A Dynamic Flexible Partial-Adjustment Model of International Diffusion of the Internet

Minkyu Lee
Techno-Economics and Policy Program,
College of Engineering, Seoul National University,
San 56-1 Shinlim-dong, Kwanak-gu, Seoul 151-744, Korea
E-mail: minkyu21@snu.ac.kr
and
Almas Heshmati
The RATIO Institute and
Techno-Economics and Policy Program,
College of Engineering, Seoul National University,
San 56-1 Shinlim-dong, Kwanak-gu, Seoul 151-744, Korea
E-mail: heshmati@snu.ac.kr

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Abstract

The paper introduces a dynamic, flexible partial-adjustment model and uses it to analyze the diffusion of Internet connectivity. It specifies and estimates desired levels of Internet diffusion and the speed at which countries achieve the target levels. The target levels and speed of adjustment are both country and time specific. Factors affecting Internet diffusion across countries are identified, and, using nonlinear least squares, the Gompertz growth model is generalized and estimated using data on Internet users for 59 countries observed over the years 1995 to 2002. The empirical results show that infrastructure variables such as personal computer ownership and telephone service increase the equilibrium level of internet diffusion. The speed of adjustment toward a target level decreases over time. Regarding model performance, the generalized dynamic Gompertz model that accounts for unobserved country heterogeneity effects outperforms other, simpler and static model specifications.

JEL classification Numbers: C23, L86, L96, O33, O57

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1. Introduction

The products and services related to information technology (IT) play an ever increasing role in the economies of the world's nations, particularly the newly industrialized nations. The IT industry contributes much to the potential of new economies to develop and prosper. The Internet, in particular, has been described as one of the three major technological breakthroughs of the modern world,[1] with the other two technologies being the steam generator and electricity (Edquist & Henrekson, in press). The Internet can improve efficiencies and add to a nation's ability to build a "knowledge-based economy" in a stable fashion, given that several studies have found that in addition to facilitating communication and the flow of information, the Internet has spillover effects on other industries.

There exists a strong positive correlation across countries between gross domestic product (GDP) per capita and Internet connectivity; moreover, the presence or absence of the Internet is a factor contributing to the widening of inequality and income differentials between countries (Kiiski & Pohjola, 2002). The Internet is a major technological innovation with key political and social consequences. Politically, access to the Internet is expected to build up participatory democracy and has been used as an indicator of a country's level of democracy and tolerance. Socially, Internet access can act as a moderator of inequality in opportunity by making information available at low cost to everyone without discrimination, but it can contribute to increasing inequality when such access is unequally distributed among populations (Hargittai, 1999).

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1 The Internet is the publicly accessible worldwide network of interconnected computer networks that transmit data by packet switching using a standardized Internet protocol without regard for location. It is made up of thousands of smaller commercial, academic, domestic, and government networks. It carries various information and services, such as electronic mail, online chat, and the interlinked Web pages and other documents of the World Wide Web.

Despite the productivity, connectivity, and many other recognized and measurable positive effects associated with the Internet, a widening international “digital divide” between and within countries following the recent decades of rapid development and diffusion of the Internet is a serious issue of concern. The digital divide is the socioeconomic difference between communities associated with access to computers and the Internet. The term refers to gaps between groups in their abilities to access and use IT services, due to differing literacy and technical skills, and the gap in availability of useful digital content. The problem is often discussed in an international context, indicating developed countries are far better equipped than developing countries to use the advantages of rapidly expanding Internet technology. A look at the worldwide geographical distribution of Internet users (see Table 1) shows that in 2002 users in Sub-Saharan Africa constituted only about 1% of the world’s total.

Table 1 about here

The more rapidly the rate at which Internet technology is developed and spread, the more the quality-of-life differences between developed and undeveloped countries become evident and significant. To judge from Figure 1, it appears that inequalities in opportunities, skills, and resources lead to a disturbing trend: the gap between high-income countries and low-income countries measured in Internet users per 100 inhabitants increases over time.[2]

Figure 1 about here

This paper introduces a flexible, dynamic partial-adjustment model by which to analyze the international diffusion of Internet services. It specifies and estimates respective countries’ desired level of Internet diffusion and the speed at which countries try to

[2] Country classification is based on the World Bank’s classifications according to countries’ gross national income per capita in 2004. (World Bank, 2004)

attain their target levels of diffusion.[3] Thus the desired level as well as the speed of diffusion are both country and time specific. Several factors that affect the diffusion of the Internet across countries are identified. The Gompertz growth model is generalized to accommodate such flexibilities and estimated using data on Internet users for a sample of 59 developed and developing countries observed over the years 1995 to 2002. The empirical results show that personal computers and telephone main lines are among factors that increase the level of Internet diffusion. The speed of adjustment toward the target level of diffusion decreases over time as the overall diffusion level increases. The generalized dynamic Gompertz model accounting for country heterogeneity effects outperforms the simpler and static model specifications. In sum, the results show evidence of significant heterogeneity in both the level of optimal Internet diffusion and its adjustment across countries and over time.

