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ICT Use in the Developing World: An Analysis of Differences in Computer and Internet Penetration

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Abstract

Using panel data for 161 countries, we explore the determinants of cross-country disparities in personal computer and Internet penetration. We find evidence indicating that income, human capital, the youth dependency ratio, telephone density, legal quality, and banking sector development are associated with technology penetration rates. Estimates from Blinder–Oaxaca decompositions comparing rates in the developed-country total to developing countries (Total, Brazil, China, Indonesia, India, Mexico, and Nigeria) reveal that the main factors responsible for low rates of technology penetration rates in developing countries are disparities in income, telephone density, legal quality, and human capital. In terms of dynamics, our results indicate fairly rapid reversion to long-run equilibrium for Internet use, and somewhat slower reversion for computer use.

1. Introduction

The rapid diffusion of computers and Internet use has been a fixture of the global landscape over the past decade. Estimates from the International Telecommunications Union's (ITU) World Telecommunication Indicators Database indicate that world personal computer penetration (the number of PCs per 100 people) rose from 4.2 in 1995 to more than 12 in 2004 (see Figure 1). Internet use grew even faster, from less than 1% to 13.7% (Figure 2). The dispersion of information technology use to the developing countries has also been remarkable. For the less developed countries (LDCs), there were only six computers per 1000 people and four Internet users per 10,000 people in developing countries. The computer/population ratio climbed to 3.7 computers per 100 people and the percent of the population using the Internet grew to nearly 6% by 2004.[1]

Despite this rapid rate of penetration in developing countries, a large digital divide remains between the developed and developing world. This gap is especially pronounced in African countries. For example, in Nigeria there are 0.68 computers and 1.39 Internet users per 100 people in 2004. On the other hand, some developing countries have much higher rates. Among the largest developing countries, Brazil and Mexico have the highest computer rates (11 per 100 people) and Internet use rates (12–13 per 100 people). Overall, there exists a substantial amount of variation in rates of technology use between developed and developing countries and even across the set of developing countries.[2]

In this paper we build on the findings of Chinn and Fairlie (2007), which examines the determinants of cross-country differences in computer and Internet penetration from

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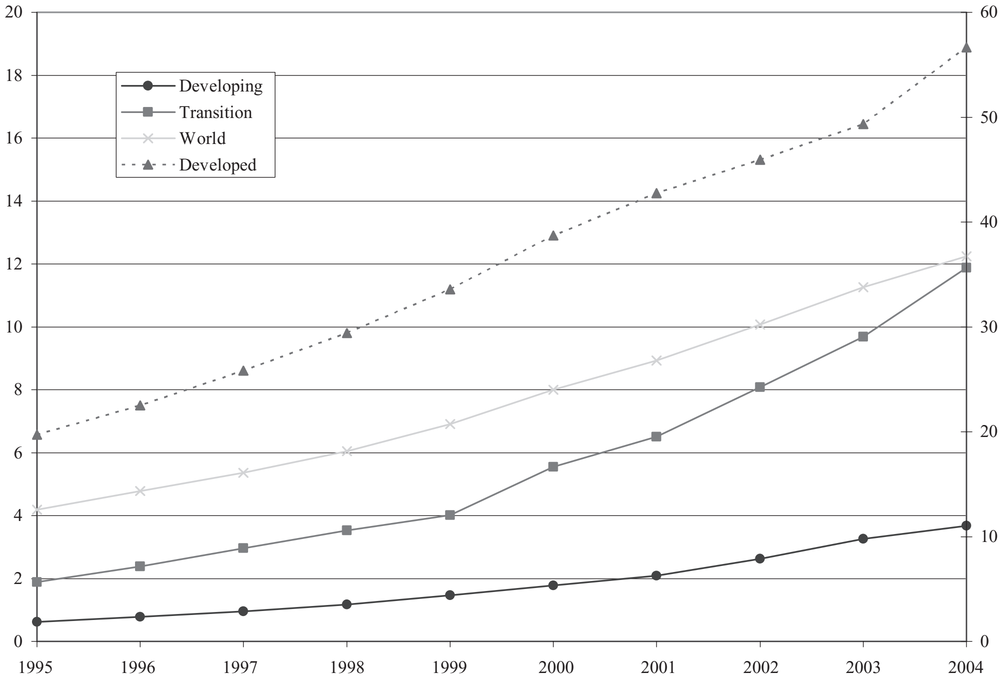

Figure 1. Computer Penetration Rates by Country Type (ITU 1995–2004)

