

AN ESTIMATION OF THE PATTERN OF DIFFUSION OF
MOBILE PHONES: THE CASE OF COLOMBIA

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An estimation of the pattern of diffusion of mobile phones: The case of Colombia*

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Abstract

In this paper we find that the diffusion pattern of mobile telephony in Colombia can be best characterised as following a Logistic curve. Although in recent years the rate of growth of mobile phone subscribers has started to slow down, we find evidence that there is still room for further expansion as the saturation level is expected to be reached in five years time. The estimated saturation level is consistent with some individuals possessing more than one mobile device.

JEL Classification: C53; L96; O30.

Keywords: Technology diffusion; Mobile telecommunications; Gompertz curve; Logistic curve; Colombia.

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1 Introduction

In a little over a decade, the mobile telephony industry has exhibited an impressive growth throughout the world, with developed (or high-income) countries expanding not as rapidly as less developed (or non-high-income) countries. Banerjee and Ros (2004), for example, indicate that between 1995 and 2001 mobile subscribers grew at much lower (compound annual growth) rates in regions of the world such as Canada / USA (25.1%), Japan / South Korea / Hong Kong / Singapore (40.8%) and OECD European countries (53.3%), than in Rest of Americas (67.4%), Rest of Asia (72.5%) and Africa (84.7%). These differential growth rates reflect the fact that developing countries adopted mobile telephony later, and so benefited from the experiences of developed countries which had adopted the new technology earlier. According to Banerjee and Ros (2004), the markedly different growth path observed across countries has been driven either by economic or technological substitution. That is, in countries where both fixed (or wireline) and mobile network services are of acceptable quality, prices appear to provide the signalling mechanism that guides substitution. By contrast, in countries where access to fixed telephony has been limited or the service is of poor quality, consumers have found in mobile services a good substitute for fixed network services regardless of the relatively high price of the former.¹

There are several studies concerning the growth pattern of mobile telephony markets, and most of them are linked to the diffusion theory. Illustrative examples of country-case studies are Barros and Caddima (2000), Botelho and Costa Pinto (2004) and Carvalho (2006) for Portugal; Michalakelis, Voroutas, and Sphicopoulos (2008) for Greece; Singh (2008) for India; Doganoglu and Grzybowski (2007) for Germany. Examples of comparative studies for several countries are Jang, Dai, and Sung (2005) for OECD countries and Taiwan; and Gruber and Verboven (2001) for the 15 members states of the European Union. Massini (2004) distinguishes between

¹It is also worth mentioning that mobile telephony devices can now be used for many purposes other than basic voice telephony, as they support extended features such as short message services, internet navigation, data transmission and personalised ringtones, among others.

short-run and long-run effects in the diffusion process of mobile phones in Italy and the United Kingdom and finds that handset prices, tariffs and consumption expenditures affect diffusion speed and saturation levels, while Grajek and Kretschmer (2008) examine the dynamics of usage intensity in 41 countries using quarterly data over a period of 6 years. A salient common feature of these studies is that the sample size available for estimation purposes is small; in most cases it is lower than 20 (quarterly or yearly) observations. This, of course, is explained by the fact that the mobile telecommunications sector is a recent technological development.

The studies cited above typically examine the penetration of mobile phones by means of the estimation of S-shaped growth curves, such as the Logistic and the Gompertz curves, and present estimates of the speed of diffusion and saturation level (or maximum size) of the market. The usefulness of S-shaped curves relies on the fact that they depict the life cycle of a new product entering a market: growth starts off slowly, then accelerates, and finally slows down again until the saturation level is reached.² To rationalise the derivation of the Logistic curve one must postulate a differential equation where the relative growth rate of a product decreases monotonically with time, while in the case of the Gompertz curve the relative growth rate decreases in an exponential fashion; see Winsor (1932) and the references therein.

