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Abstract

This study examines the growth of global mobile telephony and the economic factors that affect this growth. Mobile telephony has exhibited substantial growth in the decade to 2000 and this growth is expected to continue with the introduction of technically advanced mobile cellular networks. A dynamic demand model is estimated by using global telecommunications panel data comprised of 56 countries. Results from the estimation are provided along with elasticity estimates and impulse response functions for price and income.

Keywords: Mobile telephony; Fixed-line telephony; Network effect; Substitution; Global analysis

1. Introduction

A mobile telephone network is comprised of the physical components required to connect users. The basic physical components are the handset, base station and mobile service switching station (MSC) (Gruber & Hoenicke, 1999). A call made from a handset is transmitted to a base station and then to an MSC. An area that is serviced by this network is divided geographically into cells. A cellular system can employ many small radio coverage areas to provide service (Foreman & Beauvais, 1999). Since 1990 mobile telephone subscription has doubled globally every 20 months. From an 11 million subscriber base and an average penetration of 1% at 1990, the mobile telecommunications industry now supports a half billion subscribers (International Telecommunication Union, ITU, 1999). The average global penetration at June 1999 was 27% (Gruber & Valletti, 2003).

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Several institutional developments have had an impact on mobile telephony growth.[1] Introduction of digital technology substantially relaxed the radio spectrum constraint. Transmission rates increased from 0.33 bits/s/Hz to approximately 1.40 bits/s/Hz as TDMA allowed more efficient use of the radio spectrum (Gruber & Valletti, 2003). Digital technology brought features for commercial mobile telecommunications not available with analogue technology. In particular, digital technology permits data transmission, e.g., short message service, e-mail and increased sound quality. Digital networks require lower power levels for operation that results in lighter and smaller handsets (ITU, 1999). Second-generation (2G) mobile systems operation have drawn on the experience of first-generation (FG) mobile systems in the realization of network effects and economies of scale. This has resulted in the creation of fewer systems than for FG mobile.

The early mobile telephony industry was mostly monopoly operator supplied. Existing fixed-line operators initially provided mobile telephony as an extension or value-added service. In 1990 three-quarters of the 29 Organization for Economic Co-operation and Development (OECD) member countries with mobile telephony had a monopoly provider—by 2000 none had monopoly providers. Duopoly providers serviced four countries, 11 had three operators, and 14 had more than three mobile operators (Gruber & Valletti, 2003). Regulatory innovation in mobile telephony markets concerns the timing and number of licenses granted, the method by which licenses are granted and whether a technological standard is set (Gruber & Verboven, 2001). With technological advances, the subscriber base that a network can support is increased, as is the demand for mobile service.

Ultimately the number of licenses granted also grew. Additional licenses allowed for intensified competition, which further fuelled diffusion. Gruber and Verboven suggest that the timing of first and second licenses might explain why diffusion occurred more rapidly in certain countries. Reasons given for catch-up include economies of scale (infrastructure investment, including the cost of mobile handsets, decreases through time), whereby average network set-up costs decline with network size. Late adoption externalities may also arise due to learning spillovers. Entry of mobile providers into former monopoly markets ensured the evolution of a more competitive environment. Mobile operators developed tariff (pricing) packages in an attempt to differentiate themselves from their competitors, isolate market segments and target customer groups and geographic regions (ITU, 1999).[2]

The focus of this study is the analysis of economic drivers of market growth, viz., price, income and network effects (endogenous) within this evolving institutional context. In particular, the price of acquiring and using mobile telecommunications since its inception has declined. Further, Jha and Majumdar (1999) find that mobile telephony penetration has varied substantially among countries according to their gross domestic product (GDP) per capita. They argue that greater prosperity translates into an enhanced demand for mobile telecommunications service. Gruber and Verboven (2001) find no support for this case from within the OECD. Finally, Gruber and Valletti (2003) argue that network effects in production are due to economies of scale equipment supply and operation of networks, and that consumption externalities arise from subscribers'

[1] Gruber and Valletti (2003) provide a discussion of such developments with particular reference to the OECD.