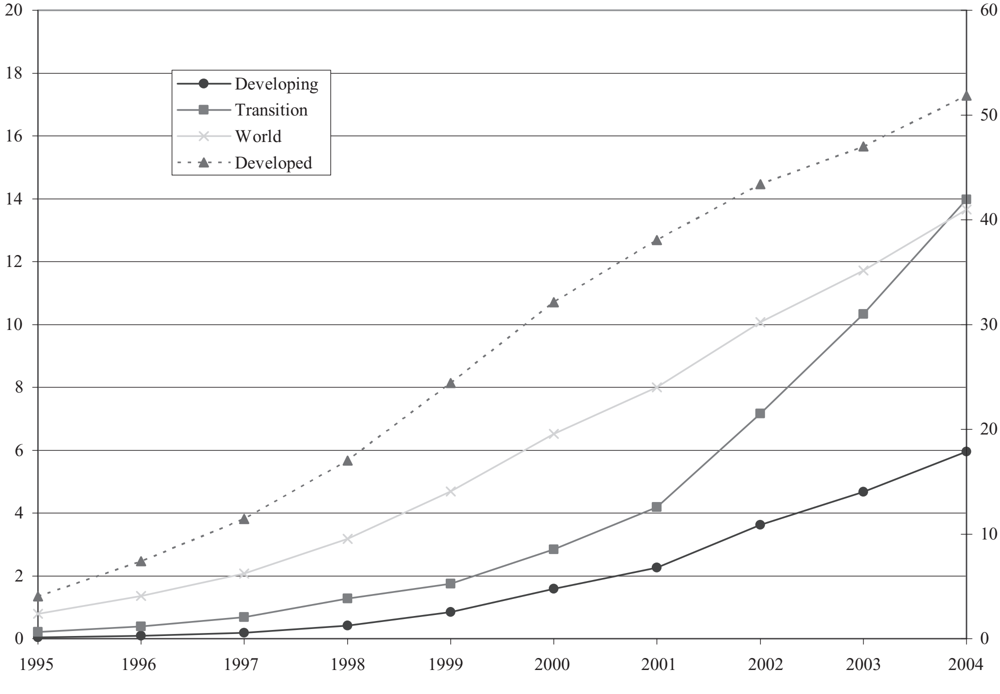

Figure 2. Internet Penetration Rates by Country Type (ITU 1995–2004)

1999 to 2001, by examining patterns in more recent years. Income per capita, years of schooling, illiteracy, youth and aged dependency ratios, the urbanization rate, telephone density, electricity consumption, and regulatory quality are found to be associated with computer and/or Internet penetration rates in the earlier period. A limitation of this study and the literature more generally is that there is no comprehensive empirical study of technology use in developing countries that includes a large number of developing countries and includes an extensive set of controls for economic, demographic, infrastructure, institutional, and financial variables.[3] We also provide the first estimates of the importance of financial openness and quality of access to financial capital in explaining computer and Internet penetration rates, and the first detailed analysis of the determinants of the rapid growth rates in technology that have occurred recently. We undertake a systematic analysis of the relative importance of different factors in contributing to the differences across developing countries using a technique commonly used to decompose earnings gaps between groups (Blinder, 1973; Oaxaca, 1973). Finally, we provide a new examination of the determinants of cross-country differences in rates of technology diffusion, which is important because static analysis may miss important aspects of the technology diffusion. Some countries may be away from their respective long-run equilibrium levels of technology penetration.

2. The Determinants of Computer and Internet Use

Empirical Model of Computer Use

We estimate several reduced-form equations for computer penetration rates that include infrastructure, demographic, economic, institutional quality or policy variables, and financial variables. We first turn to the results for computer penetration rates from 2002–04, which are reported in Table 1. In column (1), the results indicate that there are a number of clearly identifiable determinants of computer use. Unsurprisingly, income per capita comes in as a powerful determinant of PC use; each $1000 increase in per capita income is associated with a 1.7 percentage point increase in the number of PCs per capita. Also not unexpectedly, human capital appears to be important. A one-year increase in average schooling is associated with roughly a 1.5 percentage point increase in PC penetration. Recent research on the determinants of computer ownership using micro data also finds strong relationships between computer ownership, and income and education (see Fairlie, 2004, and Ono and Zavodny, 2005, for example).

One surprising result is the importance of telephone line density. A one percentage point increase in this variable is associated with a 0.3 percentage point increase in PC penetration. It is hard to interpret this result; it may be there are complementarities between computers and telephone lines. Telephone lines may be important for one of the most common uses of computers, accessing the Internet. Another explanation is that countries that have a well-developed communication infrastructure are also likely to have other unobservable attributes that encourage PC use.

We also include measures of telephone costs in the computer penetration regression, mostly to retain the consistency of the specifications across the two types of technology. While telephone costs may affect computer adoption through Internet use, which is one of the main uses of personal computers, our estimates do not provide strong evidence of such a relationship. Both monthly telephone subscription charges and the cost of three-minute local calls have statistically insignificant coefficients in the computer penetration regressions.

Table 1. Computer Penetration Rate Regressions (2002–04)

