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Kenneth L. Kraemer

*Paul Merage School of Business, University of California, Irvine*

Dale Ganley

*Paul Merage School of Business, University of California, Irvine*

Sanjeev Dewan

*The Paul Merage School of Business, University of California, Irvine*

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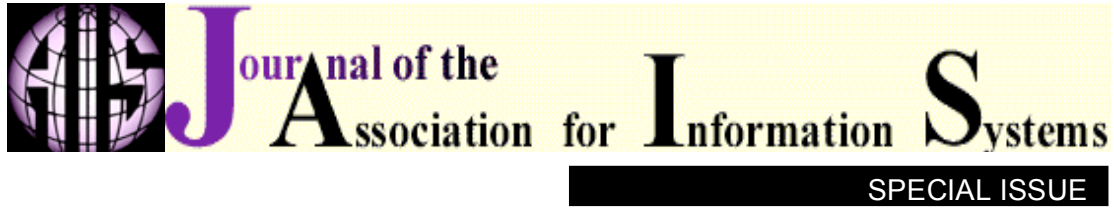
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## Across the Digital Divide: A Cross-Country Multi-Technology Analysis of the Determinants of IT Penetration <sup>1</sup>

**Sanjeev Dewan**

Paul Merage School of Business  
University of California, Irvine  
[sdewan@uci.edu](mailto:sdewan@uci.edu)

**Dale Ganley**

Paul Merage School of Business  
University of California, Irvine

**Kenneth L. Kraemer**

Paul Merage School of Business  
University of California, Irvine

### **Abstract**

*This paper studies the country-level digital divide across successive generations of IT, providing detailed insights into the magnitude and changing nature of the divide. We examine a panel of 40 countries from 1985-2001, based on data from three distinct generations of IT: mainframes, personal computers, and the Internet. Using two measures of IT penetration, we conduct an empirical investigation of socio-economic factors driving the digital divide. We find that IT penetration is positively associated with national income for all three technology generations, and the association between penetration and income is stronger for countries with higher levels of IT penetration. We also examine other demographic and economic factors, going beyond income, and find significant differences in the nature of their effects across countries at different stages of IT adoption. Importantly, factors that previously may have been expanding the divide with earlier technologies are narrowing the gap as the Internet becomes the defining technology of the Information Age.*

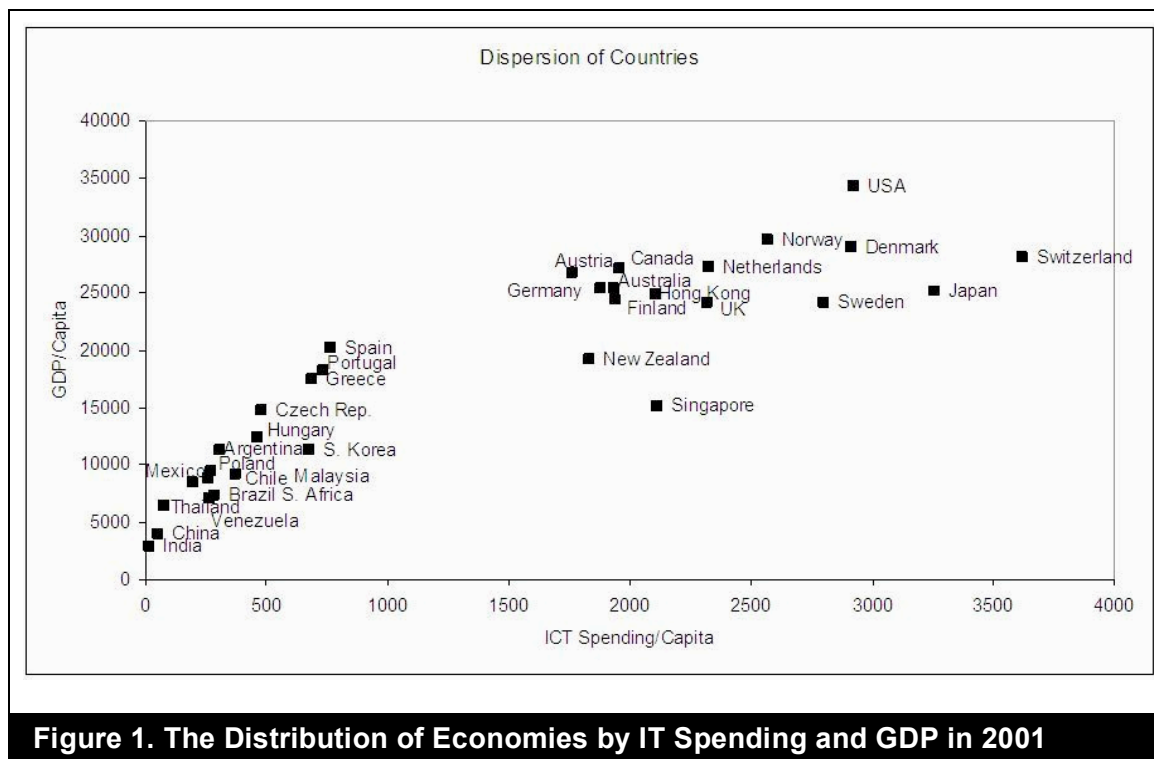
**Keywords:** Digital divide, information technology, Internet, global IT, IT diffusion, quantile regression, socio-economic perspective.

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<sup>1</sup> Fred Riggins and Robert Kauffman were the accepting senior editors.

## Introduction

As the Information Revolution has become a significant driver of the global economy, the digital divide — the gap in access to information technologies (IT) between developed and developing countries — is receiving increasing attention from researchers and policy makers. There is ample evidence that the divide is quite substantial. For example, Clarke (2000) notes that, “although developing and transition economies accounted for 85 percent of the world’s population in 2000, they accounted for only 20 percent of Internet users and 10 percent of global spending on information technology.” Figure 1 illustrates the dispersion in IT investment across countries, as related to per capita GDP. It is clear that there is a high correlation between national wealth and IT investment levels, and that there is a large gap between developed and developing countries (see also Dewan and Kraemer, 2000). What is less clear is how this gap is changing over time and across generations of IT, and how the digital divide is affected by underlying socio-economic differences among countries. These are the key questions that motivate the present research.



**Figure 1. The Distribution of Economies by IT Spending and GDP in 2001**

There is some prior work that has examined the nature of the global digital divide (e.g., Hargittai, 1999; Wong, 2002; Corrocher and Ordanini, 2002; Robison and Crenshaw, 2001; Oxley and Yeung, 2001; Dasgupta et al. 2001; Kiiski and Pohjola, 2001; Norris, 2000; and Chinn and Fairlie, 2004), as we review in the following section. In order to advance the collected knowledge in the research stream, we specifically align our work with previous efforts and focus on extending and expanding the results to make several important contributions. Whereas many studies are limited to one or two IT generations (most typically PCs or the Internet) over relatively short time periods, our analysis covers three IT generations (mainframes, PCs, and Internet) over the comparatively long period of 1985 to 2001. Further, we go beyond the results of previous studies to conduct a

more comprehensive analysis of the relationship between IT penetration and its covariates using quantile regression techniques (see e.g., Koenker and Hallock, 2000). This allows for a detailed examination of how the impact of the various socio-economic factors varies with the level of IT penetration, providing a more nuanced view of the forces shaping the digital divide.

Briefly, our main findings are that, while the dispersion of IT penetration across countries is increasing in absolute terms, using the simple quantity of IT per capita, it is actually shrinking in percentage terms when the dispersion is normalized by global average penetration. That is, IT penetration levels are increasing in both rich and poor countries, but at a substantially higher rate in poor countries, so that the magnitude of the gap as a percentage of average penetration is shrinking. When examining the determinants of the divide, there are several factors that affect the adoption of IT, the most significant being per capita GDP, technology costs, size of urban population, average education level, and the importance of the trade sector.