This paper is organized as follows. Section 2 discusses the theoretical basis for our diffusion model. Section 3 reviews relevant literature on dynamic technology diffusion models. Section 4 discusses the empirical model and estimation procedures used. A description of the study's data and variables is provided in section 5. The performance of different models, the model selection, and the empirical results are discussed in section 6. Finally, section 7 presents conclusions and possible directions for future research.

2. The Theoretical Model

The diffusion of an innovation has been defined as "the process by which that innovation is communicated through certain channels over time among the members of

[3] Any changes in the internet connectivity are towards a desired level which is the optimal level of diffusion from the producer's perspective. Given the conditions we assume this is corresponding to the equilibrium level. Thus, the terms desired, optimal and equilibrium are used interchangeably in this paper.

a social system" (Rogers, 2003). The elements of diffusion are the innovation, the channels of communication, time, and the social system. Diffusion has a cumulative adoption distribution of the form of an S-shaped (sigmoid) curve. In the initial stages of the diffusion process, a few members of the social system adopt the innovation. In subsequent time periods, an increasing number of adoptions occur at an increasing rate. Finally, the trajectory of the diffusion curve slows and begins to level off, reaching an upper asymptote corresponding to the maximum potential number of users of the technology (Mahajan & Peterson, 1985).

In the IT literature one finds three models that are frequently used to analyze technology diffusion: the Bass model, the Gompertz model, and the logistic growth model. The Bass (1969) model is a general model often used to explain the diffusion of a new technology with an S-shaped diffusion pattern. In the Bass model, it is assumed that consumers can be divided into two groups: innovators and imitators. Each group's members are motivated to purchase the product differently. That is to say, innovators are affected only by external factors, such as mass communication, regardless of who else is purchasing the technology, but imitators adopt the product on the basis of word of mouth of cumulative adopters.

In an analysis of the performance of the Bass model, Meade and Islam (1995) report that in the case of telecommunications equipment, the estimates of the innovation coefficient were negative for every time series, and the model was thus reestimated with the innovation coefficient constrained to be zero.[4] Such constraint means that the theoretical division of potential adopters into innovators and imitators is not an appropriate representation of the adoption of telecommunications equipment. In

[4] In Meade and Islam's study, the local logistic, simple logistic, and Gompertz models outperformed the other growth curve models considered.

addition, given that telecommunications services are interactive in nature, it appears to us that the diffusion of Internet services, with its late takeoff, exhibits a significant degree of asymmetry. Thus, on the basis of fitness criteria, we have chosen the Gompertz model instead of the Bass or the logistic growth models.[5]

Dixon (1980) has shown that the Gompertz model, with its long-tailed diffusion curve characteristics, is appropriate for data that exhibit a significant degree of asymmetry. Dixon describes a model developed to study the spread of hybrid corn in the United States as a case study in the economics of technological change, expressed as follows:

(1) $$P_{it} = K_i \alpha_i^{\beta_i T},$$

where P represents the proportion of the total corn acreage of a state, K_i is the ceiling value of corn acreage (= 1.00), and α and β are unknown parameters to be estimated. The subscripts i and t indicate observation and time periods, while the variable T represents a time trend.

The differential and rate-of-growth equations for the Gompertz diffusion model outlined in equation 1 may be written as the following relations:

(2) $$\frac{dP_{it}}{dt} = (\ln \beta_i)(P_{it})(\ln(P_{it} / K_i)).$$

(3) $$\frac{dP_{it}}{dt} \cdot \frac{1}{P_{it}} = (\ln \beta_i)(\ln P_{it} - \ln K_i).$$

Dixon found that the Gompertz model was preferred to the logistic model in 27 out of a total of 31 cases in the case of the diffusion of hybrid corn.

Using the Gompertz model, Kiiski and Pohjola (2002) estimated the diffusion of Internet hosts per capita at the country level.[6] The model, in the form of a partial-adjustment process, is written as follows:

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[5] The logistic growth curve is appropriate for data that exhibit a significant degree of symmetry.

[6] A host is a computer through which users access network services.

(4) $\ln H_{it} - \ln H_{it-1} = \alpha_i (\ln H^*_{it} - \ln H_{it-1})$.

(5) $\ln H^*_{it} = \beta_{i0} + \beta_{i1} \ln Y_{it} + \beta_{i2} \ln P_{it} + \gamma ' Z_{it}$.