	Specification				
Explanatory variables	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*
Main telephone lines per 100 people	0.3141	0.3608	0.2894	0.2942	0.2762
	(0.1164)	(0.1276)	(0.1333)	(0.1073)	(0.0955)
Monthly telephone subscription charge	–0.0189	–0.0168	–0.0640		
	(0.0655)	(0.0685)	(0.0818)		
Cost of three-minute local call	–4.8559	–4.8667	–7.0884		
	(3.8358)	(4.1236)	(4.6178)		
Electric power consumption (kWh per capita)	–0.0007	–0.0009	–0.0006		
	(0.0011)	(0.0013)	(0.0013)		
Population ages 0–14 (% of total)	0.6360	0.6507	0.5148	0.5507	0.2731
	(0.2333)	(0.2569)	(0.2691)	(0.1937)	(0.1756)
Population ages 65 and above (% of total)	–0.6412	–0.8679	–0.9740	–0.7563	–0.6100
	(0.4432)	(0.5126)	(0.5115)	(0.4134)	(0.3744)
Urban population (% of total)	–0.0933	–0.0567	–0.0452	–0.0205	–0.0190
	(0.0596)	(0.0676)	(0.0643)	(0.0509)	(0.0430)
Gross national income per capita (000s)	1.6948	1.6803	1.5682	1.7328	1.7124
	(0.2649)	(0.2959)	(0.3009)	(0.2230)	(0.1964)
Years of schooling	1.4555	1.2997	1.7843	0.7466	
	(0.6430)	(0.7075)	(0.7671)	(0.5609)	
Rule of law	2.0991	2.8534	2.6947	0.2115	–0.7675
	(2.0201)	(2.3442)	(2.3140)	(1.8815)	(1.5066)
Trade in goods (% of GDP)	0.0273	0.0190	0.0131	0.0121	0.0149
	(0.0186)	(0.0248)	(0.0252)	(0.0195)	(0.0179)
Financial openness		–0.0900	–0.2159	0.0381	0.0273
		(0.6749)	(0.7357)	(0.5324)	(0.4728)
Private credit by banks and other financial institutions/GDP		0.3457		2.4619	1.9805
		(3.1363)		(2.8051)	(2.6362)
Stock market total value traded/GDP			3.3105		
			(2.0922)		
Illiteracy rate					0.0020
					(0.0531)
Average computer penetration rate	20.29	20.84	23.56	17.72	15.17
Sample size	221	197	170	240	301

Notes: (1) The dependent variable is the number of personal computers per 100 people. (2) Estimates account for country-level random effects. (3) Standard errors are reported below coefficient estimates.

We do not find that higher rates of electricity consumption are associated with higher rates of computer penetration after controlling for other factors. This is somewhat surprising because access to electricity is essential for the use of personal computers. The reported specification includes a modified measure of electricity consumption in which values in excess of 6000 kWh per capita are top coded at the value (which represents a clear breakpoint in the bivariate relationship), but an unmodified measure of electricity consumption also results in a negative and statistically insignificant coefficient estimate. The problem may be due to collinearity with income, as the two variables are strongly correlated. We find a positive and statistically significant coefficient estimate on our electricity consumption variable after removing income from the equation.

Demographic variables generally enter in with the expected signs. A higher proportion of youth is associated with greater rate of PC use. Children may generate a stronger demand for technology, especially for educational purposes. Although statistically insignificant at conventional levels, the point estimate for ages 65 and above is negative, providing suggestive evidence that the elderly have a lower demand for technology either for personal use or because of absence from the labor force. The coefficient estimate on the percent of the population located in urban areas is negative and statistically insignificant at conventional levels.

In the next set of variables, we find that the rule of law is not statistically significant.[4] Openness to trade also enters the equation with a positive and statistically insignificant coefficient at conventional levels. We also include a few financial variables that have not been previously examined in this context. First, we include a measure of financial openness (see column (2)). There appears to be no relationship between financial openness and computer penetration. We also include a measure of the development of the banking sector in the country. Specifically, we measure the ratio of private credit by deposit money banks and other financial institutions to GDP. The coefficient estimate on this variable is also small and statistically insignificant. In column (3), we replace this measure with the ratio of the total value traded on the stock market to GDP. The coefficient is positive, but statistically insignificant. Overall, the financial openness of the economy and level of internal financial development do not appear to be correlated with computer penetration after controlling for income and other factors.

To increase the sample size substantially, we exclude the telephone cost variables which are not statistically significant in any of the specifications (column (4)). We also drop electricity consumption, which is missing for many countries. The results for income, telephone density, and youth are robust to increasing the sample of countries. The main change is that the coefficient on years of schooling is now smaller and statistically insignificant at conventional levels. We also try excluding average years of schooling and replacing it with the illiteracy rate (column (5)). The illiteracy rate has a small and statistically insignificant coefficient.

Internet Use

We now take up the results for Internet penetration rates. To maximize comparability with the results for PC penetration rates, we retain the same basic set of regressors in our specifications. The Internet results are somewhat different than the computer results. Income has a smaller coefficient, but remains statistically significant. An increase of $1000 is associated with slightly less than a one percentage point increase in the Internet penetration rate in column (1). The same increase in income is associated with a larger, 1.7 percentage point, increase in the computer penetration rate. The finding is consistent with Internet service being relatively inexpensive compared to the cost of purchasing personal computers. This is especially true in some parts of the developing world where Internet cafés are an important source of access (Wallsten, 2005). The association between Internet penetration and education is also weaker. In this case, the coefficient estimates are positive, but statistically insignificant in all specifications. The coefficient on illiteracy is positive, but statistically insignificant.

Another difference in the results is that telephone density is not a statistically significant determinant of Internet use in some of the specifications. This is somewhat surprising given the statistically significant coefficient on this variable in the computer penetration regressions. We should note, however, that the telephone density is close to statistical significance in some of the specifications and is statistically significant in the final specification that includes a broader sample of 331 observations. By dropping the access costs and increasing the number of countries to include more developed countries in this specification, we are increasing the variability of telephone density so that this factor's signal-to-noise ratio is increased. The coefficient using this broader set of countries is not substantially different than the computer penetration coefficient. The smaller Internet penetration coefficient on telephone density may also be due to a nonlinearity in the relationship that we are not capturing or the different ways of measuring the two dependent variables (i.e. Internet users vs number of personal computers).

