Information Technology and Productivity in Developed and Developing Countries

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ABSTRACT: Previous research has found that information technology (IT) investment is associated with significant productivity gains for developed countries but not for developing countries. Yet developing countries have continued to increase their investment in IT rapidly. Given this apparent disconnect, there is a need for new research to study whether the investment has begun to pay off in greater productivity for developing countries. We analyze new data on IT investment and productivity for 45 countries from 1994 to 2007, and compare the results with earlier research. We find that upper-income developing countries have achieved positive and significant productivity gains from IT investment in the more recent period as they have increased their IT capital stocks and gained experience with the use of IT. We also find that the productivity effects of IT are moderated by country factors, including human resources, openness to foreign investment, and the quality and cost of the telecommunications infrastructure. The academic implication is that the effect of IT on productivity is expanding from the richest countries into a large group of developing countries. The policy implication is that lower-tier developing countries can also expect productivity gains from IT investments, particularly through policies that support IT use, such as greater openness to foreign investment, increased investment in tertiary education, and reduced telecommunications costs.

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The question of whether information technology (IT) investments lead to greater productivity has been studied extensively at multiple levels of analysis, with strong evidence that the returns to IT investment are positive and significant for firms [10, 11, 14, 21, 42, 43, 44], for industries [16, 36], and for the U.S. economy [35, 47]. Moreover, the firm-level research shows that organizational factors interact with IT, increasing the returns to IT [7, 9, 60].

Most research at the cross-national level has found that IT investment is associated with significant productivity gains for developed countries but not for developing countries [20, 54, 56].[1] Nonetheless, developing countries have increased their investment in IT dramatically. For instance, China had fewer than 10 million PCs (personal computers) in use in 1997 and barely 1 million Internet users [17]. In 2011, China passed the United States as the largest PC market [24] and led the world with more than 400 million Internet users [33]. Similar rapid growth in places such as Eastern Europe, India, Latin America, and Southeast Asia has transformed the landscape for IT use in developing countries. Given all of this IT investment, there clearly is a need for research to study whether the investment has begun to pay off in greater productivity for developing countries. To our knowledge, there have been no cross-country studies on the effects of IT investment using data sets that extend beyond 2001.

In addition, most prior studies [18, 20] employed a production function approach with labor, IT capital, and non-IT capital as inputs, and gross domestic product (GDP) as the output. They did not consider how variance in country characteristics, such as organizational factors at the firm level, might influence the productivity effects of IT.[2] Yet factors such as human capital, economic openness, and telecommunications infrastructure and pricing are important variables that may directly interact with the use of IT to improve productivity. These factors have been shown to be related to levels of IT investment at the country level [57, 58] and have been used as controls in studies of the productivity effects of information and communications technology (ICT) investment [51] and IT imports [52]. It is important to determine whether these factors have an impact on productivity gains from IT investment. If so, governments and firms will have guidance to make investments and policy decisions that are likely to increase the returns to their ongoing IT investments. Researchers will have evidence to better understand the nature of the relationships among IT and other assets and the ability to develop more fully estimated models of the effects of IT investments.

In this study, we utilize data on IT investment and productivity for 45 countries from 1994 to 2007, and compare the results with earlier years (1985–93) that were covered by Dewan and Kraemer [20]. The goal is to find out whether developing countries have been able to achieve significant productivity gains from IT investment in the more

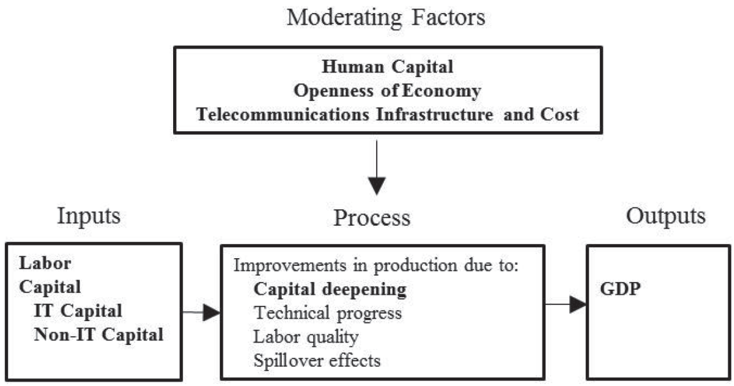

Figure 1. Analytical Framework

Source: Adapted from Dedrick et al. [19].