Inserting equation 5 into equation 4 and rearranging the relation, the model specified in terms of observable factors is written

(6) $\ln H_{it} - \ln H_{it-1} = \alpha_i \beta_{i0} + \alpha_i \beta_{i1} \ln Y_{it} + \alpha_i \beta_{i2} \ln P_{it} + \alpha_i \gamma ' Z_{it} - \alpha_i \ln H_{it-1}$,

where H_{it} denotes the number of Internet hosts per capita in country i in year t, H^* is the corresponding optimal or target level, and α is the speed at which the current level of Internet connectivity diffuses toward the optimal level of connectivity. Kiiski and Pohjola assume that the equilibrium level of Internet hosts per capita is a function of other observable variables such as GDP per capita and Internet access cost, but they assume the speed of adjustment is invariant both across sample countries and over time.

Yet the assumption of invariant speed of adjustment is unrealistic. In this study we relax that assumption. In other words, we allow the optimal level of connectivity and the speed of adjustment to vary by both country and time. Both of them are specified as functions of observable variables. Furthermore, we allow for nonlinearity of the relation and estimate the model by using an iterative estimation procedure whereby both optimal level of connectivity and speed of adjustment are estimated simultaneously.

3. A Review of the Literature

Although study of the diffusion of Internet connectivity is a relatively new area of focus, various studies exist focusing on how to model that diffusion and how to compare Internet penetration across countries. Several works were mentioned in the previous section, and here we review a number of others relevant to the current study. The objective is to put our model into context and not necessarily to provide a comprehensive review of the literature.

Gatignon, Eliashberg, and Robertson (1989) developed an econometric model for the diffusion of innovations at the individual-country level that allows the parameters of the process to differ systematically across the sample countries. Then, specific variables characteristic of a country such as cosmopolitanism, mobility, and sex roles can affect the innovation coefficient and imitation coefficient of the Bass model. Thus, their model allows for heterogeneity in both the intercepts and the slopes. Kumar, Ganesh, and Echambadi (1998) investigated how to identify factors that explain why the adoption process differs among countries. As a result, the clustering of countries with similar diffusion patterns is possible.

The two multinational diffusion studies mentioned in the previous paragraph describe estimated diffusion parameters, which are then used as a dependent variable affected by other country-specific characteristics. However, a one-step procedure is desired, as that would prevent the inconsistency in the underlying assumptions of the two steps. The present study is a one-step procedure in that it estimates the technology diffusion process and, in addition, explains variations in the desired level and the speed at which technology diffuses over time and across countries.

In a third study, Dekimpe, Parker, and Sarvary (2000) looked at global adoption processes by observing countries that had sequentially adopted cellular technology. They attempt to learn how exogenous variables (such as country demographics and economic, political, and social factors) and an endogenous variable (elapsed time) affect the diffusion process of cellular technology. The results suggest that a global demonstration effect exists and counties whose GDP per capita is relatively high adopt cellular technology early.

Hargittai (1999) analyzed variations in the number of Internet hosts per 100 inhabitants across Organisation for Economic Co-operation and Development (OECD) countries for the year 1998. She relates variations in the density of Internet hosts to several explanatory variables measuring economic indicators—such as human capital, institutional legal environment, and existing technological infrastructure. Hargittai concludes that economic wealth and telecommunications policy are especially important explanatory factors affecting the diffusion of the Internet.

In a more recent study, Kiiski and Pohjola (2002) investigated the factors that determine the diffusion of Internet connectivity across countries by using the Gompertz model specification. The model, presented in the previous section, serves as a starting point, or benchmark, for the current study. Kiiski and Pohjola conclude that the observed growth rate in the number of Internet hosts per capita is best explained by GDP per capita and Internet access cost. Their sample includes both developing and developed countries.

The present study extends Kiiski and Pohjola's framework in a number of ways. First, as an indicator representing the diffusion of Internet connectivity, we take into consideration not only the number of Internet hosts per capita but also the number of Internet users per 100 inhabitants. Thus, not only diffusion but intensity of use of the Internet are represented, which is a more thorough measure of penetration of the Internet. Second, in view of each country's respective economic conditions, the speed of adjustment in the Gompertz model is represented as a function of country- and time-variant variables, so that the model is non-constant and less restrictive compared with previous models we have cited. Furthermore, it is a one-step procedure, avoiding the disadvantages of a two-step estimation procedure.