Some of the Internet results are surprising. Counter to the conventional wisdom, we find that the Internet access pricing proxies—the monthly telephone subscription charge and the average cost of a three-minute local call—do not enter in with statistical significance. These results may differ from those reported in Dasgupta et al. (2005) and Liu and San (2006) because we examine a more recent period (2002–04), and a different sample of countries. In particular, the effect that Mann et al. (2000) identify—that high per minute charges may negatively affect Internet use more than a high monthly subscription charge—may be swamped by other factors in our broader cross-country sample.

The demographic variables are not good predictors of Internet access, with the potential exception of the youth dependency ratio. Having a young population is associated with higher Internet penetration rates, but is statistically significant at conventional levels in only one of the reported specifications. The elderly population percent and urban percent have inconsistent signs across specifications and are statistically insignificant in all specifications.

The quality of legal institutions in a country *is* associated with Internet penetration. The coefficient estimate on rule of law is large and positive in all specifications and statistically significant in most specifications.[5] Using the median reported coefficient estimate, a one standard deviation increase in rule of law is associated with a five percentage point increase in Internet penetration. In contrast to these results, we find that trade openness is not statistically significant in its relationship with Internet penetration. The finding of a positive effect of trade openness in other studies may reflect the omission of a regulatory or legal policy variable such as the one we include in our regressions.

The estimates reported in Table 2 do not provide evidence that financial openness or the relative level of the stock market development matter for Internet penetration, but they do provide evidence that banking sector development is important.[6] The coefficient on banking sector development is large and positive in all specifications and statistically significant in most specifications. The level of development of the banking sector may be important in providing loans to Internet providers and businesses needing to purchase IT equipment.

We also conducted several robustness checks including country fixed effect models and regression models that weight countries by their population. In both cases, we generally find similar results. We also estimate separate regressions for developing countries and all other countries. We find that the factors associated with computer and Internet penetration do not differ substantially between developing and more developed countries. See Chinn and Fairlie (2006) for more discussion of these results.

Table 2. Internet Penetration Rate Regressions (2002–04)

Explanatory variables	*Specification* (1)	(2)	(3)	(4)	(5)
Main telephone lines per 100 people	0.0889	0.0971	0.0759	0.1263	0.2163
	(0.1199)	(0.1283)	(0.1406)	(0.1123)	(0.1035)
Monthly telephone subscription charge	0.0370	0.0308	–0.0071		
	(0.0605)	(0.0613)	(0.0782)		
Cost of three-minute local call	–3.9731	–3.3835	–3.7733		
	(3.3398)	(3.3129)	(3.6419)		
Electric power consumption (kWh per capita)	0.0008	0.0009	0.0015		
	(0.0012)	(0.0014)	(0.0014)		
Population ages 0–14 (% of total)	0.4460	0.5927	0.4994	0.3471	0.1762
	(0.2690)	(0.2947)	(0.3222)	(0.2192)	(0.1921)
Population ages 65 and above (% of total)	0.0248	0.1791	–0.1253	–0.0283	0.3354
	(0.5046)	(0.5745)	(0.6029)	(0.4659)	(0.4112)
Urban population (% of total)	–0.0017	0.0570	0.0631	0.0579	0.0521
	(0.0693)	(0.0774)	(0.0780)	(0.0583)	(0.0476)
Gross national income per capita (000s)	0.9636	0.7930	0.6587	1.0664	0.7053
	(0.2810)	(0.3125)	(0.3304)	(0.2383)	(0.2136)
Years of schooling	0.9995	0.9711	1.3508	0.6758	
	(0.7368)	(0.8043)	(0.9152)	(0.6340)	
Rule of law	5.9491	5.2261	8.7481	2.3046	2.3349
	(2.1681)	(2.5006)	(2.6257)	(1.9584)	(1.5837)
Trade in goods (% of GDP)	0.0044	0.0024	–0.0144	0.0069	0.0171
	(0.0195)	(0.0246)	(0.0264)	(0.0189)	(0.0177)
Financial openness		–0.4032	–1.0225	–0.1007	0.6194
		(0.6757)	(0.7856)	(0.5471)	(0.4938)
Private credit by banks and other financial institutions/GDP		5.8935		6.7487	7.2865
		(3.3235)		(3.0227)	(2.8765)
Stock market total value traded/GDP			0.3267		
			(1.9302)		
Illiteracy rate					0.0307
					(0.0564)
Average computer penetration rate	21.58	22.10	25.16	18.33	16.02
Sample size	235	211	180	266	331

Notes: (1) The dependent variable is the number of Internet users per 100 people. (2) Estimates account for country-level random effects. (3) Standard errors are reported below coefficient estimates.