Our quantile regression analysis finds that not only is the level of IT penetration increasing in GDP per capita, but the influence of this factor on penetration is stronger in countries with higher IT penetration. When considering mainframes and PCs, several other factors – telephone lines per capita, years of schooling, and trade in goods – have had a similar but stronger effect in developed countries than in developing countries. The differential effect of the socio-economic factors across developed and developing countries has served to drive a wedge between the two groups of countries, and appears to be a primary causal force underlying the digital divide to date. However, the mechanisms appear to be changing with the newest technologies. In particular, with respect to Internet users, telephone costs, years of schooling, and trade in goods have a stronger impact in countries at lower penetration levels, even accounting for wealth differences. Thus, the effects previously expanding the divide may be undoing themselves and narrowing the gap as the Internet becomes the defining technology of the Information Age.

The plan of the paper is as follows. The next section provides a survey of the relevant literature and a summary of the open issues that guide our inquiry. We, then, provide an overview of our framework and data, and present some summary statistics. Next, we describe the empirical results regarding the determinants of the divide, and finally close with some discussion and concluding remarks.

## **Literature Survey**

In this section we provide a brief survey of the literature most relevant to the aspects of the country-level digital divide examined in this paper. We start with a review of past work focusing on the measurement of the cross-country divide, followed by research uncovering the important determinants of the divide, as they relate to the key research questions being addressed in the paper. The research focusing on measuring the digital divide informs our choices of dependent variables and the research on the determinants of the divide guides us in our selection of independent variables, which results in a framework for our study that is strongly connected to previous work.

## **Measures of IT Penetration**

The largest portion of research that aims to measure the digital divide takes a technological perspective, which emphasizes access to fundamental information technologies — most often telephone and Internet access. A case in point is Wong (2002), which evaluates the divide in Asian countries based on penetration levels of telephone main lines, PCs, and Internet use. Analyzing comparisons of the scale of IT adoption relative to national income, he finds that the digital divide in Asia is wide and has potential to become more severe, these results are echoed in the analysis of Gibbs et. al. (2003) when the divide is measured in absolute terms (i.e., when the divide is measured as the actual difference in per capita IT penetration, without normalizing by the mean of IT penetration), the evidence shows that it is growing. On the other hand, using alternative measures of the divide in terms of growth relative to economic wealth or per capita income, Gibbs et al. conclude that some developing countries might already be overtaking certain developed countries. Their findings highlight the fact that different measures of the divide can result in very different inferences about the nature of the divide.

As an alternative, some researchers have quantified the digital divide as a multidimensional construct that combines multiple socio-economic factors into one. Arquette (2002) develops a comprehensive instrument with a sociological focus on the digital divide. After evaluating more than 100 countries in a cross-section from 1999, he finds that the digital divide parallels the gap in economic and human development. Corrocher and Ordanini (2002) extend this concept by combining the measurements and the factors into an index of digitization. An examination of this index for ten European countries in 2000 and 2001 suggests a large gap between the U.S. and the European countries, however the dispersion lessens if just European countries are considered, and drops in general from 2000 to 2001.

Atrostic et. al. (2000) advocate gathering metrics to measure the electronic economy that align with the traditional economic production function approach using inputs and outputs to e-Business activities, an idea echoed in a similar effort by IBM Corporation (2003).

In total, the research to date is preliminary and fragmented. While all the studies conclude that a divide exists, the findings on its size and its evolution have been highly dependent on the chosen method to operationalize the digital divide and the data available in the study. In this paper we make new contributions to the measurement of the divide. We incorporate multiple technology generations into our study to get a sense for how the divide is evolving from one generation to the next. Additionally, we analyze a sixteen-year period to be able to draw conclusions about the evolution of the digital divide over time — and into the future.

## **Determinants**

Several empirical methods have been used to analyze the relationship between IT penetration and its various determinants, but the biggest differentiator of the research efforts has been the choice of dependent variable. Many authors have focused on the spread of Internet use, often using the same dependent variable — Internet hosts per 1,000 inhabitants. Hargittai (1999) examines a data set of OECD countries in 1998 and concludes that, while GDP is a large driver of Internet connectivity, telecommunications

policy can also have a large effect that is correlated with the telephone density level. Similarly, Oxley and Yeung (2001) present a study of 30 countries in the same year and find that Internet host penetration was positively associated with physical communication infrastructure, rule of law, and credit card use, and negatively correlated with telephone service costs. Robison and Crenshaw (2001) examine the level of economic development, political openness/democracy, mass education, and the presence of a sizeable tertiary/services sector as drivers of Internet diffusion. In a cross-sectional analysis of per capita Internet penetration for 74 countries over 1995-1999, they find that the most significant explanatory variables are development level, political freedom, and education. Beilock and Dimitrova (2003) examine Internet use in a sample of 105 countries in 2000, finding that GNP is "by far" the most important determinant, and that increasing civil liberties have a positive and significant impact. Using a diffusion model of Internet penetration, Kiiski and Pohjola (2001) examine data from 60 countries over the years 1995-2000, and report that GDP per capita and Internet access cost are important factors in OECD countries, but education is not. However, when developing countries are included in the sample, education becomes significant.

Guillen and Suarez (2001) study the number of Internet hosts and the number of Internet users per capita, using a matched set of independent variables in a cross section of 141 countries in 1998-99. They include variables related to telecommunications policy and infrastructure, as well as predictable policymaking and a democracy index, which are indicative of an environment conducive to entrepreneurship. They find that policy variables have an impact when the entrepreneurship variables aren't included, but lose their effect when they are. They conclude by asserting that public policy should look at general conditions supporting entrepreneurship, beyond just telecommunications policy.