The purpose of this paper is to complement the body of literature that examines the pattern of diffusion of mobile telecommunications, by considering the case of a Latin American country such as Colombia. We believe that the study of the Colombian case is interesting for several reasons: First, Colombia is a country where mobile telephony has complemented fixed telephony due to technological rather than economic reasons. Indeed, the country's diverse geography has historically limited the coverage and access of the fixed telephony network, especially in rural and remote areas of the country. Moreover, in urban areas quality of service in fixed telephony was mixed, and waiting times for new phone lines were long. Second, some private

²For more details on technology diffusion see e.g. Geroski (1999) and Rogers (2003).

leasing contracts became an obstacle for the diffusion of fixed telephony, because in many cases it was strictly forbidden for tenants to install phone lines in the properties they leased, in order to prevent them from leaving unpaid telephone bills when moving to another property. Last, but not least, Colombia witnessed the emergence of informal street markets where some individuals resell minutes in mobile phones which, along with the large share of subscribers in the prepayment category, may help explain the low usage of mobile devices in comparison to other Latin American countries.³

Following the introduction of mobile telephony in Colombia during the second half of 1994, and like in many other developing countries, the sector experienced an initial phenomenal expansion with annual growth rates of more than 100%. Nowadays, approximately 86% of the subscribers are in prepayment, an attractive payment method for individuals who are neither interested nor financially eligible to acquire a fixed price plan. Despite the phenomenal initial growth rates, during the last couple of years or so the annual growth rates of mobile subscribers have started to slow down to around 15%. Thus, one may be tempted to conclude that the mobile telephony sector in Colombia will soon reach its saturation level. However, this is a question that can only be answered by estimating an S-shaped growth curve for the number of mobile phone subscribers, and providing out-of-sample forecasts with their associated measures of forecast uncertainty. The analysis of mobile telephony diffusion has not been a topic of extensive research neither for Colombia, nor for any other Latin American country. A recent exception is Mariscal (2007), who analyses the pattern of expansion that the mobile telephony sector has experienced in Mexico in the context of the Latin American region; the estimation of S-shaped growth curves is not considered in Mariscal's paper though.

Our paper differs in two important aspects from existing literature on the diffusion of mobile telephony. First, we apply the testing procedure developed by Franses (1994b) and Franses (1998) to decide between the two functional forms that

³See Gutiérrez and Gamboa (2008) for a detailed description of the current state of the mobile telecommunication sector in Colombia.

are most frequently used in the literature, namely the Gompertz and the Logistic curves. The related literature cited above does not apply any formal statistical procedure to select between these two functional forms. Second, we present an evaluation of the out-of-sample forecasting performance of the estimated model, which allows us to predict the estimated time when the saturation level is likely to be reached. The forecasting exercise used here also provides measures of forecast uncertainty by means of the calculation of forecast intervals, which are in turn based on the implementation of a parametric bootstrap.

The paper is organised as follows. Section 2 offers an overview of the diffusion of the mobile telecommunication sector in Colombia. Section 3 presents a brief description of the time series models typically used for analysing situations that arise when a new product is entering a market. Section 4 describes the data and summarises the main results of the empirical analysis. Section 5 concludes.

2 The diffusion of mobile phones in Colombia: An overview

The legal framework of the telecommunications sector in Colombia has been guided by the Ministry of Communications, a policy making institution created through Law 923 of 1953. The ministry has been in charge of traditional forms of communication such as telegraphs, fixed telephony (local and long distance calls), postal services and, more recently, mobile telephony. In 1994, the Colombian Congress issued Law 142 which established the guidelines that would rule public utilities (including telecommunications), and created the industry regulator, that in the particular case of the telecommunications service is known as Comisión de Regulación de Telecomunicaciones (CRT). Before the introduction of Law 142, the structure of the communications sector in Colombia was characterized by the existence of a long distance provider (Telecom) as well as local state companies, that enjoyed statutory monopolies on all aspects of network operation. This structure turned out to be inefficient particularly in rural areas, as access to the service was limited, quality

was poor, and prices were high. During the early 1990s, the country entered the privatisation trend that had been occurring in other places, and this required the establishment of a new legal framework to promote competition. This period of time coincided with the arrival of mobile telephony to the country during the second half of 1994.⁴

In December 1991, the Ministry of Communications issued Decree 2824 which laid the foundations for the operation of the mobile telephony sector in the country. This Decree established that the sector would operate within a context of competition between companies in private ownership and companies in public-private ownership, where the latter would result from alliances between Telecom, local telephony operators and domestic and foreign partners. In 1993, the Colombian Congress, through Law 37, issued a series of regulations with the purpose of adjudicating licenses to operators interested in offering mobile telephony services. This Law divided the country into three different regions, namely Atlantic, Eastern and Western. Further, it ruled that two companies would operate in each region, one of which would be in public-private ownership (Network A) while the other one could be entirely in private ownership (Network B). The spectrum was defined between 800 and 900 Mhz. under the advanced mobile phone service (AMPS) technology. As a result of this scheme, Celcaribe (Network A) and Celumovil Costa (Network B) started to operate in the Atlantic region; Comcel (Network A) and Celumovil (Network B) in the Eastern region; and Occel (Network A) and Cocelco (Network B) in the Western region; see e.g. Comisión de Regulación de Telecomunicaciones (2002).