3. Explanations for the Global Digital Divide

Methodology

The regression analysis presented above reveals that factors such as income, human capital, telecommunications, rule of law, and banking sector development may contribute to the global digital divide. The analysis, however, does not identify the relative importance of these factors in contributing to the alarming differences between developing countries and developed countries. To explore these issues further we borrow from a technique of decomposing inter-group differences in a dependent variable into those due to different observable characteristics across groups and those due to different "prices" of characteristics of groups (see Blinder, 1973; Oaxaca, 1973).[7] The Blinder–Oaxaca technique can also be used to decompose a gap between any two countries. In particular, the difference between an outcome, Y, for groups i and j, can be expressed as:

$$\bar{Y}^i - \bar{Y}^j = \left(\bar{X}^i - \bar{X}^j\right)\hat{\beta}^i + \bar{X}^j\left(\hat{\beta}^i - \hat{\beta}^j\right), \tag{1}$$

where $\bar{X}^i$ is a row vector of average values for the individual-level characteristics and $\hat{\beta}^i$ is a vector of coefficient estimates for group i. The first term in the decomposition represents the part of the gap that is due to group differences in average values of the independent variables, and the second term represents the part due to differences in the group processes determining the outcome, which is often referred to as the "unexplained" component.

The technique is commonly modified to use coefficients from a pooled sample of both groups, $\hat{\beta}$, to weight the first expression in the decomposition (see Oaxaca and Ransom, 1994, for example). We adopt this approach to calculate the decompositions. In particular, we use coefficient estimates from regressions that include all countries in our sample (reported in column (2) of Tables 2 and 3). We then denote the average for all developed countries as the base or reference group and calculate the decomposition for computer and Internet penetration rate gaps between the developed-country average and several large developing countries. The technique allows us to quantify the separate contributions from differences in income, human capital, telephones, and other factors, to the gaps in computer and Internet penetration rates between the developed-country average and developing country j.

Computer Use Contributions

Table 3 reports the results for contributions to the gaps in computer penetration rates between the average for developed countries and several of the largest developing countries and an average for all developing countries. The decomposition is performed for the four largest developing countries—China, India, Indonesia, and Brazil. We also report decomposition estimates for Nigeria and Mexico which are the seventh and eighth largest developing countries, respectively. All developing countries have substantially lower computer penetration rates than the developed-country average. The computer penetration rate is 50.5% for developed countries.

The largest single factor contributing to the disparities in computer penetration rates is per capita income. Income differences explain 43.7 percentage points of the gap between developed and developing countries. The large contributions to the computer penetration rate gaps are not surprising considering the enormous disparities in income levels between developed and developing countries. The average per capita income (PPP adjusted) in developed countries is $30,108 compared to $4085 in developing countries. The income gap is likely affecting computer penetration by way of the cost relative to income. A personal computer costing $1000 represents one-fourth of a person's average annual income in developing countries. Interestingly, the explanatory power of income differs somewhat across countries. For example, income differences explain 35.1 percentage points of the computer penetration rate gap for Mexico, whereas these differences explain 50.7 percentage points of the gap for Nigeria.

Another important factor in contributing to the computer penetration rate gaps is per capita telephone lines. This factor explains 16.1 percentage points of the overall gap

Table 3. Computer Penetration Rate Decompositions Relative to Developed Country Total (2002–04)

	Developing						
	Total	*Brazil*	*China*	*Indonesia*	*India*	*Mexico*	*Nigeria*
Computer penetration rate gap	47.3	41.5	46.9	49.2	49.5	40.9	49.8
Contribution from:							
Main telephone lines per 100 people	16.1	11.7	12.8	18.4	18.4	14.1	22.2
Monthly telephone subscription charge	–0.1	0.1	–0.1	–0.1	0.0	0.1	0.2
Cost of three-minute local call	0.3	0.2	0.2	0.0	0.1	0.6	1.2
Electric power consumption (kWh per capita)	–4.5	–3.6	–4.2	–4.9	–4.9	–3.7	–5.2
Population ages 0–14 (% of total)	–8.4	–5.8	–3.3	–7.2	–9.0	–8.9	–12.9
Population ages 65 and above (% of total)	–7.9	–7.8	–6.3	–8.3	–8.1	–8.0	–12.3
Urban population (% of total)	–2.1	0.3	–2.3	–1.9	–2.8	–0.2	–1.0
Gross national income per capita (000s)	43.7	37.7	42.1	45.1	45.8	35.1	50.7
Years of schooling	6.1	6.7	4.9	6.5	6.4	3.7	
Rule of law	5.3	4.8	5.2	6.6	4.1	4.9	9.3
Trade in goods (% of GDP)	–0.1	0.3	–0.4	–0.1	0.4	–0.3	–0.1
Financial openness	–0.3	–0.2	–0.3	–0.1	–0.3	–0.2	0.4
Private credit by banks and other financial institutions/GDP	0.4	0.4		0.4	0.4	0.4	0.5

Notes: (1) The dependent variable is the number of personal computers per 100 people. (2) Coefficient estimates are reported in Table 3, Specification (2). (3) All contribution estimates are relative to the developed-country total.

between developed and developing countries, and from 11.7 to 22.2 percentage points of the gaps for specific countries. These results suggest that the assertion that the global digital divide is just a manifestation of a long-standing disparity in telecommunications access appears to be partly true (Dasgupta et al., 2005). Interestingly, however, the effects of differences in telecommunications infrastructure are not due to costs, at least as measured by monthly subscription and per minute telephone charges. The contributions from these factors are essentially zero for all countries.