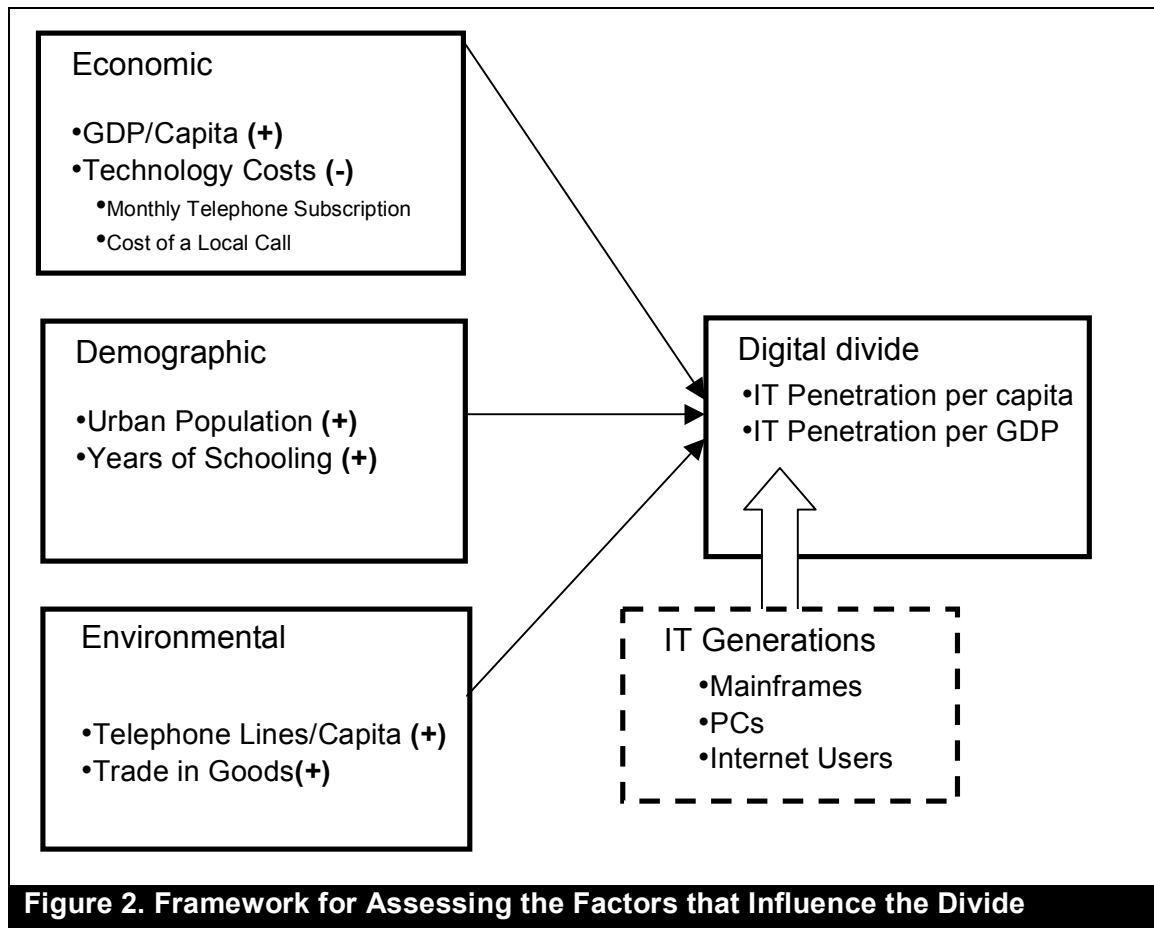
Dasgupta et. al. (2001) examine Internet use in a sample of 44 countries from 1990-1997, but use the measure of Internet hosts/telephone mainlines as the dependent variable. They conduct a log-log regression against measures of the baseline (1990) value of the ratio, finding that the ratio is significantly and positively related to policy and percentage urban population, and negatively related to the baseline value. Differing from other studies, income per capita was not found to be significant. Pohjola (2003) examines a data set over the years 1993-2000 and finds that IT investment is tightly related to income measures and human capital, and inversely related to the importance of agriculture in the economy. Caselli and Coleman (2001) use a measure of computer imports/worker ratio as a proxy for IT investment, for 89 countries over 1970-1990, and find that openness to imports from OECD countries, the level of educational attainment, and the index of property rights are statistically significant. Using a flexible accelerator investment model, Shih et al. (2003) study 39 countries from 1985-1999. They find that there is a positive correlation with the existing stock levels of IT capital, GDP, and education levels, and a negative correlation with interest rates.

Finally, there are a few studies that examine more than one technology concurrently. Quibria et al. (2003) examines a data set of more than 100 countries in 1999 that includes counts of PC and Internet use per capita. They find that GDP, education levels, and infrastructure play critical roles in the levels of these and other information technologies. Chinn and Fairlie (2004) use the same two dependent variables with a panel of 161 countries over the 1999-2001 period. They find that GDP, telephone density, and regulatory quality (as measured by an index assessing market-friendly policies) are important determinants of PC and Internet density.

Our own examination of the determinants of the digital divide is closest to the analysis of Chinn and Fairlie (2004) described above. While the Chinn and Fairlie (2004) study is restricted to data on PCs and Internet over the 1999-2001 period, we consider three generations of IT (mainframes, PCs and Internet), and track the evolution of the divide, using suitable metrics, over the substantially longer period of 1985-2001. Further, we consider multiple measures of IT penetration, defined on the basis of both per capita and per income. Finally, we go beyond the panel regression analyses of Chinn and Fairlie (2004) to conduct quantile regressions, in order to gain a more complete understanding of the sometimes complex relationship between IT penetration and its determinants.

## Empirical Framework

After reviewing the literature surveyed in Section 2, we can specify the variables in our framework, both dependent and independent, to build on previous efforts, while expanding the analysis to incorporate new insights. We present our framework in Figure 2 and discuss it in detail in the following subsections.



### Dependent Variables

The most common characterization of the global digital divide is in terms of the dispersion in IT penetration across countries, under the premise that if there were no

divide then there would be no differences in IT penetration across countries. We use per capita measures, which is the most conventional approach to scaling IT penetration at the country level. Another way of characterizing relative IT penetration (Fink and Kenny, 2003) normalizes penetration levels by the overall output of the economy; i.e., GDP. We adopt this measure as well, in order to account for the tight association of digital access with income levels, and the collinearity of income with other interesting factors like education and telephone penetration. These two types of measures – IT penetration per capita and IT penetration per GDP – are simple and yet very insightful, especially in combination. We can use them to examine how the divide is changing, by examining the trends in the mean and dispersion of IT penetration. First we look at the *absolute* penetration levels, as in previous studies, and then examine the trends in *relative* penetration levels, which present a very different picture.

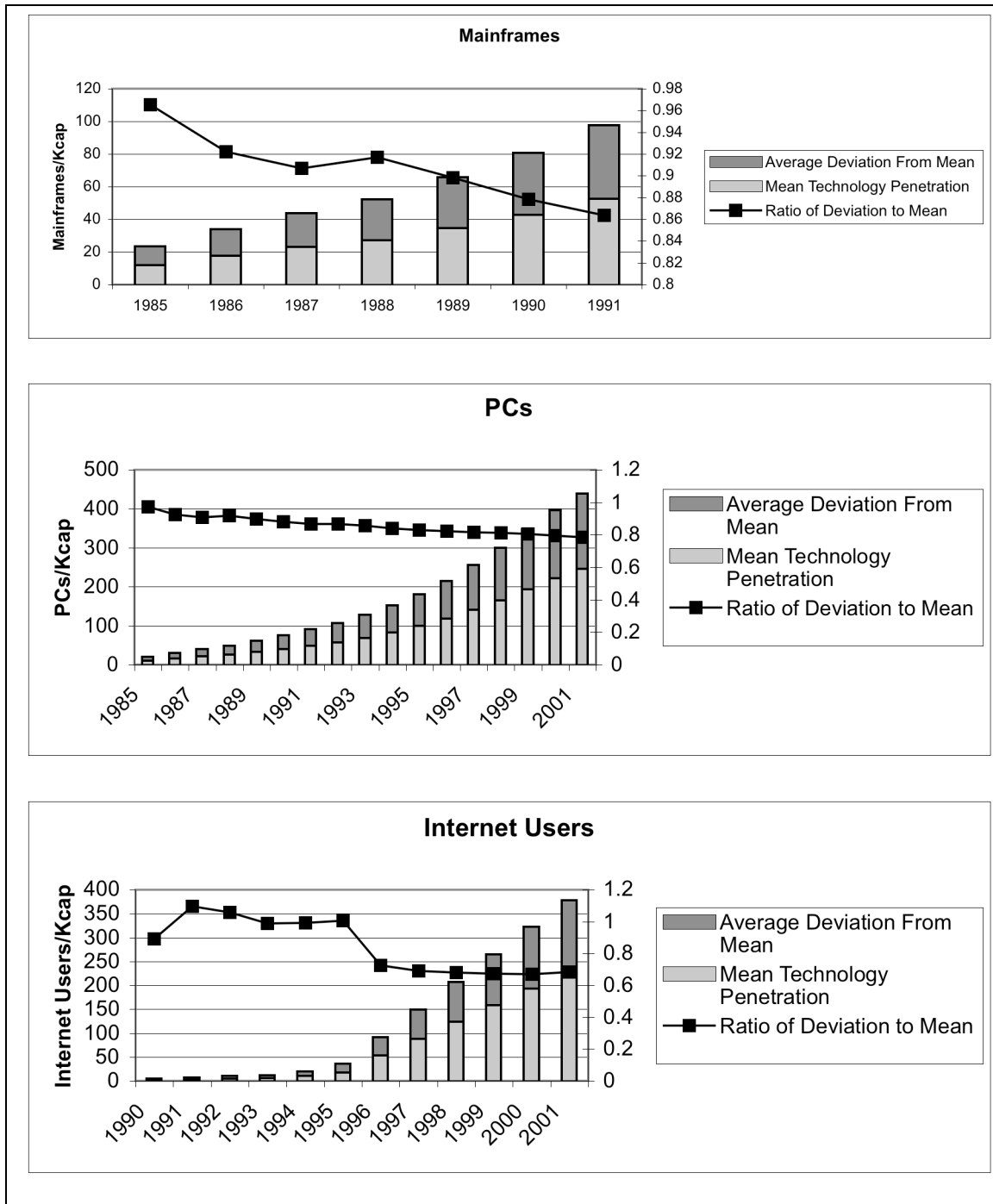
The trends in the *absolute* levels of the mean and dispersion in IT penetration are shown in the bar graphs in Figure 3. This figure shows the average IT penetration per 1,000 people (i.e., per Kcap) for every year in the data set, along with the average absolute deviation from the average, for the three IT generations under consideration.<sup>2</sup> The charts clearly show that average IT penetration is steadily growing over time, for all three IT generations, but the average absolute dispersion is also growing commensurately. In 1985 there were 11 mainframes per 1000 population, while the average deviation was 11 mainframes; and in 1991, there were 52 mainframes and the average deviation was 45 units. The numbers for the PC penetration levels grew from 42 PCs per Kcap, with an average absolute deviation of 37, to 263 PCs and a range of 204 in 2001. The number of Internet users has grown even more markedly. In 1995 there were 17 Internet users per 1,000 population, with an average spread of 17 around the mean; and in 2001 it had quadrupled to 224 users and an average spread of 154 users.