Note: The boldface variables in the figure are included in the quantitative analysis whereas the others are not.

recent period as they have increased their IT capital stocks and gained experience with the use of IT. We incorporate a set of country factors, including human resources, openness to foreign trade and investment, and telecommunications infrastructure and cost to determine whether these factors have an impact on the relationship of IT to productivity.

Literature Review

To frame the analysis, we review the country-level literature on IT and productivity and the factors potentially influencing productivity effects. Figure 1 provides an overview of the framework derived from the literature review discussed below. Moving from left to right, the framework identifies the various inputs (labor, IT and non-IT capital) to production in the economy, country factors that may act as moderators of the effects of IT investment, processes by which IT investment can affect output, and the contribution of the inputs to output (GDP).

Improvements in the production process through capital deepening, technical progress, improved labor quality, and spillover effects from technology investments can increase output relative to a given amount of labor inputs. Production processes are the means by which IT investment is translated into greater output (GDP), for instance, through the use of supply chain management tools in goods production or transaction processing applications in financial services. In the case of IT, the relationship of inputs to outputs may be moderated by country factors such as the level of human capital, openness of the economy, and the cost and availability of telecommunications. Each of these increases the ability of individuals and organizations to make effective use of IT as well as the incentives for them to do so.

IT and Productivity

Earlier research on IT and productivity across multiple countries found that IT investment was associated with significant productivity gains for developed countries but not for developing countries [20, 54, 56]. At the time of those studies, various explanations were offered for the lack of productivity gains from IT investment in developing countries. One explanation was that developing countries lacked resources such as human capital and telecommunications infrastructure needed to support IT use [54]. Another explanation was that developing countries had less experience with IT, and as a result, had not learned to use IT effectively, or to make organizational and process changes needed to achieve productivity gains from IT [20].

The data in these early studies came mostly from the late 1980s through the mid-1990s, a time when most developing countries had limited IT experience and low levels of IT capital stock. A later study covering the period 1980–2000 concluded that IT investments resulted in productivity gains for some developed and industrializing countries, but not for developing ones [41]. That study also found considerable variability among countries in the short- and long-run economic effects of IT investments.

Another study, covering the period 1993–2001, examined the contributions of IT capital to labor productivity growth [51]. That study decomposed IT capital into communications, computer hardware, and software and found that communications and hardware accounted entirely for the effect of IT on productivity growth, while software was significantly and negatively related to productivity. The study also found that "it seems that developing countries have started to benefit from IT" [51, p. 180] although the effect was lower compared to that of developed countries. The study controlled for country factors (schooling, government share of GDP, openness to trade, transparency) and found that the IT coefficient remained positive. However, the study did not examine the interaction of these country factors with IT capital—an important distinction and contribution of the current paper. A summary of the previous studies of IT in developed and developing countries is shown in Table 1.

Despite the lack of evidence of positive returns up to the early 2000s, developing countries continued to invest in IT, and as a group have accelerated their investment faster than developed countries. Developing countries have doubled their IT investments (hardware, software, and data communications) from 0.5 percent to 1.0 percent of GDP.[3] Developing countries have been buying newer technology that is cheaper, more powerful, and easier to use, providing a better fit with worker knowledge and skills. It should be remembered that earlier studies in developed countries such as the United States failed to show measurable IT payoffs, in part because technology was expensive and the level of investment was low relative to non-IT capital. As the level of IT capital increased, so did the measured contribution of IT to the economy [8]. Given the steady investment in improved IT by developing countries and the experience gained over the past decade, it is likely that IT investments have become more productive in recent years and more likely that the effects will show up in econometric analyses.