[2] Gruber and Verboven (2001) found that entry by a competitor into a national mobile telecommunications market slightly increased diffusion.

ability to roam.[3] Network effects are larger in the presence of a common standard. Consumption effects lead to self-propelling or endogenous growth. Such endogenous growth is particularly important during the early adoption stage for new networks.

The literature concerning patterns of technology diffusion has mostly considered the dominant stylized fact that adoption typically follows an S-shaped curve, i.e., diffusion rates initially rise and then fall over time ultimately leading to market satiation (Geroski, 2000). Many underlying motivations can generate S-shaped curves (see Parker, 1994). The estimation of such models typically requires long time-series.[4] This data requirement limits the potential to provide projects on market growth early in the diffusion process, and also ignores the problem of parameter variation in new product diffusion models (see Meade & Islam, 1998; Putsis, 1998). The approach adopted here follows Madden and Coble-Neal (2001). Rather than modelling the diffusion process per se they consider optimizing economic agent behaviour directly. They assume that an individual's instantaneous indirect utility of subscribing to mobile telephony depends on income, price and current network size, where network size is the number of current subscribers. An advantage of the approach is that it can be applied to developing country penetration issues by using short time-series employing a pooled sample. Pooled samples better enable the role of income in the diffusion process to be assessed in the absence of long time-series.

The paper is organized as follows. Section 2 provides a brief discussion of the economic factors that drive mobile subscription. In Section 3 a model to examine mobile telephony network growth that incorporates a network effect is specified. Data and variables used in the estimation are presented and described in Section 4. The empirical modelling strategy is explained in Section 5, and estimates are reported. Concluding remarks and policy implications are provided in Section 6.

2. Economic factors and mobile subscription

2.1. Mobile telephony pricing

In the early stages of mobile telephony diffusion, subscription was mostly business-related. Prior to digital cellular technology there was no incentive for providers to lower their prices, as they faced excess demand. High service and access prices *de facto* rationed the limited spectrum. The introduction of digital technology allowed service provider entry into these monopoly markets. This entry led to competition among operators for subscribers and resulted in lower prices. Subsequent price reductions were used to expand an operator's subscriber base—and were the first consumer-orientated tariff strategies. ITU (1999) *World Development Report* describes current mobile pricing strategy as based on extensive market research and analysis of usage. For instance, mobile telephone operators are now expanding the market by targeting late-adopter groups.

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[3] Roaming is the use of handsets with the same number in areas not covered by the firm that the user subscribes to (Gruber & Valletti, 2003).

[4] Dekimpe, Parker, and Sarvary (1998) and Gruber and Verboven (2001) provide exceptions.

2.2. Gross domestic product

Jha and Majumdar (1999) expect GDP per capita to enhance mobile telephony diffusion. They argue that greater GDP per capita signifies greater affordability and so leads to increased demand for mobile telecommunications service. Gruber and Verboven (2001) find no empirical support for this proposition; however, their finding may arise because of the relatively 'narrow band' of high-income countries they examine. Further, the role of GDP in mobile telephony diffusion may not be as clear as Jha and Majumdar (1999) propose; e.g., countries such as Cambodia have seen mobile telephony subscription outstrip that of fixed lines. Gruber (2001), however, finds no such relationship for Central and Eastern Europe.

2.3. Network effects

New subscribers joining a network increase the utility of current subscribers. This process leads to self-propelling or endogenous network growth, and suggests that current subscription is positively influenced by previous subscription (Economides & Himmelberg, 1995). In particular, little if any utility is gained from an individual subscribing to the network unless there are sufficient subscribers already using the service. However, the viability of a new network relies on the spontaneous existence of an initial critical mass of subscribers. Intuitively, early adopters must derive a high level of value from the good, even though it has limited use.