To examine *relative* growth and dispersion, the normalized deviations from the means<sup>3</sup> over time are superimposed as a line in each of the graphs in Figure 3. This enables us to evaluate the change in the digital divide as a proportion of global average IT penetration. The chart clearly shows the relative dispersion to be narrowing for all three technologies. Mainframes and PCs show a slow and steady decline since 1985. The relative dispersion for the Internet dropped sharply between 1995 and 1996 as the World Wide Web exploded in global markets, and remained lower than the average dispersion in earlier technologies. These metrics suggest that the global digital divide in IT access is actually narrowing over time, when penetration levels are measured in relative terms. IT penetration levels are growing in all countries, but the developing countries are increasing their access at a faster rate relative to the developed countries, so that the dispersion among the countries, relative to average penetration levels, is decreasing over time. The gradual reduction in the gap between countries is at times accelerated by the arrival of disruptive technologies, such as the personal computer or the World Wide Web, as is clear from the chart.

<sup>2</sup> To be precise, if we denote by  $x_{it}$  the penetration level of an IT generation in country  $i$  at time  $t$ , then Figure 2 shows the average penetration levels,  $\bar{x}_t = 1/N \cdot \sum_{i=1}^N x_{it}$  and the average absolute deviation  $d_t = 1/N \cdot \sum_{i=1}^N |x_{it} - \bar{x}_t|$ .

<sup>3</sup> The normalized deviation from the mean is computed as  $D_t = d_t / \bar{x}_t$ .





**Figure 3. The Change in Technology Penetration Levels per Capita, Yearly Averages and Deviations From the Mean**

**Independent Variables**

Having established a base to evaluate the trends in the global digital divide, we turn to analyzing the factors that impact its development. We have selected the most likely candidates for inclusion in our model based on the data availability and importance in

past results. We have divided the selected variables into three categories, depending on the nature of their influence on IT adoption. The first category, Economic, incorporates the income and cost factors that affect technology adoption decisions. The average per capita income is proxied by the variable, GDP per capita, as is common in country-level studies of this nature. Consistent with the evidence suggesting the existence of a digital divide, we would expect an obvious positive relationship between GDP per capita and all the measures of IT penetration (see e.g., Dewan and Kraemer, 2000; Quibria et al., 2003). The cost variables are proxies for the costs of acquiring and using technology, which in our case are represented by two specific variables: monthly telephone subscription cost and cost of local calls, as in Chinn and Fairlie (2004), which we assert to be negatively associated with IT penetration.

Our second category of variables is Demographic, which includes factors that affect the value of access to technology. Two variables are included in this category. The first is the size of the urban population, as represented by the proportion of the population residing in urban areas. While the inclusion of this variable is motivated by prior studies (e.g., Forman et al., 2002; Chinn and Fairlie, 2004), its effect on IT penetration is ambiguous. On the one hand, the larger the proportion of urban population, the higher the demand for information-intensive products and services (such as financial services), and therefore the stronger the derived demand for IT. On the other hand, there are arguments in the literature that the more urban the population, the less pressing the need for IT to compensate for distance-related communications (Forman et al., 2002; Chinn and Fairlie, 2004). Which of these effects dominates is an empirical question that will be answered by our analysis. The second demographic variable is the stock of human capital, as characterized by the average education level of the population in terms of years of schooling. As delineated in earlier research (Hargittai, 1999), we expect this variable to be positively associated with IT penetration since higher education levels are likely to simultaneously decrease the cost and increase the value of technology use.

The third category, Environmental, includes factors that are synergistic with IT adoption. The first is telephone infrastructure, which is a prerequisite for the productive use of information technologies — it is proxied here by the density of telephone main lines. Motivated by prior research, we also include a variable related to the importance of trade in the economy. An argument in support of a positive association between the trade variable and IT penetration is that the larger the trade sector, the greater the pressures to conform to technology norms and practices of the network of global trading partners, and the greater the positive impact of cross-border learning.

## Data

Our empirical analysis is conducted on a secondary data source that has been aggregated from three primary agencies, resulting in a panel representing 40 countries over the time frame of 1985 to 2001.<sup>4</sup> The efficacy of our analysis hinges on a

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<sup>4</sup> The 40 countries included in our data set are Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Czech Republic, Denmark, Egypt, Finland, France, Germany, Greece, Hong Kong, Hungary, India, Indonesia, Ireland, Israel, Japan, Malaysia, Mexico, Netherlands, New Zealand, Norway, Philippines, Poland, Portugal, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Thailand, United Kingdom, United States, and Venezuela. Based

reasonable diversity of countries in the sample, both developed and developing. However, due to lack of data availability we must omit many of the poorest countries, such as those from Sub-Saharan Africa, that also happen to have the lowest technology penetration levels. Thus, these results more fairly describe the digital divide among countries that are already present, at least to a small degree, in the global information economy. While this is a limitation, we feel that our coverage of the remaining countries is comprehensive—spanning a wide gap in development, following a long period of time from 1985 to 2001, and covering multiple generations of IT—and valuable in its own right.<sup>5</sup>

The data series used to measure the *per capita* penetration levels of three IT generations—mainframes, PCs, and Internet users — was provided by the International Telecommunications Union (ITU). We also generate metrics of technology penetration *per unit of GDP*<sup>6</sup>, to evaluate the factors in terms suggested by Robison and Crenshaw (2001). They suggest this metric to provide an alternative view of levels of digitization that considers the penetration levels in balance with the economic resources available. By evaluating the relationships using two complementary metrics, we hope to provide a more comprehensive set of results on which to make conclusions about this multi-faceted phenomenon.

We provide summary statistics for these variables in Table 1. It is clear that the worldwide average penetration levels have grown dramatically in all three technologies, especially in the last decade. The penetration of PCs has at least doubled, depending on the measure, since 1991, and the penetration of the Internet has grown from negligible to almost the same level as PCs. Mainframes and PCs are extremely closely connected, largely due to the strong overlap in definitions and data collection methods. This is primarily why we truncate the mainframe data in 1991.