Table 1. Summary of Previous Studies of IT and Productivity in Developed and Developing Countries

Study	*N*	Developed/ developing	Time period	Method	Output variable	Explanatory factors	Findings
Dewan and Kraemer [20]	30	16/14	1985–1993	Production function analysis (PF)	GDP	NA	Productivity gains for developed but not developing countries
Pohjola [54]	39	23/16 OECD/ non-OECD*	1980–1995	Growth accounting	Real GDP	NA	Supports Dewan and Kraemer [20]
Lee et al. [41]	20	15/5	1980–2000	PF + Time series analysis	GDP	NA	Supports Dewan and Kraemer [20]
Park et al. [52]	39	Does not distinguish developed/ developing	1992–2000	PF	Total factor productivity	Foreign IT stocks Openness Innovative capacity IT infrastructure	Countries with IT imports from IT-intensive countries have higher productivity
Papaioannou and Dimelis [51]	42	22/20	1993–2001	PF	GDP/worker	Schooling Openness Government as percent of GDP Transparency	Finds productivity gains for both developed and developing countries, entirely from hardware and communications investments

Notes: N/A = not applicable. * OECD = member countries of the Organization for Economic Cooperation and Development (OECD) and non-OECD means nonmember countries. The former are more economically developed than the latter.

Country Factors Influencing Productivity Effects of IT

While developed countries are the source of most technological advances and can benefit from the rents that go to innovators, developing countries generally are users of technologies created elsewhere and must benefit from improved efficiency and productivity gained from using those technologies [52]. These benefits may be realized through the process of capital deepening, giving more tools to workers to make them more effective [36], or through spillover effects, by which knowledge is transferred across national borders from more technically advanced countries in the form of technology embodied in traded goods, leading to gains in multifactor productivity that go beyond capital deepening [13, 15, 19]. Benefits may also be realized when the relationship of IT capital to non-IT capital shifts from substitution to a complementary relationship, so that investment in IT capital increases the value of non-IT capital [14].

Bell and Pavitt [5] argue that simply adopting technology embodied in capital goods is insufficient to drive economic growth and productivity in developing countries. Instead, they argue that these countries need the capability to generate and manage change in the technologies they use, even when those technologies are imported. The implication is that the mere adoption and use of IT may be insufficient to achieve productivity gains. Rather, a country must adapt the technology to its own circumstances and use it in ways that enhance the efficiency of firms and the economy as a whole. The ability to do so depends on accumulated experience with IT use and on country factors that influence the value of IT [5, 41, 52].

There are many country-level studies of the factors influencing IT diffusion and use in the IT literature [13, 22, 48, 55, 57, 58, 59]. The current study is not about IT use but, rather, about the factors that influence the relationship of IT investment to productivity. Here, there is no overarching theory or previous empirical research that we are aware of identifying the moderating factors that influence the relationship of IT investment to productivity at the national level. We have based our selection of factors on prior empirical and conceptual work in three areas: (1) factors shown to have direct effects on productivity in studies of IT and productivity [51], and which might also moderate the impact of IT on productivity; (2) factors shown to influence investments in IT at the national level [57], reflecting their impact on the perceived value of IT investment; and (3) factors shown to influence the value of IT investments at the firm level [9], and which would reasonably be expected to have a similar effect at the national level.

Based on the foregoing literature, the three main categories of country factors that we consider are human capital, openness of the economy to trade and investment, and telecommunications infrastructure and cost. We do not claim that this is an exhaustive list, but argue that these are each likely to have a significant effect on the productivity gains that can be achieved through investment in IT.

Human Capital

One key resource needed to support effective IT use is *human capital,* including people who know how to use and operate the technology, support and extend the technology to new uses, and even create new technology. IT has been shown to be a skill-based technology whose value is closely linked to the skill levels available to the firm or country [9, 39]. Educated workers not only have the skills to use computers but are more flexible and more readily adapt to the introduction of new technologies [4, 55]. Several multicountry empirical studies have found a strong association between the level of education and IT investment [13, 53, 57]. We expect that the effects of IT on productivity will be higher in countries with higher education levels.