3. Theoretical model

The approach adopted here follows Madden and Coble-Neal (2001) who rather than modelling the diffusion process per se consider optimizing economic agent behaviour directly. They let the instantaneous utility of subscribing to mobile telephony for an individual with income Y and a network of size N be given by $u(Y,N)$, where the size of a network is determined by the number of subscribers.[5] Assuming that network connection yields an infinite stream of future utility, given an expected future time path of network size $N^{\mathrm{e}}(t)$, the present value of the benefits from network subscription for a consumer with income Y is

$$V(Y,t,N^{e}(t)) = \int_{t}^{\infty} \mathrm{e}^{-\rho s} u(Y, n^{\mathrm{e}}(s))\, \mathrm{d}s, \tag{1}$$

where ρ is the discount rate. Suppose subscription is offered at time t at price $P(t)$. When subscribed at t, the corresponding present value of access cost is

$$q(t) = \mathrm{e}^{-\rho t} P(t). \tag{2}$$

Consumers choose to subscribe at t^* to maximise

$$V(Y,t,N^{\mathrm{e}}(t)) - q(t). \tag{3}$$

[5] $U(Y,N)$ is based on duality theory. See Diewert (1974), and Train (1986, p. 78) and Economides and Himmelberg (1995) for an explanation.

Assuming (3) is concave over the relevant range, t^* is characterized by

$$u(Y, N^{e}(t^*)) = \rho P(t^*) - \frac{\partial P(t^*)}{\partial t} \equiv \lambda(t^*), \quad (4)$$

where $\lambda(t^*)$ is the opportunity cost of subscription. With utility specified Cobb–Douglas, (4) translates to

$$u(Y_t, N_t^{e}) = A Y_t^{\kappa} N_t^{e\omega} = \lambda_t \quad (5)$$

and implies an equilibrium network size

$$\ln N_t^e = \mu + \alpha \ln \lambda_t + \beta \ln Y_t, \quad (6)$$

where $\mu = -\omega^{-1} \ln A$, $\alpha \ln \lambda_t = \omega^{-1} \ln \lambda_t$ and $\beta \ln Y_t = -\omega^{-1} \ln Y_t$. Further, assuming that the market does not instantaneously adjust to its long-run equilibrium and the expected network size in equilibrium at t (N_t^{e}) is not observed, they follow Cabal and Leita (1992) by assuming that the actual value of N_t results from a process of partial adjustment toward N_t^{e},

$$\ln N_t - \ln N_{t-1} = \gamma(\ln N_t^{e} - \ln N_{t-1}), \quad (7)$$

where the partial adjustment coefficient is $0 < \gamma < 1$. Substitution of (6) into (7) yields the network equilibrium correction model for estimation:

$$\ln N_t - \ln N_{t-1} = \gamma(\mu + \alpha \ln \lambda_t + \beta \ln Y_t - \ln N_{t-1}) \quad (8)$$

which after rearrangement becomes

$$\Delta \ln N_t = \alpha_0 + \alpha_1 \ln \lambda_t + \alpha_2 \ln Y_t - \alpha_3 \ln N_{t-1}, \quad (9)$$

where $\Delta \ln N_t = \ln N_t - \ln N_{t-1}$, $\alpha_0 = \gamma\mu$, $\alpha_1 = \gamma\alpha$, $\alpha_2 = \gamma\beta$, and $\alpha_3 = \gamma$.

4. Data and variables

Annual data are required to estimate the model, and are collected for 56 countries for 1995–2000 from the ITU (2002) World Telecommunications Indicators Database. These data are comprised of GDP, mobile telephone subscription, monthly mobile telephone subscription charge, and population. Countries represented include 8 Low, 11 Lower-Middle, 9 Upper-Middle and 28 High income nations from Africa, Asia, Europe, the Middle East and the Western Hemisphere.

GDP is denominated in Special Drawing Rights (SDR) to offset the rapid appreciation in the USD during the mid- to late-1990s and deflated by the consumer price index (CPI) (1995 = 100). CPI is obtained from the World Bank (2002) World Development Indicators Database. Deflated GDP series are divided by population to provide per capita INCOME series. Cellular mobile telephone subscribers per 100 inhabitants (SUBSCRIBERS) comprise analogue and digital users (CDMA, DAMPS, GSM, PCS and PHS systems). PRICE is constructed by using the cellular monthly subscription charge denominated in SDR and deflated by the CPI index. Missing data for OECD member countries are sourced from the OECD Communication Outlook (OECD, 1997, 1999, 2001). The remaining missing observation for the US (1997) is obtained from the Cellular Telecommunications and Internet Association's Semi Annual Mobile Telephone Survey (2000). Other data are detailed in the appendix.