Under this market configuration the number of mobile phone subscribers increased from about 250,000 in 1995 to almost 2 million in 1999. Most of the rapid growth took place in the Eastern region where the city of Bogota, which is not only the capital of the country but also the most populated city with approximately 6 million inhabitants, is located. The rapid growth can be explained by the existence of the "Calling Party Pays" system, and the introduction of the modality of pre-

⁴Other Latin American countries such as Argentina, Chile, Perú and Venezuela RB entered the mobile telephony revolution in the early 1990s.

payment, among other factors. However, according to Comision de Regulación de Telecomunicaciones (2002) the level of penetration appeared modest when compared to other Latin American countries such as Argentina and Chile.

Between 2000 and 2003, a series of acquisitions took place in the market. First, Comcel gained control of Ocel, and Celumovil gained control of Cocelco. Then, America Movil from Mexico acquired Comcel and Bellsouth from the United States acquired Celumovil. Comcel is the only mobile operator that has not changed its commercial name since the introduction of mobile telephony in Colombia. These acquisitions led to a duopoly with Comcel and Bellsouth as the only operators. At the end of 2003, following the introduction of the Personal Communication Services (PCS), a third operator known as Ola entered the market.⁵ Ola was owned by two important local telephony companies, namely Empresa de Teléfonos de Bogotá (ETB) and Empresas Públicas de Medellín (EPM), and Millicom from Luxembourg. Ola implemented an aggressive strategy of market penetration based on the offering of lower prices, and in 2006 ETB and EPM decided to leave the alliance and sell their company shares to Millicom, who gained full control of the company and changed the brandname from Ola to Tigo. Subsequently, Bellsouth was acquired by the Telefónica group of Spain, which continued operations under the brandname Movistar.

The market shares of mobile telephony firms have shown an unstable pattern. Indeed, from 1995 to the end of 2000 the Herfindhal-Hirshman Index (HHI) of market concentration remains relatively stable at a level of around 0.5, which may be alternatively interpreted as two firms with similar market power. In 2001 the increased market share of Comcel is reflected in an upward movement of the HHI, that is subsequently reverted in 2004 following the entrance of the third operator. Once Ola entered the market, prices went down and this attracted many new users. After a brief period of time some new users moved to another operator, since Ola

⁵PCS is a wider legal concept than mobile including concepts such as voice, data, and broad band.

experienced severe network capacity limitations.⁶ Currently, the mobile telecommunications sector in Colombia is characterised by a dominant operator (Comcel) with approximately 63% of the subscribers, followed by Movistar with a market share of 22%, and Tigo with the remaining 15%.

Table 1 shows that during the last years the composition of the telecommunications sector in Colombia has witnessed a marked change due to the presence of mobile telephony. Indeed, while the share of local and long distance calls in the total sales of the telecommunications sector declined from almost 80% to 33% between 1996 and 2007, the corresponding share of mobile calls in total sales increased from 11% to approximately 41% during the same period. The increased relative importance of mobile telecommunications can be viewed as a result of the technological substitution process which we referred to in the previous section, and the emergence of a subsequent falling price differential with respect to fixed telephony. By the end of 2003 mobile penetration equated mainlines penetration.

Figures 1a. to 1c. plot the evolution of some sector indicators. Figure 1a. shows that the average revenue per user (ARPU) has exhibited a downward trend since the introduction of mobile phones, which appears consistent with the behaviour observed in other countries; see e.g. Hausman (2002), McCloughan and Lyons (2006) and Mariscal (2007). Industry regulators argued that a downward trend in ARPU reflects a more competitive market. For example, during the last five years business practices by the two main service providers in Latin America, i.e. Telefónica and America Movil, have led to lowering prices with the aim of attracting new customers. Figure 1b. shows that the average number of minutes per user exhibits a U-pattern. The time period during which the indicator increases coincides with the introduction of prepayment pricing structures, and the appearance of informal street markets where some individuals resale minutes in mobile phones.⁷ Figure 1c. graphs the

⁶The data used to calculate the HHI are not reported here, but are available from the authors upon request.