Human capital disparities, as measured by years of schooling, contribute to the divide between developed and developing countries. Differences in education explain 6.1 percentage points of the total developed/developing country gap, and from 3.7 to 6.7 percentage points of the individual country gaps even after controlling for differences in income. Computers require some education for use, limiting demand in countries with relatively low levels of human capital. Hence, we confirm the findings of Caselli and Coleman (2001) and Pohjola (2003).

Developing countries generally have younger populations than developed countries, a factor which provides a negative contribution to the computer penetration rate gaps.

Table 4. Internet Penetration Rate Decompositions Relative to Developed-Country Total (2002–04)

	Developing						
	Total	*Brazil*	*China*	*Indonesia*	*India*	*Mexico*	*Nigeria*
Internet penetration rate gap	42.7	37.2	41.4	43.3	45.2	35.4	46.6
Contribution from:							
Main telephone lines per 100 people	4.3	3.2	4.3	5.0	5.0	3.8	6.6
Monthly telephone subscription charge	0.1	–0.2	0.3	0.2	0.0	–0.1	0.5
Cost of three-minute local call	0.2	0.1	0.1	0.0	0.0	0.4	0.8
Electric power consumption (kWh per capita)	4.5	3.6	4.2	4.9	4.9	3.7	5.2
Population ages 0–14 (% of total)	–7.7	–5.3	–2.7	–6.6	–8.2	–8.1	–12.4
Population ages 65 and above (% of total)	1.6	1.6	–0.6	1.7	1.7	1.7	0.9
Urban population (% of total)	2.1	–0.3	1.5	1.9	2.8	0.2	2.6
Gross national income per capita (000s)	20.6	17.8	24.3	21.3	21.6	16.6	24.3
Years of schooling	4.6	5.0	3.8	4.9	4.7	2.8	
Rule of law	9.7	8.8	11.2	12.1	7.5	8.9	16.1
Trade in goods (% of GDP)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Financial openness	–1.2	–1.0	–1.5	–0.5	–1.4	–0.8	–0.8
Private credit by banks and other financial institutions/GDP	6.3	6.0		6.9	6.2	7.1	7.2

Notes: (1) The dependent variable is the number of Internet users per 100 people. (2) Coefficient estimates are reported in Table 3, Specification (2). (3) All contribution estimates are relative to the developed-country total.

In other words, the computer penetration rate gaps would be even larger if developing countries had older populations more similar to the developed world. In particular, a larger percent of the population in developing countries is between the ages of 0 and 14 years, which leads to higher demand for computers, all else equal.

Most other factors provide small contributions to the gaps in computer penetration rates between developed and developing countries. This finding is consistent with the relatively small and statistically insignificant coefficients on these variables in the regression models. One exception is that the point estimate, although insignificant, on rule of law and large differences in average values for this measure lead to a positive contribution of roughly five percentage points. The imprecision of the coefficient estimate and lack of robustness across alternative specifications reported in Table 2 provide some uncertainty regarding the importance of this factor.

Internet Use Contributions

Table 4 reports the results for contributions to gaps in Internet penetration rates between developed and developing countries. The Internet rate is 47.4% in developed countries compared to 4.8% in developing countries (a 42.7 percentage point gap). Similar to the results for the computer gaps, income differences are the most important factor. For differences in Internet penetration, however, the explanatory power is somewhat smaller. For example, income differences explain 20.6 percentage points of the gap in Internet penetration between developed and developing countries. This finding is consistent with the cost of Internet access being substantially lower than the cost of purchasing a personal computer and the prevalence of Internet cafés providing inexpensive access in some developing countries (Wallsten, 2005).

The second most important factor contributing to differences in Internet penetration rates is rule of law. Overall, differences between developed and developing countries in this measure explain nearly 10 percentage points of the Internet penetration rate gap. The quality of legal institutions may represent an important barrier to increasing Internet penetration in developing countries. This appears to be especially likely in Nigeria, where 16.1 percentage points of the Internet penetration rate gap is explained by lower-quality legal institutions than in the developed world. For comparison, income differences explain 24.3% of the gap for Nigeria.

Differences in the development of the banking sector explain part of the gaps in Internet penetration rates. For all developing countries, this factor explains 6.3 percentage points of the Internet gap. The contribution estimates for large developing countries do not vary substantially, contributing 6.0 to 7.2 percentage points to the gaps. Restricted access to credit provided by the banking sector may limit investment in IT equipment in many developing countries.

The decomposition estimates indicate positive contributions from differences in access to telephones, electricity, and human capital, but the original coefficient estimates are statistically insignificant limiting the confidence placed on these estimates. In no cases, however, are these contributions large even with imprecisely measured coefficients. The contribution estimates from the telephone cost variables are very small. Similar to the results presented above, the relative youth of developing countries mitigates the extent of the digital divide.