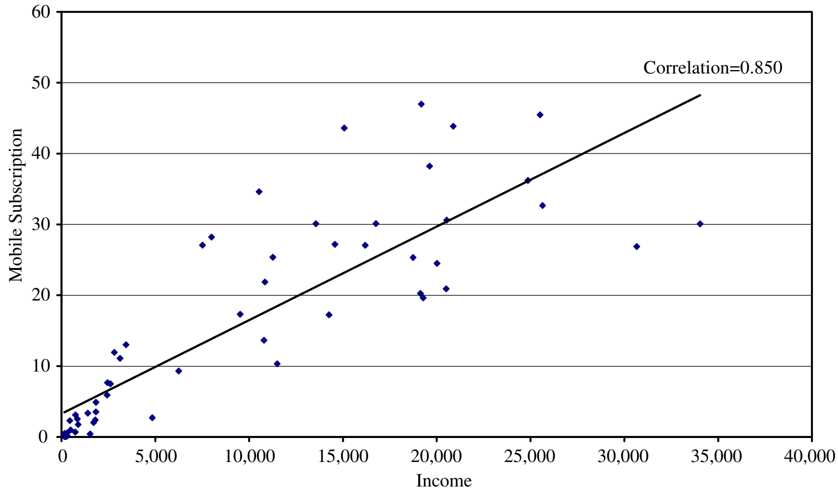

Fig. 1. Mobile subscriber and income, 1995–2000. *Note*. Observations are six-year averages for each country.

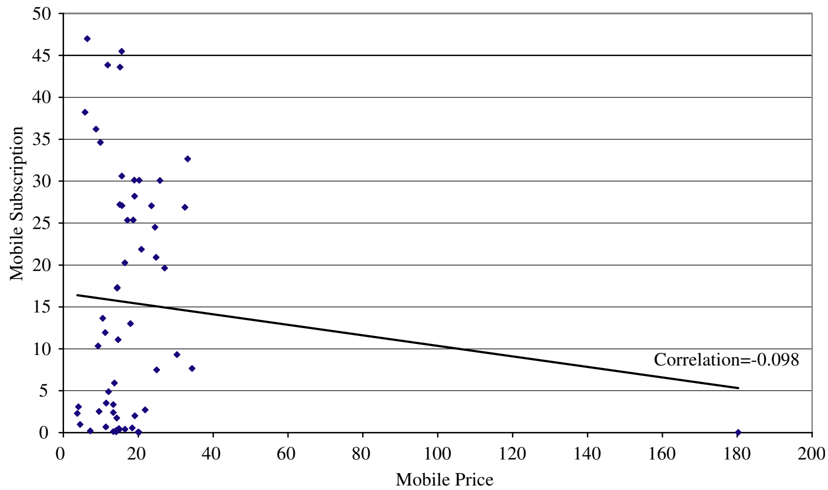

Fig. 2. Mobile subscriber and price, 1995–2000. *Note*. Observations are six-year averages for each country.

Figs. 1 and 2 illustrate the relationship of SUBSCRIBERS versus INCOME and PRICE. Indicated pair-wise correlations reveal expected relationships between SUBSCRIBERS and the explanatory variables INCOME and PRICE. Also evident is the high degree of variation by country, particularly for PRICE. Capello (1994) argues that the limited PRICE influence is symptomatic of early adoption where endogenous network growth dominates the PRICE effect. Three outliers in the upper-left segment of Fig. 1 correspond to Korea, Portugal and Taiwan.