Openness to Trade and Investment

Another factor that is likely to influence the effects of IT on productivity is a country's *openness to foreign trade and investment,* which can provide access to a broad range of technical and managerial knowledge from beyond its borders [6, 26]. Trade and investment provide channels through which knowledge can flow between firms and individuals in different countries [7, 15]. Countries that are more open to foreign trade and investment than others attract multinational corporations (MNCs) that introduce new uses of IT and transfer knowledge to local subsidiaries and workers in developing countries. There is evidence that European establishments have experienced accelerated productivity growth after being taken over by U.S. MNCs and that U.S. MNCs in Europe earned higher returns from IT investments than other firms [7]. The presence of MNCs in a country can drive IT investment by local firms to compete with, or do business with, MNCs that are sophisticated users of IT. Intensity of competition in downstream industries has been shown to moderate the effect of internal IT investments on firm productivity as well as the spillover effects of IT at the industry level [27].

Countries with greater inflows of foreign investment have been shown to achieve higher productivity growth [51], although the evidence that this is due to knowledge spillovers is mixed for developing countries [34, 63]. Park et al. [52] found that countries importing IT from more IT-intensive countries achieved greater productivity than those importing from non-IT-intensive countries. This may be explained by the fact that IT is a knowledge-intensive good, and that imports from more advanced countries embody greater productivity-enhancing knowledge. We expect that the effects of IT on productivity will be greater for countries that are more open to trade and foreign investment.

Telecommunications Infrastructure and Cost

Another important country factor influencing productivity gains is *cost and availability of telecommunications infrastructure.* Much of the value of computers comes when they are connected via the Internet, organizational networks, and other types of networks in national and global supply chains. Such networks require an underlying infrastructure to link individuals and organizations. Previous empirical studies show a positive association between IT diffusion and the various measures of telecommunications infrastructure [37, 50, 55, 57]. Research also shows that there is an interactive effect between computer and network use, with greater PC use leading to greater Internet use and Internet use in turn influencing greater PC use [22].

Access to the Internet and other networks is strongly influenced by telecommunications cost—especially in developing countries. One study found that the number of Internet hosts in a country was negatively associated with telephone service costs [50]. Two cross-country studies indicated that average monthly telephone cost is negatively related to Internet diffusion in developing countries [22, 38]. Various policy studies on telecommunications regulation have indicated that the high cost of telecommunications is a major inhibitor of IT adoption and use, particularly in developing countries, and have advocated greater competition in telecommunications and Internet markets to reduce prices [48, 49]. We expect that the productivity gains from IT use will be greater when Internet use is more widespread and when telecommunications costs are lower.

All the foregoing factors are strongly influenced by government policy, including educational policy, trade and investment policies, and regulations on telecommunications pricing and government investments in infrastructure. Whether these factors turn out to have a moderating effect on the productivity effects of IT will have implications for policymakers in developing countries.

Relation to the Prior Literature

Our work builds on the studies cited above to make important contributions to two streams of research on IT and productivity. First, we contribute to knowledge of the effects of IT investment on productivity in developing countries. We created a unique multicountry panel database covering 14 years from 1994 to 2007 that enables us to extend Dewan and Kraemer's [20] earlier analysis of IT investment and productivity in developed and developing countries from 1985 to 1993. In doing so, we contribute new findings to the IT productivity discussion at the cross-country level.

Second, we contribute to understanding the factors that influence IT productivity. While other studies [51, 52] use national factors as controls in their study of IT imports and productivity, we test the interaction effects between country factors and IT investment on productivity. To our knowledge, we are the first to test such moderating effects. This is an important distinction, as we are analyzing whether national characteristics influence the value of IT investments. In other words, we are not examining whether investment in education or telecommunications or a country's openness increases productivity by themselves. Rather, we are asking whether countries with educated workers in an open economy and broadly available, low-cost telecommunications are able to make better use of IT.