4. Empirical Model and Estimation Method

For the reasons already stated, we employ the Gompertz model in this study. It is expressed as follows:

(7) $$\frac{dY_{it}}{dt} = \delta_{it} Y_{it-1} (\ln Y_{it}^{*} - \ln Y_{it-1}) + e_{it} ,$$

where Y_{it} represents the number of Internet users per 100 inhabitants in country *i* in period *t*, Y_{it}^{*} is the equilibrium level, δ_{it} is the speed of adjustment toward the equilibrium level, and e_{it} is the stochastic disturbance term, which traditionally in econometrics is assumed to have mean zero and constant variance. However, the model is rewritten in log-log form as follows:

(8) $$\frac{d \ln Y_{it}}{dt} = \delta_{it} (\ln Y_{it}^{*} - \ln Y_{it-1}) + e_{it} .$$

(9) $$\ln Y_{it} = (1 - \delta_{it}) \ln Y_{it-1} + \delta_{it} \ln Y_{it}^{*} + e_{it} .$$

The equilibrium level can be expressed as the optimal or target level of Internet penetration as well. The modeling in equation 9 is similar to the model of capital structure introduced in Heshmati (2001). In his study, the optimal leverage ratio (debt to total capital) and the speed of adjustment are allowed to vary across firms and over time. In order to extend the Gompertz model, we use Heshmati's framework. Let the equilibrium-level variable for country i at time t be

(10) $$\ln Y_{it}^{*} = F(Z_{it}, X_{i}, X_{t}) ,$$

a function, $F(.)$, of a vector of country- and time-variant variables, Z_{it}, determining the optimal level of Internet users, where X_{i} and X_{t} are country-specific and time-specific effects. Thus, the equilibrium level is allowed to vary across countries and time. The speed of adjustment δ_{it} may itself be a function, $G(.)$, of some underlying variables, written as

(11) $$\delta_{it} = G(N_{it}, M_{i}, M_{t}) ,$$

where N_{it} is a vector of country- and time-variant variables determining the speed of adjustment. The M_i and M_t are country-specific and time-specific effects. We assume the following general functional relationship for $\ln Y_{it}^*$:

(12) $$\ln Y_{it}^* = \alpha_0 + \sum_j \alpha_j Z_{jit} + \sum_s \alpha_s X_s + \sum_t \alpha_t X_t ,$$

and the following form for the speed of adjustment δ_{it}:

(13) $$\delta_{it} = \beta_0 + \sum_k \beta_k N_{kit} + \sum_s \beta_s M_s + \sum_t \beta_t M_t .$$

Since the model in equation 9 is nonlinear in parameters, we use a nonlinear regression procedure to estimate it, where $\ln Y_{it}^*$ and δ_{it} are specified as vector of determinants of equilibrium level (Z: computer, telephone subscriptions, and urbanization); vector of determinants of the speed of adjustment (N: Gini index of income inequality, monthly telephone subscription rate, GDP per capita, and average years of schooling); and vector of unobservable (X and M: time trend, unobservable country-specific) effects.

For the purpose of comparison, we also present results from the model if the speed of adjustment δ_{it} is taken to be constant (as in traditional dynamic partial-adjustment models) and if country dummy variables are not included (corresponding to a pooled model).

To estimate the nonlinear regression model, TSP (Time Series Processor), version 4.5, a computer package widely used for the computation, is executed.

5. Data and Variables

The data are obtained from various secondary sources. GDP per capita in U.S. dollars at constant (1995) prices and average years of schooling are from the World Bank's *World Development Indicators 2004* (2004). The Gini index measuring income inequality in a country is obtained from the World Income Inequality Database (United Nations University/World Institute for Development Economics Research, 2005).[7] Telecommunications data are from *World Telecommunication Indicators 2004* (International Telecommunication Union, 2004).

The sample includes data covering 59 countries observed over an eight-year period, from 1995 to 2002. The total number of observations is 472 (59 × 8). The sample is small, but it includes most OECD members and several developing countries.[8] In terms of population, land area, or GDP, the data cover a significant portion of global Internet use. Table 2 shows the country classifications by Internet users per 100 inhabitants as of 2002. The data indicate that among the 59 countries in the analysis, Sweden has the most Internet users per 100 inhabitants. In contrast, the fewest number of users are found in Nepal and Uganda. On the whole, OECD countries are leaders in terms of number of Internet users per 100 inhabitants.

Table 2 about here

Table 3 describes the variables used in this study and presents some summary statistics. According to the Gini index, the lowest levels of income inequality are found in the Slovak Republic and Sweden, whereas the greatest levels are found in South Africa and Zimbabwe. Because they represent necessary infrastructure for Internet connectivity, personal computers and telephone main lines are taken into consideration. The average number of personal computers per 100 inhabitants is 14.70. In terms of GDP per capita, Japan and Switzerland are the wealthiest countries in the sample. With regard to average years of schooling, the United States and Norway lead the way in education.

7 The Gini coefficient is defined as the ratio of the area between the Lorenz curve of the distribution and the curve of the uniform distribution to the area under the uniform distribution.

8 Among the OECD's 30 member countries, only the Czech Republic, Iceland, and Luxembourg are not included in our analysis.