5. Model estimation

The estimation strategy employed for (9) is as follows. Eq. (9) corresponds to the Pooled model that assumes mobile telephone demand is identical across countries. Variation in demand by

Table 1
Global mobile telephone demand elasticities

Variable	Global			High-income countries		
	Coefficient	*t*-statistic	Elasticity	Parameter	*t*-statistic	Elasticity
Constant						
Income	1.57	3.83	4.76	0.52	2.09	3.47
Price	−0.18	−2.60	−0.55	−0.08	−1.83	−0.53
Subscribers_{-1}	−0.33	−10.45		−0.15	−5.32	
$\bar{R}^2$	0.42			0.51		

Note. The Hausman (1978) test rejects the REM specification. All coefficients are statistically significant at the 5% level. Parameter refers to the identified structural parameters derived from the estimated coefficients.

country requires that (9) be modified. The alternative specifications considered are the one-way Fixed-Effect (FEM) and Random-Effect (REM) models. The FEM allows intercepts to vary by country at a point in time, and is depicted by

$$\begin{aligned}\Delta\,\text{Log}\,(\text{SUBSCRIBERS})_{it} \\ &= \alpha_{i0} + \alpha_1\,\text{Log}\,(\text{INCOME})_{it} + \alpha_2\,\text{Log}(\text{PRICE})_{it} \\ &\quad - \alpha_3\,\text{Log}(\text{SUBSCRIBERS})_{it-1} + \varepsilon_{it},\end{aligned} \tag{10}$$

where subscript $i = \{1, 2, 3, \ldots, 56\}$ is country-specific. The REM model specification considers country variation to be randomly distributed and uncorrelated with explanatory variables; the result is a complex disturbance term

$$\varepsilon_{it} = \alpha_{i0} + v_{it}, \tag{11}$$

and v_{it} is a white-noise error process with zero mean and constant variance.

Table 1 reports the final results of the estimation of (10), which is conducted in stages.[6] In Stage 1, the null hypothesis of no country-specific intercepts (or $\alpha_{10} = \alpha_{20} = \alpha_{30} = \cdots = \alpha_{i0}$) is tested by using the Pooled model. Rejection leads to choice between FEM and REM specifications. A Hausman (1978) test of the correlation between the error and the regressors is used to check whether the REM is appropriate. A test of the significance of group effects rejects the Pooled model. Hausman's (1978) test rejects the null that the REM estimator is efficient. The appropriateness of the FEM over the REM supports the use of dummy variables to control for country-specific effects or differences in the cross-country demand for mobile telephony. Finally, since a number of studies (e.g. Perl, 1983; Ahn & Lee, 1999) have reported significant non-linear income effects, tests for non-linear income terms are conducted. Second-order income terms are found to be statistically insignificant. However, re-estimating (10) across the high-income countries results in substantially smaller coefficients. Finally, reported *t*-statistics indicate INCOME, PRICE and SUBSCRIBER_{-1} are all significant.

[6] The two-stage instrumental variables technique is used for all models. In the first step, total mobile subscribers is regressed on current and previous period fixed-line prices and fixed-line subscribers, along with the previous period's mobile price, and mobile subscribers are used and a time index. Tests of homoescedasticity are rejected in the FEM and pooled models. Therefore, generalized least squares is applied in estimation.

The calculated PRICE and INCOME variables elasticities' are also presented. The identified income elasticities are large and imply, for the global model, that a percent increase in income yields close to 4.8% increase in mobile subscription growth. Income elasticity for high-income countries is 27% less than the global model, but is also highly elastic. Large income elasticities provide an indication that subscribers place high value on mobile telephony. Price elasticities for both models are inelastic and close in magnitude. Hence, price reductions will yield the same response in subscription growth, irrespective of location. The identified subscriber parameters (network effect) are 0.33 and 0.15 for global and high-income countries, respectively. This implies that for the global model, a 1% increase in subscribers yields an average 0.33% increase in network subscription growth. The network effect for high-income countries is approximately half of the global model. Given the higher penetration rates for high-income countries, the results indicate that the network effect is also non-linear. The effect appears to decrease with an increasing subscriber base, with the marginal effect least in high-income countries where upper critical mass is achieved. Nevertheless, the INCOME and SUBSCRIBER estimates show that rising GDP and subscription positively affects network size.