4. The Dynamics of ICT Diffusion and Adoption

Modeling Issues

Estimates from the 2002–04 panel regressions shed light on the determinants of current disparities in computer and Internet penetration for developing countries, but do not highlight the dynamics associated with the diffusion and adoption of new information and communication technologies *over time*. As noted above, computer and Internet penetration rates among developing countries have risen dramatically over the past several years. To examine this issue more closely, we appeal to the large literature on technology adoption. Many models of technology adoption incorporate a type "S"-shaped curve of use; early references include Stoneman's (1976) early study of computer use. As Geroski (2000) observes, there are many different types of theoretical models that are reconcilable with such patterns, ranging from exotic ones such as epidemic models and information cascades, to more prosaic partial adjustment models.

We choose to use a Gompertz model, which implies an asymmetric "S" time-path for technology penetration. This specification was also adopted by Kiiski and Pohjola (2002) in their examination of the diffusion of the Internet, although we apply this to a broader set of countries over a more recent period, and use a different measure of technology diffusion.

Let y denote the log value of the variable of interest, and $\tilde{y}_i$ be the post-diffusion or equilibrium level of penetration:

$$y_{it} - y_{it-k} = \varphi_1(\tilde{y}_i - y_{it-k}). \tag{2}$$

This specification has the flavor of an error-correction model (ECM) commonly used in time-series analysis. However, one key difference is that $\tilde{y}_i$ is the current equilibrium, rather than the lagged, as would be the case in a conventional ECM. Assuming the equilibrium is time-invariant would make the two specifications identical. Then φ_1 has the interpretation of being the rate of reversion to equilibrium.

We allow for time variation in the equilibrium value of y. Letting X_{it} denote the determinants of $\tilde{y}_{it}$ leads the following specification:

$$y_{it} - y_{it-k} = -\varphi_1 y_{it-k} + X_{it}B. \tag{3}$$

Empirical Implementation

We undertake these dynamic regressions using the same set of explanatory variables as those discussed in section 2. In principle, the lag length and the horizon over which the growth rate is calculated can take on any value. However, because there is so much noise in year-to-year changes, we undertake some averaging by way of examining the *average* growth rate over five years (hence the coefficients on the lagged log technology penetration ratios can be taken as the annual rate of reversion).

Estimates for computer and Internet penetration are reported in Table 5. For all computer specifications, the reversion coefficients uniformly show up as statistically significant. The half life of a deviation from the long-run equilibrium ranges between 11 and 17 years. It is important to understand that this does *not* mean that the gap between current levels of PC use and PC use in the country will disappear in 11–17 years; rather half the gap between the current levels of computer use and the *long-run equilibrium* level of use implied by current per capita income, current telephone density, etc., is eliminated in this period, on average. Since the right-hand-side variables are also moving over time, the actual time taken to close half the gap may be longer.

In column (1), the pricing variables enter in significantly, with the price of a three-minute call negatively related to computer penetration. On the other hand, the subscription price has a positive effect, although this result might be rationalized by the fact that high prices are correlated with good telephone service (in terms of connectivity). Dropping the telephone pricing and electricity variables, in column (2), does not substantially change the nature of the results, with the exception of the coefficient on the bank lending variable. This statistically significant result indicates that higher levels of private credit to GDP lead to a higher equilibrium computer penetration rate. The different result probably arises from the expanded sample (about 30% larger). If a stock market variable is substituted for the bank lending variable, the sample size drops while the qualitative nature of the estimates on the other coefficients is unchanged.

For the Internet penetration regressions (columns (4)–(6)), the results are clearer. In all instances, the rate of reversion to equilibrium is again statistically significant; indeed the rate of diffusion is even more rapid than in the case of computers. Half of the gap between the current level of internet penetration and the equilibrium is eliminated in between seven and eight years.

The number of telephone main lines is statistically significant across specifications, although—interestingly—the pricing variables do not exhibit significance, just as they

Table 5. Technology Penetration Dynamics

	Specification					
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Dependent variable	*Computer*	*Computer*	*Computer*	*Internet*	*Internet*	*Internet*
Lagged log technology penetration level	–0.0416	–0.0407	–0.0610	–0.0972	–0.0988	–0.0824
	(0.0206)	(0.0141)	(0.0160)	(0.0247)	(0.0173)	(0.0167)
Main telephone lines per 100 people	–0.0330	–0.0151	–0.0313	0.0771	0.0642	0.0642
	(0.0250)	(0.0174)	(0.0202)	(0.0363)	(0.0248)	(0.0236)
Monthly telephone subscription charge	0.0427			0.0040		
	(0.0143)			(0.0199)		
Cost of three-minute local call	–0.0412			–0.0062		
	(0.0138)			(0.0192)		
Electric power consumption (kWh per capita)	–0.0092			–0.0072		
	(0.0209)			(0.0257)		
Population ages 0–14 (% of total)	–0.1766	–0.1235	–0.0933	0.0198	0.0615	0.0939
	(0.1166)	(0.1090)	(0.1114)	(0.1424)	(0.1362)	(0.1172)
Population ages 65 and above (% of total)	–0.1068	–0.0482	–0.0423	0.0629	0.0736	0.0688
	(0.0765)	(0.0589)	(0.0616)	(0.0928)	(0.0738)	(0.0660)
Urban population (% of total)	–0.0365	0.0215	0.0357	0.0450	0.0575	0.0555
	(0.0459)	(0.0297)	(0.0329)	(0.0650)	(0.0386)	(0.0344)
Gross national income per capita (000s)	0.0648	0.0358	0.0859	–0.0761	–0.0517	–0.0977
	(0.0377)	(0.0299)	(0.0361)	(0.0513)	(0.0384)	(0.0372)
Years of schooling	0.0214	–0.0034	0.0064	–0.0707	–0.0019	0.0233
	(0.0415)	(0.0293)	(0.0494)	(0.0579)	(0.0360)	(0.0551)
Rule of law	0.0042	–0.0276	–0.0207	–0.0049	–0.0308	–0.0121
	(0.0274)	(0.0196)	(0.0214)	(0.0347)	(0.0257)	(0.0242)
Trade in goods (% of GDP)	–0.0007	–0.0020	0.0037	0.0234	0.0318	0.0201
	(0.0199)	(0.0172)	(0.0181)	(0.0262)	(0.0216)	(0.0201)
Financial openness	0.0006	–0.0005	0.0020	0.0139	0.0136	0.0108
	(0.0082)	(0.0066)	(0.0076)	(0.0105)	(0.0087)	(0.0085)
Private credit by deposit money banks and other financial institutions/GDP	0.0174	0.0431		0.0205	0.0198	
	(0.0201)	(0.0163)		(0.0276)	(0.0211)	
Stock market total value traded/GDP			0.0057			0.0140
			(0.0043)			(0.0045)
Observations	56	73	60	63	82	66
R-squared	0.55	0.36	0.5	0.78	0.72	0.79