⁷These informal street markets can be thought of as playing the role that public phones used to play in the past, the only difference being that this time they are owned by the "private" sector; see e.g. Gamboa and Gutierrez (2008).

evolution of the number of mobile phone subscribers. Between 2004 and 2008Q2 the number of mobile phone subscribers increased from 10 to 38 million approximately. It is worth mentioning that during the last couple of years or so the number of subscribers has started to grow more slowly.

3 Time-series models for market penetration

One of the most frequently used functional forms to characterise situations that arise when a new product is entering a market is the so called S-curve. Unlike standard linear, quadratic or polynomial trend models, an S-shaped curve allows one to model the key feature of a marketing time series: the fact that the series converges to a maximum level; in other words, the series is bounded both below and above. The idea underlying an S-curve is that penetration into a market is typically slow at first, then follows a period of rapid acceleration through the adoption of the new product by the majority (also known in the literature as "critical mass", see e.g. Fildes and Kumar (2002) and Michalakelis, Voroutas, and Sphicopoulos (2008)), and finally the growth rate slows down again so that the level of sales of the new product converges to some saturation level. Early uses of S-curves include applications in biology (growth of organisms), demography (population growth) and economics (economic growth); see the references cited in Winsor (1932).

Mathematically, there are many different equations that can be used to represent an S-shaped curve. Perhaps the two most common equations are the Gompertz (1825) growth curve, given by

$$y_t = \alpha \exp[-\beta \exp(-\gamma t)], \quad (1)$$

and the Logistic growth curve, given by

$$y_t = \frac{\alpha}{1 + \beta \exp(-\gamma t)}. \quad (2)$$

In these equations α is a positive parameter that indicates the saturation level of the time series y_t , β and γ are also positive parameters of location and shape, and t

is a linear time trend ($t = 1, \dots, T$). Both the Gompertz and Logistic curves involve the estimation of three parameters, and range between a lower asymptote of 0 and an upper asymptote of α . For both the Gompertz and logistic curves the point of inflection occurs at time $t^* = \frac{\log(\beta)}{\gamma}$, and the corresponding ordinate at the point of inflection is $y_t = \frac{\alpha}{\exp}$ in the Gompertz curve, and $y_t = \frac{\alpha}{2}$ in the Logistic curve. The mathematical properties of the Gompertz and Logistic curves are summarised in Winsor (1932); see also e.g. Franses (1998).

The parameters in equations (1) and (2) must be estimated using non-linear least squares (NLS), after providing suitably chosen starting values, since the two curves are non-linear in the parameters of interest. The estimated parameters can be then used to obtain out-of-sample forecasts of the variable y_t , and forecast intervals can be estimated using a parametric bootstrap, as recommended in Franses (1994a). To implement the bootstrap procedure suppose we have T_1 observations for estimation, and that forecasts are required for T_2 periods ahead. Suppose further that the estimated regression equation variance is $\hat{\sigma}^2$. The bootstrap procedure involves generating $(T_1 + T_2)$ observations for $\varepsilon_t^* \sim N(0, \hat{\sigma}^2)$, and then generating the bootstrap values of y_t , denoted as y_t^* , which in the case of the Gompertz curve are given by:

$$y_t^* = \hat{\alpha} \exp \left[-\hat{\beta} \exp(-\hat{\gamma}t) \right] + \varepsilon_t^*, \quad (3)$$

and in the case of the Logistic curve are given by:

$$y_t^* = \frac{\hat{\alpha}}{1 + \hat{\beta} \exp(-\hat{\gamma}t)} + \varepsilon_t^*, \quad (4)$$

where $\hat{\alpha}$, $\hat{\beta}$ and $\hat{\gamma}$ are the NLS estimates of α , β and γ , respectively. Next, equation (1), or (2), is re-estimated using the first T_1 observations of y_t^* , and forecasts are generated for the remaining T_2 observations. The procedure described previously is repeated B times, obtaining B forecasts for each horizon. Finally, one can calculate the mean of the B forecasts for each horizon and, for example, a 95 per cent confidence interval for the forecasts can be obtained by finding the 2.5 and 97.5 percentiles in the list of B forecasts for each horizon⁸.