**Table 1. Summary Statistics on Measures of Technology Penetration**

		Mean	St dev
Mainframes/Kcap	1985	11.90	15.60
	1991	53.00	52.50
PCs/Kcap	1985	10.10	13.60
	1991	48.90	48.80
	2001	248.60	216.10
Internet users/Kcap	1991	1.80	3.80
	2001	204.60	179.60

		Mean	St dev
Mainframes/GDP	1985	1.20	1.10
	1991	3.60	2.60
PCs/GDP	1985	1.10	0.90
	1991	3.40	2.40
	2001	12.70	6.50
Internet users/GDP	1991	0.11	0.21
	2001	11.60	6.90

Our choice of endogenous variables has been motivated by results from existing research, as reviewed in the previous section. Data on most of the socio-economic

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on GDP per capita, twenty-two of these countries can be classified as “developed” while the rest are “developing.”

<sup>5</sup> The mainframe data runs from 1985 to 1991; the PC data is from 1985 to 2001; and the Internet series is from 1990 through 2001.

<sup>6</sup> All monetary values throughout are expressed in US dollars, corrected where applicable for purchasing power parity (PPP) in 2003 dollars.

variables — density of main telephone lines, size of urban population, GDP, years of schooling, and trade in goods — were obtained from the World Bank and the World Trade Organization. We obtained data from the ITU on the monthly telephone subscription cost and the cost of a (3-minute) local call, calculated as the average of the residential and business rates, corrected for PPP (purchasing power parity). These measures closely align with those used in Chinn and Fairlie (2004) to allow for comparison of the results.

The correlations between the independent variables, as shown in Table 2, are useful for assessing the independence of the variables. As is clear from the table, there are several significant correlations (in bold) between the endogenous variables, namely GDP, MAIN, and SCH. This is likely to cause multicollinearity problems in our regressions, especially in cases where the correlation is over 0.8 (Kennedy, 1998), which may result in variables appearing to be less significant than they otherwise would. Additionally, we tested the Variance Inflation Factor (VIF) after each regression to quantify the potential impact on the results. Typically, VIFs over 10 are a concern, and in our regressions only MAIN has a VIF of over 10 (ranging from 10.2 to 11.7). To evaluate the seriousness of the impact, we have evaluated the regressions, omitting one or more

Table 2: Summary Statistics on Independent Variables				Correlation Matrix					
		Mean	St.dev	MAIN	TEL	CALL	URBAN	GDP	SCH
MAIN	1985	212.6	170.8						
	1991	272.6	14.0						
	2001	382.6	209.6						
TEL	1985	--	--	-0.286***					
	1991	15.9	14.0						
	2001	17.7	11.5						
CALL	1985	--	--	-0.198***	-0.106**				
	1991	.1	.06						
	2001	.1	.09						
URBAN	1985	64.8	20.3	0.578***	-0.173***	-0.249***			
	1991	67.1	19.6						
	2001	69.9	18.7						
GDP	1985	8417.7	4603.4	<b>0.906***</b>	-0.185***	-0.134***	0.571***		
	1991	11310.2	6527.9						
	2001	16311.4	9456.1						
SCH	1985	7.3	2.3	<b>0.751***</b>	-0.028	-0.108**	0.541***	<b>0.722***</b>	
	1991	7.8	2.2						
	2001	8.5	2.1						
TRADE	1985	58.3	49.1	0.139***	-0.162***	-0.138***	0.276***	0.127***	0.045
	1991	56.3	51.7						
	2001	74.9	53.1						
MAIN = Density of main telephone lines per 100 people; TEL = Average monthly telephone subscription cost; CALL = Average cost of local call; URBAN = Size of urban population, as a percentage of total population; GDP = GDP per capita, adjusted for purchasing power parity; SCH = Average years of schooling; TRADE = Size of trade in goods in the economy, as a percentage of GDP; *p<0.1. **p<0.05. ***p<0.01									

of the collinear regressors, and are satisfied that the statistical significances and scale of the estimations are not appreciably affected. Thus, we feel confident that retaining all the regressors, in the final, reported model is statistically sound and that interpreting the results jointly using both the per capita and per GDP forms of dependent variables will mitigate against any major omissions. We note in the results discussion where we believe multicollinearity may be affecting our results.

## Determinants of the Divide

Having established our conceptual framework for examining the relevant factors that affect the divide, we now turn to describing our empirical models. We will then estimate the models on data from over 40 countries during the period 1985-2001, using suitable regression methods.

### Model and Methodology

The conceptual framework described in Section 3 drives our empirical analysis, which is conducted using a variety of regression models. We first estimate the following regression equation:

$$IT_{it}^T = \beta_0 + \beta_1 \cdot MAIN_{it} + \beta_2 \cdot TEL_{it} + \beta_3 \cdot CALL_{it} + \beta_4 \cdot URBAN_{it} + \beta_5 \cdot GDP_{it} + \beta_6 \cdot SCH_{it} + \beta_6 \cdot TRADE_{it} + (\text{year dummies}) + \varepsilon_{it}, \quad (1)$$

where, for country  $i$  in year  $t$ :

$IT_{it}^T$  = Penetration of IT generation  $T$ ,  $T \in \{\text{Mainframe, PC, Internet}\}$ , measured alternatively in per capita and per GDP terms;

$MAIN_{it}$  = Density of main telephone lines per 1000 people;

$TEL_{it}$  = Average monthly telephone subscription cost;

$CALL_{it}$  = Average cost of local call;

$URBAN_{it}$  = Size of urban population, as a percentage of total population;

$GDP_{it}$  = GDP per capita, adjusted for purchasing power parity;

$SCH_{it}$  = Average years of schooling;

$TRADE_{it}$  = Size of trade in goods in the economy, as a percentage of GDP;

$\varepsilon_{it}$  = error term.

We estimate the regressions above using a pooled sample across the countries and time periods. All variables are standardized (i.e. converted to zero mean and unit standard deviation) for ease of interpretation of the relative magnitudes of the estimated coefficients. To correct for heteroskedasticity, or a biased error structure, which is not uncommon in models of this type, our hypothesis tests are based on White's (1980) heteroskedasticity-consistent standard errors.

The conditional mean function estimated by OLS regression, such as the ones described above, provides only a limited view of the relationship among the variables (see e.g., Koenker and Hallock, 2000). Prior empirical evidence suggests that the impacts of IT investments are quite different in developed versus developing countries (Dewan and Kraemer, 2000; Shih et al., 2003), calling for a more careful analysis of the heterogeneity

in the determinants of IT penetration across countries. To better understand this heterogeneity, we make use of quantile regressions, with the premise that the effect of the independent variables might be quite different at different points in the conditional distribution of the dependent variable (IT penetration in our case).

Recent applications of quantile regression include analyses dealing with the effects of maternal behavior on birth weights (Abreveya, 2001), returns to schooling (Arias et al., 2001), changes in the U.S. wage structure (Kahn, 1998; Lopez et al., 2001), and risk regulation (Viscusi and Hamilton, 1999), among others. Methodologically, quantile regressions can be viewed as an extension of classical least squares estimation of conditional mean functions in OLS regressions, to the estimation of a series of conditional quantile functions. As reviewed by Koenker and Hallock (2000), the key strength of quantile regression is its ability to examine the heterogeneous impact of the factors at different IT penetration levels without losing degrees of freedom by running subsets of data. A side benefit is relatively greater robustness to outliers in the data, as compared to OLS regression. The results of quantile regression analyses can be interpreted simply as a series of regressions corresponding to the various percentage points of the distribution of IT per capita.

Our analysis is similar to that of Chinn and Fairlie (2004), with some key differences: we examine three generations of IT over 1985 to 2001, while the earlier study was more limited in its scope (two IT generations over 1999 to 2001); and we conduct a series of quantile regressions for a more complete and nuanced view of the divide than heretofore available.