Methodology

Production Function Analysis of IT Productivity

A two-step analysis is used in this paper. The first step identifies the productivity effects of IT investments, and the second step assesses the influence of national characteristics on productivity effects. To estimate productivity effects, we adopt an intercountry production function of the form

$$Q_{it} = F\left(L_{it}, K_{it}, IT_{it}; i, t\right), \tag{1}$$

where Q_{it} is the annual GDP, and we model it as a function of total labor hours employed annually (L_{it}), non-IT capital stock (K_{it}), and IT capital stock (IT_{it}). The i and t following the semicolon in Equation (1) are dummy controls for country- and year-specific effects. Equation (1) is estimated as a Cobb–Douglas production function using a panel data set that covers 45 countries over 14 years (1994–2007). The Cobb–Douglas production function is the most common function for studying the effects of IT on productivity and was adopted in other major studies [10, 20, 52, 60]. It has been shown to be a good approximation in the IT and productivity context and is pervasive in other productivity research [25] used to study the impact of research and development (R&D).

Using the production function, we have for country i ($i = 1, 2, ..., N$) in year t ($t = 1, 2, ..., T$):

$$\log Q_{it} = \beta_0 + \beta_{IT}\log IT_{it} + \beta_K \log K_{it} + \beta_L \log L_{it} + \lambda_t + \nu_i + \varepsilon_{it}. \tag{2}$$

In Equation (2), λ_i is a year dummy that captures the effect of years in the regression, v_i is the country-specific effects invariant over time, and ε_{it} is the random error term in the equation that represents the net influence of all the unmeasured factors that affect output. One useful feature of adopting the Cobb–Douglas production function is that we can focus our analysis strictly on B_{IT}, B_K, and B_L, which capture the increase (or decrease) in output associated with changes in corresponding input (IT capital, non-IT capital, and labor). In other words, the parameters can be interpreted as elasticity effects of input factors on output as in earlier studies [20].

Equation (2) can be estimated as a fixed effects panel regression model. While the fixed effects model can be estimated with ordinary least squares (OLS), a common problem with a panel regression of this type is for OLS standard errors to be biased, leading to either overestimation or underestimation of the true variability of the coefficient estimates. This is because there are two general forms of residual dependence that are common in panel regression that researchers need to account for. Residuals of a given country may be correlated across years (time-series dependence) or the residuals of a given year may be correlated across different countries (cross-sectional dependence). Historically, researchers have used different solutions to this problem such as reporting the White standard error, which is adjusted to account for the possible correlation within a cluster. However, these methods only account for either time-series or cross-sectional dependence and not both simultaneously. Instead, we adopted the recently introduced two-dimensional cluster bias correction procedure to estimate standard errors [53], which will address both types of dependence.

On the one hand, the fixed effects model specification above, while very consistent, requires estimation of a large number of dummy variables. Given the modest number of countries and years available in our panel data set, this may not be the best approach. On the other hand, although more efficient, a random effects model requires stringent assumptions regarding the error structure. In this paper, we estimated fixed effects models, fixed effects models with two-dimentional standard error correction, and random effects models. We tested the appropriateness between fixed and random effects specifications. Specifically, the Lagrangian multiplier test was used to see whether the country-specific errors are equal to 0, and the Hausman test was used to check the orthogonality of the country specific error with the explanatory variables. Results suggest that the random effects model is appropriate for our analysis (Lagrange = 9.59, 6.06, 12.45, *p*s < 0.01; Hausman = 2.91, 1.05, 1.99, *p*s > 0.05 for all, developing, and developed samples).

One of our interests is to determine if the effect of IT capital on output is moderated by country factors. In our analysis, we added moderating effects of the variables relating to country factors by examining their interactions with IT capital stock. Conceptually, we identified three potential moderators: openness of the economy, the availability of human capital, and the existence and cost of IT infrastructure. Openness of the economy is measured by the amount of imports relative to GDP (*Imp*) and the level of foreign investment relative to GDP (*FDI*). Availability of human capital is measured by the level of tertiary education (*Edu*). IT infrastructure is measured by the cost of business monthly telephone subscription (*Cost*), penetration of cellular phones (*Cel*), and penetration of the Internet (*Int*). All the moderating variables and production inputs are mean centered prior to computing their interaction terms in order to reduce multicollinearity and facilitate interpretation of effects, as suggested by Aiken and West [1].