Table 3 about here

With respect to the determinants of equilibrium level, personal computers per 100 inhabitants, telephone main lines per 100 inhabitants, the level of urbanization, and country dummy variables are considered. Use of the Internet requires adoption of a computer and, as a means of connection, the presence of telephone lines. We expect that such telecommunications infrastructure indicators have a positive effect on the equilibrium level. We include an urbanization-share variable that represents the level of urban population relative to total population of the area. Generally, a high ratio of urbanization results in a rapid change from local livelihoods such as agriculture or more traditional local services to modern industry and urban and related commerce. In addition, people in urban areas are more inclined to be well informed about new technologies. We expect a positive relationship between urbanization and equilibrium level. Notwithstanding the inclusion of the determinants listed above, unobservable country-specific effects may still exist. Thus, we include country dummies to capture unobserved country heterogeneity.

Secondly, the Gini index, cost, time trend, time trend squared, GDP per capita, and average years of schooling are included in the model as determinants of speed of adjustment in Internet technology diffusion. The Gini index, representing income inequality, is a number between the extreme cases of 0 and 1, where 0 corresponds to perfect equality (i.e., everyone in a society has the same income) and 1 corresponds to perfect inequality (i.e., one person has all the income, and everyone else has zero income). It seems probable that people in countries with relatively more income equality have an easier time accessing the Internet and that consequently the diffusion speed there would be more rapid. Hence, we expect the Gini index to have a negative effect on the speed of adjustment. Clearly, if the cost to access the Internet is relatively expensive, that reduces the incentive for low-income people to pay for Internet usage and to adopt the Internet. Unfortunately, collecting data on monthly Internet access costs in all of the 59 countries has been impossible, and the monthly telephone subscription cost at the country level is assumed to be a proxy of Internet access cost.

We include the variables time trend as well as time trend squared to better capture the nonlinear S-shaped curve. GDP per capita, as a measure of the size of a country's economy, is often used as an indicator of standard of living. People in countries with a relatively high GDP per capita can easily adopt the Internet. We therefore expect GDP per capita to have a positive effect on the speed of adjustment. On the whole, better-educated people are more likely to early-adopt new technologies than less-educated ones. Accordingly, it is expected that the education variable, measured as average years of schooling, will have a positive effect on Internet adoption.

6. Empirical Results

6.1. Model Selection

The results of the nonlinear least squares regression estimation of the dynamic, flexible partial-adjustment Gompertz model (equation 9) specified in accordance with the above are reported in Table 4.

Table 4 about here

In this section, we focus on issues related to the fit and explanatory power of the model. Three alternative specifications of the model are estimated. They differ in degree of flexibility in the speed of adjustment toward the target level of Internet use. The objective is to determine whether the flexible diffusion model that uses the flexible adjustment parameter δ and incorporates unobservable country-specific effects (Model 3) offers better modeling than the restricted model that uses the constant δ

(Model 1) or the intermediate model that uses the flexible δ but does not account for country-specific effects (Model 2).

The issue of model selection is examined by determining which of the three models is a better fit for modeling the diffusion pattern of Internet connectivity. To do so, we compare the models' respective root-mean-square error ($RMSE$) and coefficient of determination (R^2) values:

$$(14) \qquad RMSE = \sqrt{\frac{\sum_{t=1}^{7}\sum_{i=1}^{59}(Y_{it} - \hat{Y}_{it})^2}{413}}.$$

As Table 4 illustrates, the superiority of Model 3 over Model 1 and Model 2 is confirmed by the lower $RMSE$ and the higher R^2 value. In the meantime, Model 2 has better explanatory power than Model 1, given the lower $RMSE$ (0.68 versus 1.09) and the higher R^2 value (0.89 versus 0.69). The key difference between Model 1 and Model 2 is that the latter includes flexible speed-of-adjustment parameters. Model 3, though, compared with Model 2, accounts for unobservable country effects by adding country dummy variables. In addition, we try to compare the models' forecasting performance for the year 2003 using $MAPE$ (the mean absolute percentage error) and $RMSE$ (the root-mean-square error—also known as the standard deviation, or dispersion-in-prediction error). The two measures are obtained as follows:

$$(15) \qquad \text{Forecast } MAPE = \left(\frac{1}{59}\sum_{i=1}^{59}\frac{|Y_{i8} - \hat{Y}_{i8}|}{Y_{i8}}\right) \times 100\%, \text{ and}$$

$$(16) \qquad \text{Forecast } RMSE = \sqrt{\frac{1}{59}\sum_{i=1}^{59}(Y_{i8} - \hat{Y}_{i8})^2}.$$