### ***Regression Results***

In what follows, we report the results from OLS and quantile regressions, emphasizing the robust qualitative findings that come out of our analysis. We report the OLS regression results for each of the three technologies are reported in Table 3. The two panels in each of these tables are for the two versions of the IT penetration dependent variable measured in per capita and per GDP terms, respectively. The results are broadly similar for the three technologies and the two versions of the dependent variable, with a few differences we address below.

The consistent results indicate that IT penetration in general is positively related to mainline density, GDP per capita, years of schooling, and the size of the trade sector, and negatively related to the two types of telecommunication costs and size of urban population. These findings are largely consistent with our predictions in the previous subsection, and with prior work, notably Chinn and Fairlie (2004) and Quibria et al. (2003). The negative coefficient on the size of the urban population is consistent with Chinn and Fairlie (2004) and Forman (2002).

If we examine the differences between the regressions with the per capita and per GDP variables, we can consider what factors that drive the digital divide are a consequence of the development divide—the gap in wealth and the closely correlated measures—and what factors may have an impact beyond that of wealth. In some cases, variables are significant for one version of the dependent variable, but not the other. In the case of main telephone lines, the lack of significance in the per capita regressions likely reflects the correlation with GDP masking its importance, since it is significant in the per GDP

<b>Table 3. Pooled OLS Regression Results</b>			
<b>a) Penetration Levels per Capita</b>			
	Mainframes/Kcap	PCs/Kcap	Internet Users/Kcap
Main telephone lines per 1000 people	7.529* (4.106)	-1.441 (9.571)	-4.721 (8.163)
Monthly telephone subscription cost		4.272 (3.466)	-7.013* (3.805)
Cost of Local Call		-6.906* (3.015)	-10.006*** (2.809)
Urban Population (% of total)	-3.904*** (1.469)	-9.741*** (3.386)	-4.845 (3.463)
Gross Domestic Product per 1000 capita (PPP)	19.589*** (4.561)	92.195*** (9.051)	45.297*** (7.933)
Years of Schooling	7.646*** (1.926)	16.341*** (3.890)	13.232*** (3.917)
Trade in Goods (% of GDP)	0.237 (1.409)	7.357* (3.421)	3.224 (2.476)
Sample Size	282	456	394
Overall R <sup>2</sup>	0.752	0.814	0.754
<b>b) Penetration Levels per GDP</b>			
	Mainframes/GDP	PCs/GDP	Internet Users/GDP
Main telephone lines per 1000 people	0.956*** (0.213)	1.423*** (0.382)	0.911** (0.369)
Monthly telephone subscription cost		0.014 (0.133)	-0.366** (0.183)
Cost of Local Call		-0.127 (0.125)	-0.259* (0.146)
Urban Population (% of total)	-0.031 (0.082)	0.016 (0.144)	-0.089 (.175)
Gross Domestic Product per 1000 capita (PPP)	-0.052 (0.226)	0.643* (0.349)	-0.511 (.427)
Years of Schooling	0.628*** (0.108)	1.230*** (0.154)	0.928*** (0.221)
Trade in Goods (% of GDP)	0.199* (0.097)	0.685*** (0.158)	0.531*** (0.175)
Sample Size	282	456	394
Overall R <sup>2</sup>	0.714	0.780	0.725

**Notes:** Year dummies are included in all regressions. Standard errors (in parentheses) are calculated using White's (1980) heteroskedasticity-consistent estimation. All regression models include a constant term and year dummies. \*p<0.1. \*\*p<0.05. \*\*\*p<0.01

regressions. Education and, to a lesser extent, mainline density emerge as positive and significant across the three technologies in both the per capita and per GDP regressions.

This indicates that human capital and infrastructure have impacts that transcend the highly correlated impact of wealth. Further, trade in goods is only marginally significant in the regression on PCs per capita, but is significant in all the per GDP regressions. Although the quantile regressions will add more insight to this point, these results suggest factors that may be influenced independently of national income resources to stimulate IT diffusion.

There are a few differences between the results for the three IT generations that are worth noting. Trade is more important in affecting the diffusion of PCs and, to a lesser extent, Internet use, than in affecting the diffusion of mainframes. The percent of urban

population has almost no impact on the number of Internet users, but does impact per capita mainframe and PC penetration. Mainline density seems to have a more consistent impact on the level of PCs than the number of Internet users, but the cost variables affect Internet use more than PC adoption. This likely reflects a poor proxy for technology costs rather than a weak driver, though following our goal of aligning with earlier research, we use it since it is one of the more common choices.

Examining the impact of the telecommunications variables, the cost of a local call is generally negative and significant, and is substantially larger in magnitude for Internet users than for PCs. This is perhaps due to the fact that Internet access in most countries is still primarily over telephone lines. The other telephone cost variable is marginally significant. Mainline density is significant in the per GDP regressions but not in the per capita ones, perhaps due to the strong correlation between mainline density and GDP per capita (see Table 2).

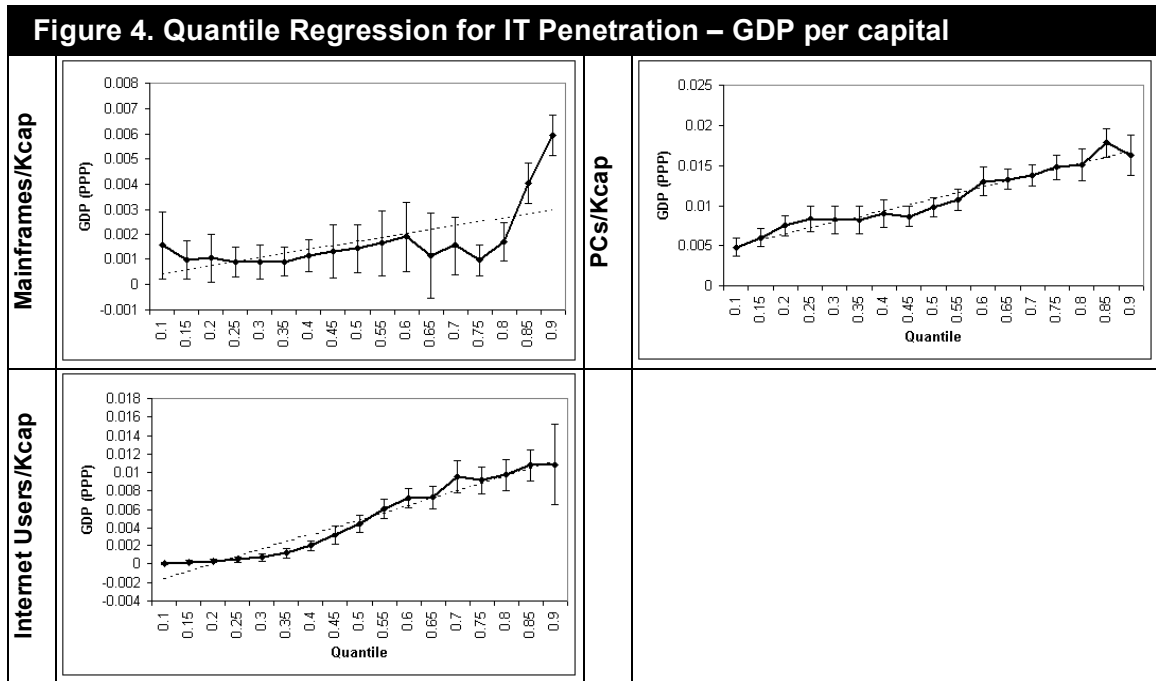
The mixed results for the telephone infrastructure variables are not unlike those in other studies (Chinn and Fairlie, 2004; Oxley and Yeung, 2001). The results stabilize a little more in the per GDP regressions, but considering that infrastructure is such an important prerequisite for IT impact, the effect is curiously inconsistent. A potential explanation, proposed by Dasgupta et al. (2001), is that there is a threshold level of telecommunications infrastructure beyond which these variables are no longer significant. Alternately, it could be that infrastructure is better proxied by telecommunications policy variables, as examined by Hargittai (1999) and Beilock and Dimitrova (2003). Future work will explore this issue more fully.

