right) \\ p_{2i} &= b_{20} + b_{21}\left(SYSTEM\right) \end{aligned} \qquad \textbf{(1.6)}$$

The results under the Level-1 model (1.3) and level-2 model (1.6) are given in Table 3.

Table 3. Results for growth curve model with SYSTEM characteristics

Fixed Effect	Coeff.	Std. Error	T-ratio	P-value
FTHC in 1994				
Intercept(b_{00})	0.935	0.003	355.9	0.000
Slope(b_{01})	-0.017	0.003	-6.58	0.000
Growth Rate				
Intercept(b_{10})	0.011	0.002	4.57	0.001
Slope(b_{11})	0.011	0.002	4.69	0.001
Acceleration				
Intercept(b_{20})	-0.002	0.000	-4.95	0.000
Slope(b_{21})	-0.002	0.000	-3.74	0.004

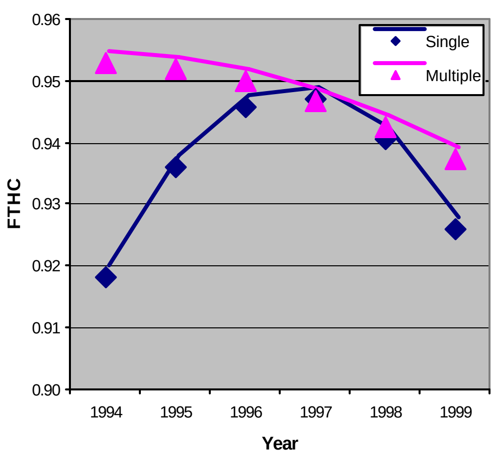
The difference in baseline FTHC in 1994 between the two mobile systems is 3.4 percent (that is, (-1)(-0.017)-(1)(-0.017) = 0.034). Similarly, there are differences of 2.2 percent and 0.4 percent in the growth rate and acceleration, respectively, between systems. In addition, the baseline FTHC in 1994 and acceleration have negative slopes for single mobile systems.

Table 4 presents estimated growth rates for FTHC for each year separately for each type of SYSTEM. Both mobile systems show a decreasing growth rate over time, and the single mobile system has more rapidly decreasing growth than the multiple mobile system. These results are also summarized in Figure 5.

Table 4. Growth rate at each year under growth curve model with SYSTEM characteristics

Year	Predicted Rate	
	Single System	Multiple System
1995	0.014	-0.001
1996	0.006	-0.003
1997	-0.003	-0.004
1998	-0.011	-0.005
1999	-0.019	-0.006

Figure 5. Predicted FTHC under a model with SYSTEM characteristics



3.4 Growth models with multiple country characteristics

The single predictor SYSTEM in Section 3.3 may be only the consequences of a number of other characteristics of the individual countries at level 2. Models were fits that included additional factors that might influence FTHC in the Level-2 model. Two characteristics of the countries also presented statistically significant results: REVENUE, the 1994 to 1999 average revenue per household from all types of mobile communications for each country, and ATPR, the 1994 to 1999 average telephone penetration ratio TPR = MPR/FPR for each country. The same Level- 1 model as in equation (1.3) was employed, but the Level-2 model was modified to include these variables as well as SYSTEM. The best fitting Level-2 model obtained that included these additional variables was the following:

$$\begin{aligned} p_{0i} &= b_{00} + b_{01}(SYSTEM) \\ p_{1i} &= b_{10} + b_{11}(REVENUE) \\ p_{2i} &= b_{20} + b_{21}(ATPR) \end{aligned} \qquad \textbf{(1.7)}$$

Table 5 summarizes the results of fitting this Level-2 model to the data. There is a statistically significant difference in the FTHC in 1994 between mobile systems of 4 percent, as in the previous model. Furthermore, the FTHC growth rate and acceleration have negative values. Thus, SYSTEM, REVENUE, and ATPR are important factors in explaining the decreasing FTHC shown in Figure 3.

Table 5. Results for growth curve model with SYSTEM, REVENUE, and ATPR characteristics

Fixed Effect	Coeff.	Std. Error	T-ratio	P-value
FTHC in 1994				
Intercept(b_{00})	0.963	0.007	140.8	0.000
Slope(b_{01})	-0.020	0.000	-226.8	0.000
Growth Rate				
Intercept(b_{10})	0.010	0.003	3.82	0.003
Slope(b_{11})	-0.000	0.000	-20.41	0.000
Acceleration				
Intercept(b_{20})	0.001	0.000	2.75	0.019
Slope(b_{21})	-0.010	0.000	-248.3	0.000

4. Conclusion

Many countries in the world have been experiencing dramatic growth in mobile telephone subscriptions at the end of 20^{th} and beginning of the 21^{st} centuries. There is mounting evidence that one of the consequences of this growth is a decrease in FTHC. This decrease appears due to an increase in mobile only households which use mobile service instead of fixed line service.

The results summarized in this paper show that the HMLM is useful for analysis of the relationships between FTHC and mobile service. Several factors that may explain the changes in FTHC have emerged. One is the difference in mobile systems between European and non-European countries. Revenue in mobile communications service also clarifies the trends in FTHC. Although we examined only a few countries and a short time period, the HMLM approach is valuable and should be used for sustained studies as more years and countries are added to the available data.

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