Table 5 about here

As Table 5 indicates, Model 3 has the lowest forecast $MAPE$ (22.83%) and $RMSE$ (5.52) of the three models. As a whole, we find that the flexible partial-adjustment model (Model 3), with the speed-of-adjustment parameters and an equilibrium diffusion level incorporating country dummy variables, offers a more complete representation of Internet diffusion in the sample countries. Following a number of joint Chow tests conducted to select a model from among the three models, Model 3 is chosen as the appropriate model of Internet diffusion. However, test results show that the intermediate model (Model 2) is preferred Model 3 ($F_{58,392} = 2.28$) suggesting absent of significant unobserved country heterogeneity at the less than 1% level of significance (critical value < 2.32). The weak preference given to Model 3 indicate that Model 2 is not much different than Model 3 but it has more significant slope parameter estimates. Thus, the subsequent analysis will be based on the estimation results from the intermediate model specification, Model 2. This is interpreted as the equilibrium diffusion levels of Internet usage are not likely to be constant across countries, and the inclusion of unobservable country-specific variables might be essential to the estimation of the dynamic model.

6.2. Estimation Results

In the analysis of the determinants of the equilibrium level of Internet diffusion, the variables of computers, telephones, urbanization, and unobservable country-specific dummy variables are taken into consideration. The computer coefficient has a statistically significant positive sign in all three models. A relatively high density of personal computers in the population increases the equilibrium level of Internet diffusion. In the same manner, the telephone main line coefficient is statistically significant and positive in Model 1 and Model 2. In Model 2, the computer coefficient implies that a 1% increase in the number of computers will lead to 1.99% increase in the number of Internet users in the equilibrium, whereas a one unit increase in the number of telephone subscribers per 100 inhabitants will lead to 6.28% increase in the number of Internet users per 100 inhabitants. In Model 2, comparing those values, we find that the effect of telephone main lines is greater than that of personal computers. The number of personal computers and telephone main lines are indicators of the level of available telecommunications infrastructure.

Those results suggest that developing a country's telecommunications infrastructure contributes to an increase in the Internet diffusion equilibrium level. In accordance with our expectation, urbanization, as well, has a positive impact on the equilibrium level. The positive association supports the hypothesis that people in urban areas are more accustomed to adopting new technologies than their rural counterparts. A 1% increase in urbanization leads to 1.43% increase in Internet diffusion. In Model 3, the country dummy variables from M2 to M59 measure deviation from the reference country, Argentina. For example, the equilibrium level of Australia is higher than that of Argentina by 1.2590, the coefficient of M2, while it is higher than that of Zimbabwe (M59: –0.4329), but statistically insignificant. In this manner, we can find the equilibrium level by taking into consideration each country's unobservable country-specific factors.

Among the determinants of speed of adjustment, three country-characteristic variables—Gini index, Internet access cost, and GDP per capita—are statistically insignificant. That might be because inequality is low among the developed countries, and the level of GDP per capita and Internet cost does not affect diffusion, as the Internet has become a natural part of life in such countries. The measure of educational attainment—average years of schooling—has a negative effect in Model 2 and no impact in Model 3. Instead, the coefficient of time trend and its square—representing the rate of technological change—are statistically significant, indicating the speed of adjustment is nonlinear. Time trend has a negative impact, and its square term has a positive effect. Internet diffusion is decreasing, but at a decreasing rate.

In this quadratic model, to measure the percentage change of the dependent variable with respect to changes in time trend, we need to take into account the total effect, including the square coefficient. In Model 3, the turning point will be when the time trend equals 5.78. The speed of adjustment decreases in time trend at first, but will turn around at the turning point and will increase in time trend. That is reasonable because it can catch the S-shaped diffusion curve. Actually, in the early stage the diffusion speed is high, but it decreases gradually over time. That is consistent with what is found in the convergence literature, where the initial level of diffusion is negatively correlated with the speed of convergence toward the optimal, or equilibrium, level of diffusion. Somewhat unexpectedly, GDP per capita is not statistically significant in Model 2 or Model 3, indicating that GDP per capita plays no role in the speed of adjustment of Internet diffusion. Contrary to our expectation, the average-years-of-schooling variable also does not seem to explain the speed of adjustment.

In sum, the findings show that elements of telecommunications infrastructure (telephone line, personal computer) are the most important factors determining the diffusion of the Internet among the sample of 59 countries. An increased level of education has a positive effect on the rate of diffusion. Therefore, to promote the diffusion of the Internet, countries should consider investing in telecommunications infrastructure and conducting a progressive policy toward that sector in anticipation of positive spillover effects on the rest of the economy. A final point—the speed of adjustment decreases in the early stage of diffusion, but will increase after a turning point of 5.78 years.

7. Summary and Conclusions

This empirical study has two purposes: (1) to examine factors that influence the diffusion of Internet connectivity across a sample of 59 developed and developing countries; and (2) to specify the Gompertz model by applying it to panel data from the sample countries for the years 1995 to 2003. The sample consists of most of the OECD countries and several developing and newly industrialized economies. It covers a significant share of the recent years of diffusion of Internet connectivity at the global level.