Turning to the quantile regressions, we first consider the quantile estimates of the GDP per capita variable for each of the three technologies. In Figure 4 we present a graphical comparison of the series of GDP coefficient estimates on each of the three technologies per capita, along with 90% confidence intervals. The graphs show the coefficient of the GDP variable on the y-axis against the quantiles of IT penetration on the x-axis. These graphs illustrate how the slope of the trend-line follows the change in the impact of the factors across the quantiles of the conditional distribution of IT penetration. All three graphs show a definite upward trend in the estimated coefficient across the ascending quantiles, though the results for mainframes show a wide variance. In the case of PCs, the value begins around 0.005 in the 10<sup>th</sup> quantile and ends around 1.50 in the 90<sup>th</sup> quantile. In the case of Internet users, the value hovers close to 0 up to the 40<sup>th</sup> quantile, then rises up to about 0.012 in the 90<sup>th</sup> quantile.

This implies that the marginal impact of a rise in GDP is noticeably higher in countries at a high level of IT penetration — approximately three times as high in mainframes and PCs, and over six times as high in Internet use.

To the extent that the digital divide is a concept that relates IT adoption to national income, the quantile regression results for the GDP per capita variable are fundamental to illuminating the mechanisms behind the divide. We find that not only is the association between GDP per capita and IT penetration positive and significant, but it is also stronger at higher levels of IT penetration. Thus there is a “feedback effect” between GDP per capita and IT penetration in the sense that the magnitude of the positive association between GDP per capita and IT penetration is higher at higher levels of IT penetration. Indeed, our results suggest this effect is a primary cause of the wedge between developed and developing countries, reinforcing the digital divide.





We summarize other findings from the quantile regressions in Tables 4-6, presenting the results of the 25<sup>th</sup> quantile (first quartile), 50<sup>th</sup> quantile (median), and 75<sup>th</sup> quantile (3<sup>rd</sup> quartile) results in the first, second, and third columns respectively. In the fourth column, we summarize the impact of that factor across the quantiles as either “increasing,” “decreasing,” or “neutral” as follows: “increasing” if the coefficient has a larger impact in higher quantiles; “decreasing” if it has a larger impact in the lower quantiles; and “neutral” if the trend-line is not significantly increasing or decreasing. We leave the impact blank if the estimates are not significant. As we illustrated in Table 3, factors that we assess as having an increasing effect on the divide support the feedback effect, and factors that have a decreasing impact mitigate against this process. Thus, this analysis provides an insight into the nature of the divide that is uniquely available from the quantile regression method, and is beyond the scope of the OLS regression methods employed in prior research.

The patterns in the regressions on mainframe penetration (Table 4) generally show either a neutral or increasing effect on the divide (with the exception of GDP in Panel b). With respect to the penetration level of PCs (Table 5), however, the cost of a local call, years of schooling, and trade in goods break the pattern in the per capita regressions by having a decreasing impact, but return to neutral or increasing the gap in the per GDP regressions. This inconsistency could be due to collinearity between GDP and the other variables masking the effect in the per capita regressions, or it could be that while these factors allow more people to have access to IT in developing countries, they do not allow more economic resources to be devoted to IT. This latter explanation would involve a spillover effect from the factors through some secondary mechanism that bypasses income allocation. While this explanation is intriguing and worth further study, for our purposes of looking for primary effects, we conclude that, as far as the traditional technologies of mainframes and PCs are concerned, the quantile regressions as a whole indicate a trend of widening or at best maintaining the digital divide.

<b>Table 4. Pooled Regressions for Mainframes Penetration</b>				
<b>a) Penetration Levels per Capita</b>				
Independent Variable	25 <sup>th</sup> Quantile	50 <sup>th</sup> Quantile	75 <sup>th</sup> Quantile	Effect on Divide
MAIN	14.092*** (2.152)	14.993*** (3.317)	20.621*** (1.833)	Increasing
URBAN	-1.246 (0.828)	-1.949 (1.531)	-2.614** (1.053)	Increasing
GDP	5.514*** (1.925)	8.731*** (3.277)	5.914*** (1.894)	Neutral
SCH	2.804*** (1.024)	3.515** (1.827)	3.651*** (1.209)	Increasing
TRADE	0.416 (0.702)	1.395 (1.213)	0.676 (0.889)	
Pseudo R <sup>2</sup>	0.47	0.54	0.58	
N	282			
<b>b) Penetration Levels per GDP</b>				
Independent Variable	25 <sup>th</sup> Quantile	50 <sup>th</sup> Quantile	75 <sup>th</sup> Quantile	Effect on Divide
MAIN	0.956*** (0.241)	1.220*** (0.155)	1.739*** (0.142)	Increasing
URBAN	0.005 (0.097)	0.093 (0.071)	0.011 (0.076)	
GDP	-0.059 (0.214)	-0.228 (0.154)	-0.751*** (0.163)	Decreasing
SCH	0.222* (0.111)	0.271*** (0.084)	0.497*** (0.097)	Increasing
TRADE	0.225** (0.081)	0.302*** (0.056)	0.175*** (0.063)	Neutral
Pseudo R <sup>2</sup>	0.46	0.52	0.54	
N	282			

**Notes:** Year dummies are included in all regressions. Standard errors are in parentheses. We label the effects on the divide according to the following guidelines: *Increasing*, if the change from the 25<sup>th</sup> quantile and the 75<sup>th</sup> quantile is significant and positive, relative to the sign; *Decreasing*, if the change from the 25<sup>th</sup> quantile and the 75<sup>th</sup> quantile is significant and negative, relative to the sign; *Neutral*, if the change from the 25<sup>th</sup> quantile and the 75<sup>th</sup> quantile is not significant, though the variable has some impact of the equation across the quantiles. \*p<0.1. \*\*p<0.05.\*\*\*p<0.01

However, the situation emerging from the regression on Internet users (Table 6) is different. In the per capita regressions, two variables display patterns that indicate pressure to narrow the divide—mainline density and trade in goods—similarly to the PC regression. However, differing from the earlier technology generations, several also show narrowing patterns in the per GDP regression. Specifically, telephone costs, years of schooling, and trade in goods are decreasing in impact in the higher quantiles in the per GDP regression. This indicates that developing countries get disproportionate benefits from lowering their infrastructure costs, improving their human capital, and increasing their participation in the global economy. While none of these can be quickly affected, we feel that these types of long-term investments offer the best levers to the developing countries for closing the digital divide over time.