5.1. Impulse response function

The plot of an impulse response function for PRICE and INCOME is provided by Fig. 3, and visually depicts the behaviour of the SUBSCRIBERS_{it} series in response to INCOME and PRICE shocks (Enders, 1995). The impulse response function for an INCOME shock is

$$\frac{\partial\, \text{SUBSCRIBERS}_{t+i}}{\partial\, \text{INCOME}_t} = \beta\gamma(1 + (1-\gamma) + (1-\gamma)^2 + (1-\gamma)^3 + \cdots + (1-\gamma)^i), \tag{12}$$

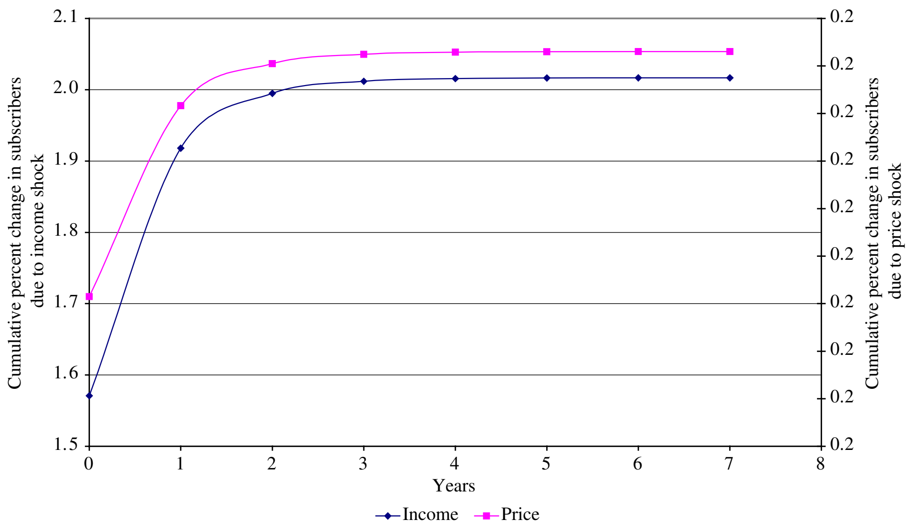

Fig. 3. Income and price impulse response functions.

where $\partial\,\mathrm{SUBSCRIBER}_{t+i}/\partial\,\mathrm{INCOME}_t$ is the change in network size resulting from a unit INCOME shock at t. β is the estimated INCOME coefficient, γ is the network externality, and i is the number of countries. The corresponding impulse response function for a unit PRICE shock at t is

$$\frac{\partial\,\mathrm{SUBSCRIBER}_{t+i}}{\partial\,\mathrm{PRICE}_t} = \alpha\gamma(1 + (1-\gamma) + (1-\gamma)^2 + (1-\gamma)^3 + \cdots + (1-\gamma)^i). \tag{13}$$

Plots of shocks (12) and (13) are contained in Fig. 3. Changes in INCOME are shown to have a more substantial effect on SUBSCRIBERS in successive periods. Indeed, for the global model, the cumulative impact of a percent change in income is 8.6 times larger than the price effect.

6. Conclusion

Global mobile telephony markets have achieved substantial growth since their inception. Since 1990, from a base of 11 million the market has grown to over half a billion subscribers. Average global penetration at June 1999 was 27%. Advances in mobile technology from FG to 2G (and eventually 3G) have relaxed the spectrum constraint. Innovations in regulation have enabled entry of competitive operators into these former monopoly markets. The sum of these effects has seen declining mobile telephony prices, apparently further expanding the market to attract marginal users. The purpose of this study is to model this exponential network growth in terms of economic drivers of income, price and network externalities, without directly considering these institutional changes in individual markets.

Because only short time-series are available, the modelling framework adopted is explicit utility maximisation. The resulting econometric model is amenable to panel data estimation. Toward this end, data are collected from ITU, UN, World Bank and IMF sources to construct national income, mobile telephony pricing and mobile subscription series (1995–2000) for 56 nations classified by GNP level. Panel data estimation of mobile subscription controls for cross-country heterogeneity. In particular, a pooled cross-section, time-series model, FEM and REM are estimated from the panel data set by using OLS and GLS estimation techniques. The FEM is preferred, and suggests that GDP and the network externality effect are important in explaining network growth. Low-income countries are more income-elastic. Network effects are inelastic, but nevertheless provide an important explanation for the rapid growth in mobile telephony. Moreover, both the income and network effects exhibit signs of non-linearity, with the marginal effects reducing as subscription growth increases. Finally, price is shown to have a uniform effect across the two models and is inelastic. While price is clearly important, the impulse response functions highlight that increases in income will yield a cumulative subscription effect 8.6 times larger than the equivalent change in price.