Based on the Gompertz model, we specify a dynamic model with partial adjustment incorporating the equilibrium level of Internet diffusion and flexible speed of adjustment toward a target level of Internet diffusion. The model incorporates unobservable country-specific effects. The model is found to have a better fit and a higher explanatory power based on its having the lowest root-mean-square error, the lowest mean prediction error, and the highest adjusted R^2. Similarities in the signs and significance levels of coefficients in the three alternative model specifications with various degrees of flexibility suggest that the underlying structure of the dynamic model is appropriate.

Computer penetration and telephone line density, measuring the telecommunications infrastructure, have positive effects on the equilibrium level of diffusion of Internet connectivity, indicating that investment in the telecommunications infrastructures can raise the equilibrium level of diffusion of Internet connectivity. Looking at the speed of adjustment, we find that the effect of time trend on adjustment speed is nonlinear. That is to say, the rate of adjustment decreases in the early stages as time passes, but it will increase after a turning point in the time trend. Surprisingly, the results of this study suggest that the basic reasons for the global divide in Internet access are not strongly related to country wealth.

This research provides a framework for examining network diffusion on a global scale.

In addition, policymakers attempting to bridge the digital divide can use the results presented here. For example, governments of developing countries would be wise to subsidize households in the purchase of computers and to support institutions that promote the penetration of personal computers. Such countries should invest in building effective communications networks to improve access to the Internet, more so than in lowering Internet access costs. Promoting increased telephone line density would be another policy target. Deregulation of the telecommunications sector might enhance connectivity diffusion. In the meantime, the results strongly suggest that the diffusion of Internet connectivity is not stable over time, and consequently policymakers will need to design and employ fluid policies over time.

It must be noted that despite its significant contributions, this study has a number of limitations. First, to refine further the model specification, comparison with other models, such as the logistic growth model, might be useful. Second, our analysis should ideally be supplemented by additional, more detailed information (on both the macro and micro levels)—such as data on competition among Internet service providers, public policy initiatives, the structure of the telecommunications market, and cultural situations. Third, because of lack of availability of data, we made use of monthly telephone subscription costs as a proxy for monthly Internet access costs. Finally, to improve coverage and allow inferences at the global level of Internet diffusion (and contribute to reducing the digital divide), the data set must be expanded to incorporate more developing countries.

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Table 1. Worldwide Geographical Distribution of Internet Users, 2002

World Region	Number of Internet Users (millions)	Percentage of World Users
World Total	622.98	100.00
East Asia & Pacific	181.63	29.16
Europe & Central Asia	176.42	28.32
Latin America & Caribbean	42.83	6.87
Middle East & North Africa	13.28	2.13
North America	175.11	28.11
South America	18.59	2.98
Sub-Saharan Africa	6.49	1.04

Sources: International Telecommunication Union, 2004.

Table 2. Number of Internet Users per 100 Inhabitants, 2002

0 ~ 10	11 ~ 20	21 ~ 30	31 ~ 40	41 ~ 50	51 ~ 60
Nepal	Argentina	Jamaica	France	Austria	Norway
Uganda	Greece	Poland	Malaysia	UK	Singapore
Ghana	Hungary	Chile	Belgium	Hong Kong	Netherlands
Sri Lanka	Slovak Rep.	Ireland	Switzerland	Germany	Finland
Kenya	Spain	Israel	Italy	Japan	Denmark
India	Portugal		Slovenia	Australia	Canada
Nicaragua				New Zealand	USA
Gambia					Korea
Indonesia					Sweden
Egypt					
Bolivia					
Guatemala					
Ecuador					
Zimbabwe					
Philippines					
Colombia					
Iran					
Venezuela					
Tunisia					
Jordan					
South Africa					
Turkey					
Thailand					
Brazil					
Peru					
Mexico					

Sources: International Telecommunication Union, 2004.

Table 3. Variables and Summary Statistics

Variable	Description	Mean	Std Dev	Minimum	Maximum
Internet	Internet users per 100 inhabitants	10.58	0.66	0.00035	57.31
Computer	Personal computers per 100 inhabitants	14.70	0.75	0.05	70.87
Telephone	Telephone main lines per 100 inhabitants	29.46	1.08	0.20	75.76
Urban	Urban population share over total population (%)	63.99	1.00	12.20	100.00
GINI	Gini index	40.88	0.50	25.11	73.20
Cost	Monthly telephone subscription cost (US $)	11.75	0.56	0.14	147.78
Trend	Time trend (year, 1995)	4.00	0.82	1.00	7.00
Trend2	Time trend square (year, 1995)^2	20.00	17.68	1.00	49.00
GDP	GDP/capita in 1995 U.S. $	12574.69	608.63	24.20	46894.90
Education	Average years of schooling	7.30	0.12	2.00	12.00
M2-M59	Country dummy variable	0.02	0.01	0.00	1.00

Sources: World Bank, 2004; International Telecommunication Union, 2004; United Nations University/World Institute for Development Economics Research, 2005.