⁸Using the quantiles of the empirical distribution of the forecasts to define the lower and upper

4 Data and empirical analysis

We consider a data set consisting of the number of mobile phone subscribers in Colombia. It is worth mentioning that the number of subscribers is not the same as the number of mobile telephony users for four main reasons. First, Colombia is perhaps one of the few countries in the world that is characterised by the operation of an informal street market where some individuals (who typically own one or two mobile devices for each service operator) resell minutes. Second, individuals may possess mobile devices for personal and business purposes, where the latter is paid by their employer. Third, a common business practice is that when customers intend to upgrade their mobile devices, service operators assign a new mobile device with its corresponding subscriber identify module (SIM) card, and offer the option of maintaining the older device in the modality of prepayment. Fourth, operators, in an attempt to increase their market share, have started to offer service plans that involve giving two SIM cards (that is, two different phone numbers) to new users. For all these reasons, a subscriber is not an individual but an "account" with a mobile telephony provider.

The data are quarterly (end-of-period) and runs from 1995Q4 to 2008Q2, for a total of $T = 51$ observations. The data were collected from worksheets produced by the Ministry of Communications of Colombia. As in Franses (1994a), the available raw observations are smoothed by running a regression of the number of subscribers at time t on an intercept, the number of subscribers at time $t - 1$, and on the new subscriptions at time t , and by taking the fitted values of such a regression as the smoothed series.

The first stage of our empirical analysis involves selecting between the two most often applied functional form specifications, namely the Gompertz curve and the Logistic curve. In order to do this, we follow Franses (1994b) and Franses (1998), who develops a simple testing procedure to select between the two specifications.

critical points of the interval forecast is what some authors refer to as the Efron percentile method; see e.g. Clements (2005).

The starting point of the test is the fact that the Gompertz curve given in equation (1) can be rewritten as:

$$\log(\Delta \log(y_t)) = \beta^* + \gamma^* t, \quad (5)$$

where y_t is the time series of interest, \log denotes the natural logarithm, Δ is the first difference operator, and β^* and γ^* are non-linear functions of the parameters β and γ . In turn, the Logistic curve given in equation (2) can be rewritten as:

$$\log(\Delta \log(y_t)) = \beta^{**} + \gamma_1 t + \gamma_2 t^2 + \gamma_3 t^3 + \gamma_4 t^4 \dots \quad (6)$$

Given that equation (5) is nested in equation (6), the testing procedure put forward by Franses (1998) involves estimating by ordinary least squares the auxiliary regression (6), and testing the null hypothesis that the estimated coefficients γ_2 , γ_3 , γ_4 , ... are statistically different from zero. If these coefficients turn out to be statistically different from zero then a Logistic specification should be estimated; otherwise, an specification based on the Gompertz curve should be preferred. It is worth noticing that since in practice values of $\Delta \log(y_t)$ may well be negative, then it would not be possible to apply the second logarithmic transformation in the left-hand side of equations (5) and (6). To overcome this, Franses (1994b) suggests that one might either replace such observations by interpolated values or alternatively treat them as missing values.

The results of estimating the auxiliary regression (6) for various degrees of the polynomial time trend suggest that the Logistic specification should be used. Indeed, our results indicate that when t^2 and t^3 are included in (6), the F statistic for the the joint significance of γ_2 and γ_3 is 7.736 (p-value 0.001). Similarly, when the auxiliary regression (6) includes t^2 , t^3 and t^4 the corresponding F statistic for the the joint significance of γ_2 , γ_3 and γ_4 is 5.070 (p-value 0.004).⁹

NLS estimation of the Logistic specification yields the following results, where Heteroscedasticity and Autocorrelation consistent (HAC) standard errors appear

⁹As an additional exercise, it was also tried to estimated the Gompertz specification. However, the estimated coefficients implied a rather implausible saturation level, and so it was decided to discard this model.

underneath each estimated coefficient in parentheses:

$$y_t = \frac{\frac{44.660}{(3.037)}}{1 + \frac{2253.132}{(1259.438)} \exp\left(\frac{-0.184t}{(0.017)}\right)}, \quad \begin{array}{l} \hat{\sigma} = 1.452 \\ R^2 = 0.985 \end{array} .$$

The results were obtained using the econometric software RATS 6.0, and convergence was achieved after 9 iterations.¹⁰ As can be seen, the estimated coefficients have the expected positive sign and are statistically significant at the 5 per cent significance level (based on one-tailed tests). The $\hat{\alpha}$ coefficient implies an estimated saturation level of about 44.6 million subscribers. Given that the Colombian population is around 43 million inhabitants, the saturation level is consistent with individuals having more than one mobile device. Singh (2008) observes that developing countries typically exhibit higher saturation levels than develop ones, due to limited access to fixed telephony networks. Thus, there is no need for individuals to possess a fixed line in order to have a mobile phone. Our estimate of the point of inflection is at time $t^* = \frac{\log(2253.132)}{0.184} \approx 42$, that is approximately in 2006Q1.