However, to take comfort in this tentative conclusion requires that better pricing data, which take account of both subscription and use, be employed. That is, the mobile telephony pricing data used here are for cellular monthly subscription only. A more complete pricing series would encompass both cellular connection charges and usage-sensitive pricing. Another aspect of pricing that needs addressing in future studies is the impact of prepaid telephony cards. This form of mobile telephony usage-sensitive pricing is particularly important for young users in developed economies, and more generally in developing economies.

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Appendix

The primary data source is the International Telecommunication Union *World Telecommunication Indicators 2002* database. Missing data are sourced as follows.

A.1. Consumer price index

Central African Republic (2000) is sourced from the World Bank web site (http://www.worldbank.org/data/). Values for China (1996–2000) are from the International Financial Statistics Yearbook 2001, p. 355. Nicaragua (2000) is available from the International Monetary Fund Statistical Appendix (http://www.imf.org/). Sudan (2000) is sourced from the Republic of the Sudan Ministry of Foreign affairs (http://www.sudmer.com).

A.2. Cellular monthly subscription price

OECD mobile telecommunications data used are the annual fixed price component converted to monthly. These data correspond to Canada (1996), Denmark and France (2000), Italy (1996, 1998, 2000), Netherlands (2000), Spain (1998, 2000), Sweden (1998, 2000), United States (1996, 1998 and 2000). Interpolated data points are Belgium, Canada, Italy and the United States (1997). The data for Colombia (2000) were located at http://www.asocel.org.co/. Initial (1995) PRICE data for Burkina Faso, the Sudan and Togo are missing because there were zero mobile subscribers. In order to calculate meaningful PRICE points to correspond to zero subscribers, the intercept price was calculated from a linear extrapolation from the line of best fit, in effect creating a virtual price. Interpolated data points are Cambodia (1998), Nicaragua (2000), Pakistan (1996, 1998), Viet Nam (1997, 1998), Tunisia (2000). Data for Hungary (2000) were located at http://www.westel900.net/dijcsomagok/alapszolgaltatas_e.html. PRICE is a simple average of market leader Westel's Eurofon I, Eurofon II, Eurofon III and MobilMester packages as of 29 February 2000. Missing data point for Israel (2000) is kindly provided in index form by the Central Bureau of Statistics. Annual index numbers converted to growth rates and the growth factor for 1999–2000 are multiplied by the 1999 ITU price to yield a currency-based measure. An average monthly mobile subscription price for Nicaragua at 2000 was interpolated from the 2002 value. This 2002 value was sourced from the National Nicaraguan Telecommunications Regulatory website at http://www.telcor.gob.ni/. This average value for 2002 was $417.97 (local currency unit) and did not include the 'extra' plans. Poland (1997, 1998 and 1999) was sourced from Teligen. Monthly rental is the arithmetic average of subscription rates for pricing plans: Halo, White, Simply, Blue, Navy-Blue and VIP.

A.3. Gross domestic product

Values corresponding to Cambodia, Central African Republic, Fiji, Japan and Kenya (2000) are sourced from the *World Development Indicators 2002*, World Bank. Values for Sudan (1998, 1999, 2000) are from *World Development Indictors 2002*, World Bank.

A.4. Residential monthly telephone subscription price

Ireland, Netherlands, and Sweden (2000) are sourced in *Communications Outlook 2001*, OECD, from Table 7.18, p. 204. Canada and Sweden (1998) are sourced from *Communications Outlook 1999*, OECD, Table 7.22, p. 190. Missing observations for China (1995, 1996) were sourced directly from staff at ChinaNex.com. Columbia (2000) was sourced from Colciencias, Colombian Institute for the Development of Science and Technology. The year 2000 residential monthly fixed line subscription price was taken directly from the National Nicaraguan Telecommunications Regulatory website at http://www.telcor.gob.ni/. It is defined there as the basic residential subscription price and is quoted in the local currency unit. Further, it states on this website that this tariff maintains its value in relation to the US dollar as of the 10th of June 2000.

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