Data and Variables

Our database contains macroeconomic and IT investment data for 45 countries split into 19 developing and 26 developed countries from 1994 to 2007 (Table 2). The categorization of developed and developing countries was based on International Monetary Fund (IMF) classifications [31].[4]

Data for the current analysis came from four primary sources. Data on IT hardware spending and average selling price of PCs for 1994–2007 were from the International Data Corporation [30]. GDP information was obtained from the Penn World Tables (PWT) version 6.3 [29]. Although not publicly released, we were also able to obtain data on total capital stock privately from the authors of the PWT. However, the capital stock series goes to only 2004. To stretch the series to 2007, we add investment for current year and depreciate prior capital stock by 5 percent. The assumed 5 percent depreciation rate follows from Park et al. [52] and Sichel [59].[5] We also conducted analysis with the shorter panel (up to 2004) and found that the coefficient's direction, magnitude, and significance do not show meaningful change.

Labor statistics are from the International Labour Organization reported in the World Bank's *World Development Indicators* [62].

Data on other variables (average manufacturing tariff, goods and services imported, foreign direct investment, tertiary school enrollment, immigration, cost of monthly business telephone subscription, Internet and cellular phone penetration) were collected from the World Telecommunication/ICT Indicators database [32], Organization for Economic Cooperation and Development [49], and the *World Development Indicators* [62].

Table 2. Sampled Countries, 1994–2007

Developing countries	Developed countries
Argentina	Australia
Brazil	Austria
Chile	Belgium
China	Canada
Colombia	Denmark
Egypt	Finland
Hungary	France
India	Germany
Indonesia	Greece
Malaysia	Hong Kong
Mexico	Ireland
Philippines	Israel
Poland	Italy
Romania	Japan
Saudi Arabia	Netherlands
South Africa	New Zealand
Thailand	Norway
Turkey	Portugal
Venezuela	Singapore
	South Korea
	Spain
	Sweden
	Switzerland
	Taiwan
	United Kingdom
	United States

Dollar values of GDP, capital stock, IT spending, average selling price of PC, and cost of monthly business telephone subscription are expressed in international dollars. The "international dollar" refers to currency conversion based on purchasing power parities (PPP) so that real quantity comparisons can be made across countries and time [29]. An international dollar has the same purchasing power over total U.S. GDP as the U.S. dollar in a given base year (2005 in the PWT 6.3).

To compute IT capital stock, we first convert the flow of IT spending from current dollars to constant dollars using the computers and peripherals price index obtained from U.S. Bureau of Economic Analysis (BEA), which adjusts the value of IT spending for quality change of technology [12]. According to the BEA [12], the quality for PCs is associated with the attributes of the components that are used to build it. Based on the speed of the CPU (central processing unit), the amount of RAM (random access memory), and the hard drive storage capacity and other attributes, a substitute to a computer is selected that contains the updated attributes in order to maintain a level of quality, a process known as "directed substitution." The directed substitution process is different from the typical consumer price index (CPI) process where an item continues to be priced until that item is no longer available in the marketplace. With directed substitution, a substitute to a new item is carried out every six months, regardless of the previous item being available. This process creates a price index that adjusts for the quality change in the computer's attributes to reflect price change for the particular quality level. Once we have a quality-adjusted IT spending series, we then convert the series into constant international dollars.