Figure 2 plots the actual values for the number of mobile phone subscribers, the forecasts for 20 quarters ahead (from 2008Q3 onwards), and the 95% confidence intervals for the forecasts, as produced by the previous Logistic specification. The lower and upper critical points of the forecasting interval were calculated applying the bootstrap approach, using $B = 1,000$ bootstrap replications. The out-of-sample point forecasts suggest that the saturation level is almost reached in 2013Q2, that is in approximately 5 years time. In other words, despite the impressive development of the mobile communications sector in the country, there still appears to be room for expansion, at least for the next five years. As Gutiérrez and Gamboa (2008) report, mobile penetration is still low among people in the lower percentiles of the income distribution.

To assess the dependence of forecast uncertainty on the forecast horizon, Figure 3 plots the histograms of the forecast errors at forecast horizons of 1 quarter, 4 quarters, 8 quarters and 20 quarters ahead. As the forecast horizon increases, the

¹⁰Nearly identical results were obtained when using the econometric software STATA 10.1.

dispersion of the forecast errors becomes larger implying that forecast uncertainty is time-dependent.

5 Concluding remarks

This paper examines the diffusion pattern of mobile telephony in Colombia. Our empirical modelling approach starts off by choosing between the two functional forms that are most frequently used in the literature, namely the Gompertz and the Logistic curves. This involves the use of a formal statistical procedure that is available in the literature. Our findings indicate that the diffusion pattern of mobile telephony in Colombia can be best characterised as following a Logistic specification. We find evidence that despite the fact that the growth rate of mobile phone subscriptions has been slowing down in recent years, there is still room for further expansion, as the saturation level is expected to be reached in five years time. The estimated saturation level is consistent with some individuals possessing more than one mobile device.

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Table 1. Structure of the communications sector in Colombia (% total sales)

Item	1996	1998	2000	2002	2004	2006	2007
Local calls	36.1	30.1	39.7	40.0	34.0	27.7	26.3
Long distance [†]	43.3	28.5	25.3	16.2	11.6	7.4	6.2
Mobile	11.0	26.9	16.9	16.9	22.8	40.0	40.9
Others [‡]	9.6	14.5	18.1	26.7	31.5	24.9	26.6

[†] Includes both national and international calls.

[‡] Includes Internet, radio, TV, Trunking, among others.

Source: Ministry of Communications and CRT.