<b>Table 5. Pooled Regressions for PC Penetration</b>				
<b>a) Penetration Levels per Capita</b>				
Independent Variable	25 <sup>th</sup> Quantile	50 <sup>th</sup> Quantile	75 <sup>th</sup> Quantile	Effect on Divide
MAIN	14.998* (7.117)	0.512 (13.299)	27.197** (10.617)	Increasing
TEL	1.959 (2.562)	6.926 (4.710)	8.029** (3.717)	Increasing
CALL	-4.431* (2.366)	-5.676 (4.474)	-3.293 (3.566)	Decreasing
URBAN	-0.642 (2.492)	-8.336 (5.134)	-10.962** (4.337)	Increasing
GDP	52.660*** (6.469)	84.943*** (12.029)	74.588*** (9.322)	Increasing
SCH	11.120*** (3.365)	14.252** (6.272)	0.505 (4.936)	Decreasing
TRADE	9.383*** (2.381)	9.091** (4.304)	1.289 (3.715)	Decreasing
Pseudo R <sup>2</sup>	0.51	0.57	0.62	
N	456			
<b>b) Penetration Levels per GDP</b>				
Independent Variable	25 <sup>th</sup> Quantile	50 <sup>th</sup> Quantile	75 <sup>th</sup> Quantile	Effect on Divide
MAIN	1.383*** (0.284)	2.038*** (0.327)	2.267*** (0.474)	Increasing
TEL	0.062 (0.098)	0.242** (0.114)	0.174 (0.169)	Neutral
CALL	0.129 (0.098)	-0.182* (0.108)	-0.169 (0.174)	Neutral
URBAN	0.302*** (0.108)	-0.079 (0.125)	-0.051 (0.203)	Increasing
GDP	0.383 (0.257)	0.243 (0.294)	-0.443 (0.435)	
SCH	0.759*** (0.113)	0.857*** (0.151)	1.158*** (0.216)	Increasing
TRADE	0.667*** (0.096)	0.732*** (0.105)	0.729*** (0.161)	Neutral
Pseudo R <sup>2</sup>	0.52	0.57	0.59	
N	456			

**Notes:** Year dummies are included in all regressions. Standard errors are in parentheses. \*p<0.1. \*\*p<0.05. \*\*\*p<0.01

**Table 6. Pooled Regression for Internet Penetration**

<b>a) Penetration Levels per Capita</b>				
Independent Variable	25 <sup>th</sup> Quantile	50 <sup>th</sup> Quantile	75 <sup>th</sup> Quantile	Effect on Divide
MAIN	8.421** (4.211)	-6.281 (6.127)	-15.264** (7.825)	Decreasing
TEL	-2.278 (1.759)	-1.881 (2.293)	-3.372 (2.854)	
CALL	0.774 (1.371)	-9.101*** (2.083)	-7.672*** (2.721)	Increasing
URBAN	0.978 (1.782)	-2.831 (2.329)	-3.948 (3.157)	
GDP	22.815*** (3.609)	29.131*** (5.366)	39.192*** (7.067)	Increasing
SCH	6.482*** (1.799)	8.069*** (2.853)	8.205** (3.758)	Neutral
TRADE	4.977*** (1.454)	3.825* (2.012)	-0.782 (2.699)	Decreasing
Pseudo R <sup>2</sup>	0.36	0.46	0.60	
N	394			
<b>b) Penetration Levels per GDP</b>				
Independent Variable	25 <sup>th</sup> Quantile	50 <sup>th</sup> Quantile	75 <sup>th</sup> Quantile	Effect on Divide
MAIN	0.391** (0.159)	0.093 (0.314)	0.599*** (0.197)	Increasing
TEL	-0.139*** (0.049)	-0.069 (0.118)	0.058 (0.075)	Decreasing
CALL	0.067 (0.051)	-0.126 (0.109)	-0.113** (0.069)	Increasing
URBAN	-0.019 (0.061)	-0.038 (0.124)	-0.159* (0.089)	Increasing
GDP	0.158 (0.142)	0.338 (0.275)	0.187 (0.175)	
SCH	0.446*** (0.061)	0.451*** (0.148)	0.280*** (0.097)	Decreasing
TRADE	0.253*** (0.050)	0.169* (0.107)	0.125* (0.067)	Decreasing
Pseudo R <sup>2</sup>	0.48	0.58	0.61	
N	394			

**Notes:** Year dummies are included in all regressions. Standard errors are in parentheses. \*p<0.1. \*\*p<0.05.\*\*\*p<0.01

## Conclusions

The digital divide between developed and developing countries in terms of differences in IT penetration is real, but we document evidence that the divide appears to be narrowing across the successive IT generations of mainframes, PCs, and Internet. A key contribution to existing research is that we are able to distinguish between factors that are widening the divide at the margin and those that serve to narrow the divide. Finally, we have shown that the dynamics of the diffusion of the Internet appear to be different from the diffusion of earlier technologies, leaving room for developing countries to catch up. These findings suggest how various “policy levers” can be used to influence the digital divide at the global level.

Our results have some interesting implications for digital divide researchers and policy-makers. First, our research suggests that the digital divide appears to have largely

stabilized, with a slight declining trend over time. This is good news for concerned parties in the developing world. Second, our results suggest that an important avenue for policy-makers in developing countries might be to simply give free reign to IT cost innovations, such as reducing tariffs and taxes on IT products and services, encouraging deregulation of telecommunications services, and accelerating the pace of technology transfer from technology exporting countries. To the extent that that quality-adjusted costs of IT have been falling on average 20% annually (see e.g., Dewan and Min, 1997), the narrowing effect of IT cost innovation on the digital divide is more critical than ever before. Finally, we have shown that factors like human capital and the size of the trade sector are having a stronger impact on encouraging Internet use in developing countries than they did with previous technologies. If Internet use is the most important marker we have to date of the digital divide, as many currently believe, then this is the opportunity that developing countries have been waiting for to catch up to their more advanced neighbors.

This paper only begins to analyze the important issues related to the definition and drivers of the digital divide. Our findings are limited by the availability of data and the preliminary nature of the analysis. In the future, we plan to expand our data set to allow for coverage of emerging countries that are underrepresented in our study. Accordingly, a few words of caution are appropriate here: while our findings apply to the range of developed and developing countries included in our data set, care should be exercised in extrapolating the results to the least developed countries, such as those in Sub-Saharan Africa, which are unfortunately absent from our data set. Along with a consideration of a broader range of countries, another direction for further research would involve a more refined treatment of the level of development, going beyond GDP per capita, to consideration of the configuration of the economy (such as industry profile, openness to trade, etc.). Finally, we should begin to consider the relationship of the countries to each other, both economically and geographically.

Despite these limitations, this research makes some notable contributions. First, we demonstrate the additional perspective gained by evaluating the divide with multiple technology measures, across generations, and with both an absolute and a relative view of the gap. Second, we provide an analysis of the state of the divide and the factors driving it that owes its foundation to previous research and extends it, thus unifying and advancing the field of knowledge. Finally, we examine the factors driving the divide using an unusual approach that allows us to differentiate the importance of the factors at different levels of IT penetration, offering insights into the divide that are unique in the research to date.

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## About The Authors

**Sanjeev Dewan** is an associate professor of information systems in The Paul Merage School of Business, UC Irvine. He received his Ph.D. in Business Administration from the University of Rochester, and previously served on the faculties of the business schools at University of Washington and George Mason University. He has expertise in empirical and analytical research methods for understanding the economic impact of information technology on organizations and markets. His current research interests are in the economics of information systems, electronic commerce and markets, and IT diffusion and adoption. He is a senior editor at *Information Systems Research* and an associate editor at *Management Science*. Further information about his research is available at: <http://web.gsm.uci.edu/~sdewan/Home%20Page/Research.htm>

**Dale Ganley** is a Research Associate for the Communication Arts and Sciences School at Michigan State University. She received her Ph.D. from the University of California, Irvine, with a focus on Information Technology and Global Economics, and earlier degrees in Mathematics, Information Systems and Economics. She has presented work in several peer reviewed conferences, and in journals such as *Electronic Markets* and the *Journal of the Association of Information Systems*. She is currently studying the diffusion of computing in the global context and the impact of trade and policy mechanisms on computing in developing environments.

**Kenneth L. Kraemer** is professor of information systems in The Paul Merage School of Business and Director of the Center for Research on IT and Organizations, University of California, Irvine. He received his PhD in public policy and management from the University of Southern California. His research includes the socioeconomic implications of IT, national policies for IT production and use, and the contribution of IT to productivity and economic development. He is completing a book on the global diffusion of the Internet and e-commerce (Cambridge University Press, in process) and starting a new study of the offshore outsourcing of knowledge work. Further information about his research is available at: <http://www.crito.uci.edu/2/kraemer.asp>

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