Notes: (1) The dependent variable is the five-year difference in the log number of personal computers per 100 people, in columns (1)–(3); and five-year difference in the log number of Internet users per 100 people in columns (3) and (4). (2) Standard errors are reported below coefficient estimates.

failed to evidence importance in the static regressions. Generally, there are few statistically significant coefficients, but this is likely a result of the relatively small sample size.

Once the telephone pricing and electricity variables are dropped from the regression, the sample size increases by about a third. The estimated rate of reversion is slightly higher, and while no other coefficients are statistically significant at conventional levels, trade openness and financial openness are significant, with the expected sign, at the 15% and 12% levels. Finally, substituting the stock market measure of financial development for the bank lending measure leaves the other coefficients largely unchanged,[8] while financial development now enters with a high level of statistical significance.

Note that in many cases the static regressions yield levels of statistical significance for certain coefficients different from those obtained in these dynamic regressions (although the signs of the coefficients typically agree). In particular, there are far fewer instances of statistical significance in the dynamic regressions; this indicates to us that it is hard to precisely identify the long-run parameters. On the other hand, given the high level of statistical significance for the estimated reversion coefficients, the dynamic regressions clearly indicate that some countries are away from their long-run levels of technology penetration. The estimation of the dynamic equations provides insights into the trajectory of these economies over time.

5. Conclusions

In this study, we have identified several results that have informed our understanding of the various determinants of the digital divide between developed and developing countries. First, as in earlier work, we confirm the importance of per capita income in explaining the gap in computer and Internet use. This factor remains the single largest factor in our static regressions. Second, we find that in a broad sample encompassing developed and developing countries, telephone access pricing variables do not exhibit statistical or economic importance in explaining the Internet gap. Third, the level of legal development is important. Differences in legal development as measured by the Rule of Law index sometimes account for substantial portions of the gaps in technology use. Our estimates suggest that over one-tenth of the aggregate Internet penetration rate gap might be closed if less developed countries had similar legal development as the average level in developed economies. Finally, in our dynamic regressions we find that the evidence for reversion to long-run equilibrium is pronounced for both technologies when the entire sample is taken into account. The evidence in favor of reversion is more muted for PC penetration when examining a fairly small and homogeneous sample of developed economies. On the other hand, in casting the net wider to encompass a diverse set of developing countries, reversion to equilibrium in Internet use is readily detectable. Moreover, we find that the gaps between current and equilibrium levels of technology penetration are shrinking faster for Internet use than for PC use. However, our modeling results are consistent with the conclusion that even if developing and developed countries were at their long-run equilibrium levels of technology penetration, gaps would still remain between penetration rates in the two groups because the determinants differ. In other words, economic growth alone is insufficient to close the global digital divide.

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Notes

1. Higher rates of Internet use than computers per capita in developing countries may be due to the preponderance of Internet cafés in many of these countries (Wallsten, 2005).
2. See Chinn and Fairlie (2006) for estimates by country.
3. See Chinn and Fairlie (2006, 2007) for a review of the literature.
4. We also estimate a specification that includes a related measure—regulatory quality. Fairlie and Chinn (2007) find using earlier data (1999–2002) that regulatory quality has a positive and statistically significant relationship with computer penetration. Instead, we find a small negative and statistically insignificant coefficient for the 2002–04 period.
5. We also try specifications with a measure of regulatory quality, but find statistically insignificant coefficients.
6. Other measures of stock market development were also tested. These include including stock market capitalization to GDP ratio, and the stock market turnover ratio.
7. See Fairlie (2005) for a nonlinear version of the decomposition appropriate for a logit or probit model.
8. The GNI per capita variable now enters with a statistically significant negative sign; this result only occurs with the smaller sample, and we conjecture it arises because of the multicollinearity between lagged log Internet penetration ratio and the log per capita income level (the two are correlated with a coefficient of about 0.80).