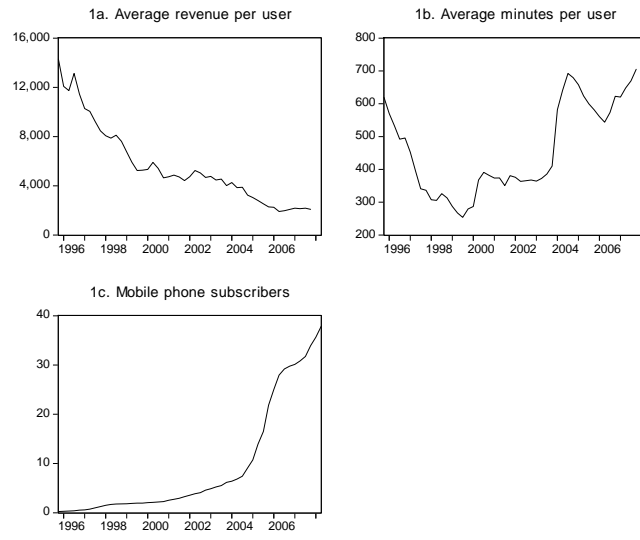


Figure 1. Basic mobile sector indicators

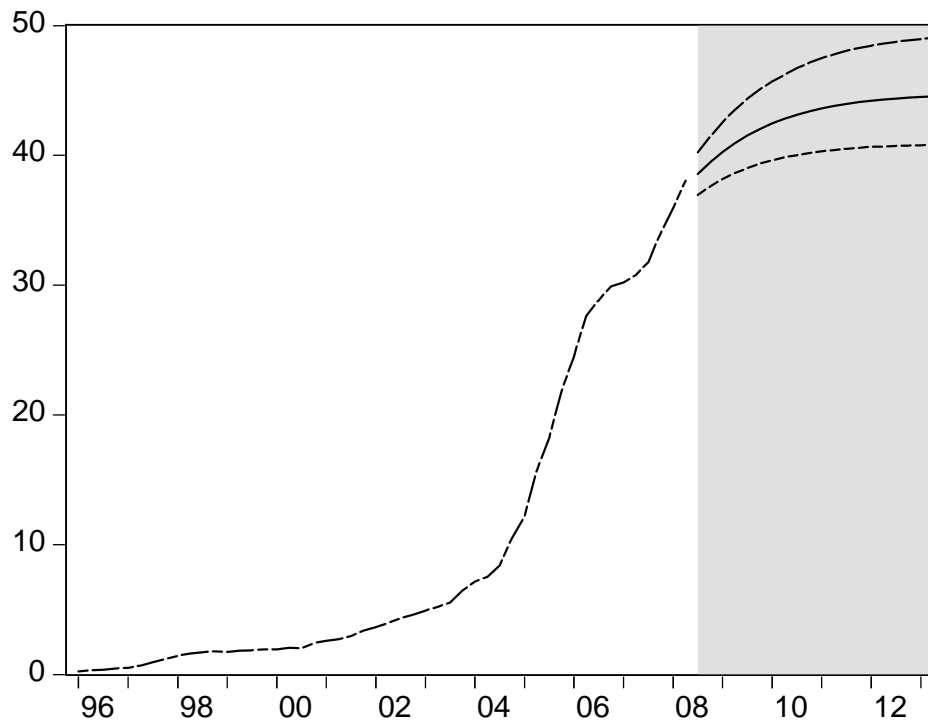


Figure 2. Actual values and forecasts with 95% forecast interval

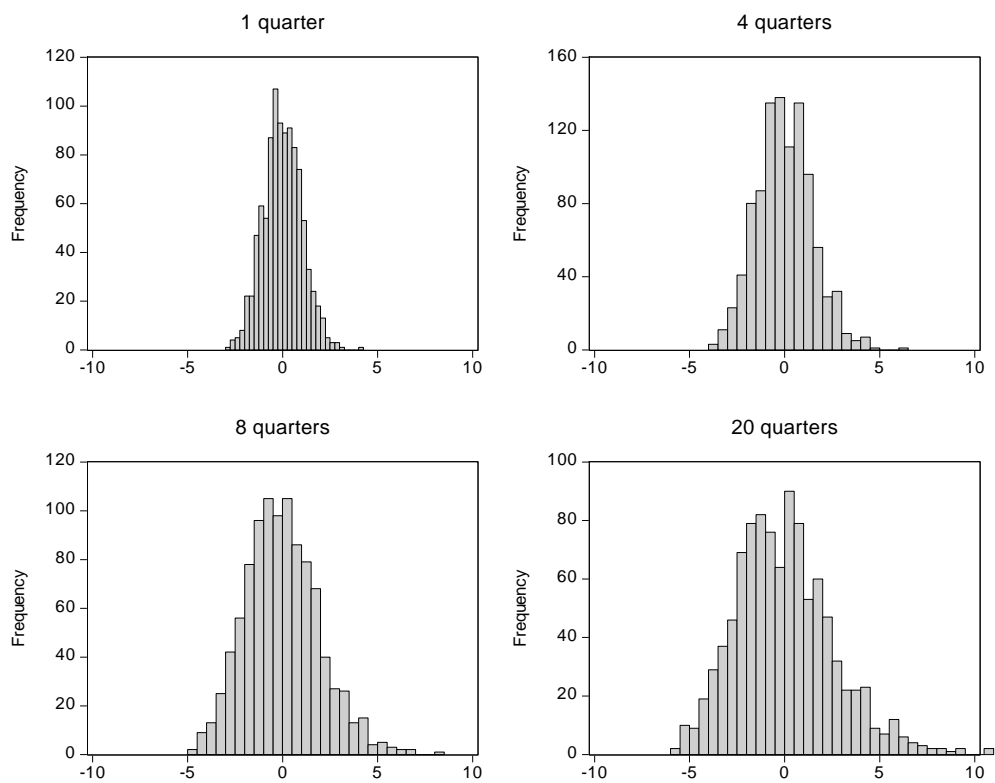


Figure 3. Histograms of forecast errors at 1-, 4-, 8-, and 20- quarter horizons