Note: Number of observations is 59 × 8 = 472.

Table 4. Nonlinear Least Squares Estimation Results, Based on 472 Observations.

Variable	Model 1		Model 2		Model 3	
	Estimate	Std Err	Estimate	Std Err	Estimate	Std Err
A. Determinants of equilibrium level						
Intercept	–1.9385***	0.2532	–2.9860***	0.2553	–3.0350*	1.6984
Computer	0.0307***	0.0095	0.0199*	0.0102	0.0380**	0.0168
Telephone	0.0454***	0.0073	0.0628***	0.0069	0.0369	0.0403
Urbanization	0.0194***	0.0045	0.0143***	0.0040	0.0071	0.0163
M2					1.2590	1.1511
M59					–0.4329	1.2509
B. Determinants of speed of adjustment						
Intercept	0.7695***	0.0377	2.1762***	0.1452	2.1899***	0.1476
GINI coeff			–0.0027	0.0020	–0.0033	0.0021
Cost			–0.0047	0.0054	–0.0005	0.0062
T (trend)			–0.7548 ***	0.0544	–0.8003***	0.0697
T squared			0.0697***	0.0067	0.0692***	0.0085
GDP			0.3456E-05	0.3064E-05	–0.3319E-05	0.3821E-05
Education			–0.0448***	0.0110	–0.0002	0.01160
Adjusted R^2	0.6940		0.9256		0.9541	
RMSE	1.1675		0.6346		0.4746	

Notes: Model 1 is characterized by constant speed of adjustment. Model 2 incorporates flexible speed of adjustment but ignores country heterogeneity effects. Model 3 incorporates both flexible speed of adjustment and unobserved country heterogeneity effects.

The superscripts ***, **, and * indicate statistically significant at 1%, 5%, and 10%.

Table 5. Comparison of Prediction Performance, for 2003, Using *MAPE* and *RMSE*

	Model 1	Model 2	Model 3
MAPE (%)	59.2053	42.7568	22.8264
RMSE	17.9990	10.0461	5.5178

Note: MAPE = mean absolute percentage prediction error; RMSE = root-mean-square error.

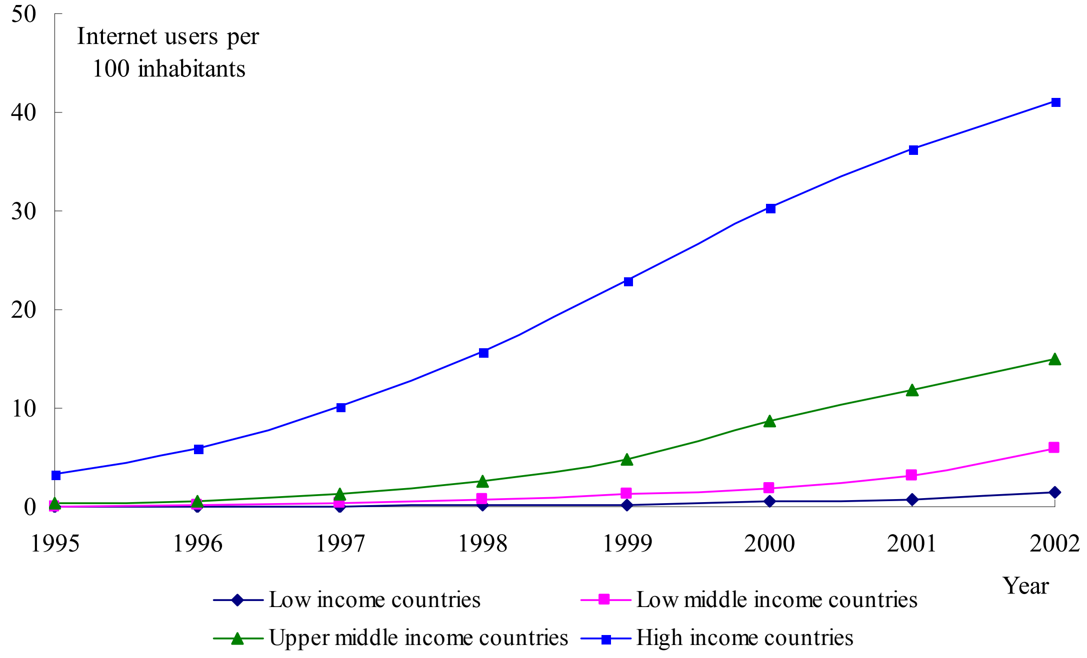

Figure 1. Diffusion of Internet Connectivity According to Country Classification by Income