To compute total IT stock, we summed the flow of quality-adjusted IT spending in constant international dollars over ten years and applied the appropriate depreciation rates. It is important that we use IT stock as opposed to IT flow when IT is accumulated over the years because its contribution to output becomes more salient and detectable. There has been considerable debate about the appropriate depreciation rates for assets such as computer hardware. Other studies [45, 46, 61] have suggested that if the quantity of investment is constructed with constant-quality deflators, the depreciation rate should be obtained from constant-quality price data by age of asset, in essence applying a partial depreciation to the asset. If not, the depreciation would be counted twice in the calculation of stock: once through the asset-specific inflation rate and again through the asset-specific depreciation rate. We used the depreciation rate for computer hardware based on the work of Doms et al. [23], which adopts this methodology.

To compute non-IT capital stock, we took the total capital stock series and subtracted the value of IT capital stock. To compute total labor hours, we computed billions of total labor hours per year for each country by taking the total labor force, adjusted by the unemployment rate, and multiplied by the average number of worker hours per year. In instances where average numbers of worker hours were not available, we substituted the average worker hours for countries in the region. Descriptive statistics for the variables used are presented in Table 3.

Panel Unit Root Test

A common problem in time-series cross-sectional regressions is that they usually involve time-series variables that exhibit nonstationarity. This means the data series may involve a time trend or exhibit a random walk process that can potentially lead to spurious results such that *t*- and *F*-tests can support significant relationships even when no such relationships exist. To check for possible nonstationarity, we conducted a panel unit root test on all the data series we used in this paper. When a data series was identified to be nonstationary, we tried to attain stationarity by first-differencing it. The resulting differenced data, which is stationary, can then be used to test our hypothesized relationships. With exception of *FDI*, *Int*, and *Cel*, our data series are nonstationary in log levels but stationary when first-differenced once. These first-differenced variables are what we used in our analysis.

Empirical Results

Production Function Analysis of IT Effects

We start our estimation by examining whether the developing and developed countries are different in their production function. Prior research by Dewan and Kraemer [20]

Table 3. Descriptive Statistics

	Developing countries		Developed countries	
	Mean	Standard deviation	Mean	Standard deviation
GDP per capita[1]	8,635.49	4,292.92	26,102.12	7,021.54
GDP[1,2]	785.73	1,394.11	999.92	2,012.89
Labor hours (*L*)[2]	155.49	371.63	29.24	51.08
Non-IT capital stock (*K*)[1,2]	1,383.52	2,618.79	2,534.58	4587.70
IT capital stock (*IT*)[1,2]	24.17	64.38	40.07	100.38
Average selling price of PC (*ASP*)[1]	2,607.22	1,274.50	1,362.74	410.31
Tertiary education (*Edu*)[3]	31.60	15.59	59.14	15.47
Immigration (*Imm*)[4]	1,194.38	132.31	5,592.76	234.94
FDI/GDP (*FDI*)[3]	3.44	3.60	4.75	8.05
Net import/GDP (*Imp*)[3]	37.36	22.06	46.34	37.93
Cost of monthly subscription (*Cost*)	24.90	18.70	17.70	8.79
Cellular penetration (*Cel*)[3]	29.59	32.60	61.48	37.33
Internet penetration (*Int*)[3]	9.89	12.18	35.65	24.80

[1] PPP adjusted international dollars. [2] In billions of dollars or hours. [3] In percentages. [4] Per million persons.

suggested a significant difference between developing and developed countries with respect to production function coefficients. To test for equality of coefficients across the two groups, we reanalyzed the full panel and included interaction terms between each of the production variables, time dummies, and a dummy variable that indicates whether the country is developing or developed in a fixed effects model. The F-test of the equality restrictions suggests that indeed the countries are significantly different in their production function coefficients ($F(14, 484) = 2.21$, $p < 0.01$). Therefore, it makes sense to present a separate analysis for developing and developed countries, along with all of the countries for comparison purposes.

Table 4 presents the results for analysis of the production functions for all countries, developing countries, and developed countries using fixed effects, fixed effects with two-dimensional cluster-corrected standard errors, and random effects models. For the various samples, we observe respectable explanatory power across all of the models (R^2 ranges from 0.433 to 0.475). The coefficients for labor and non-IT capital are all positive and significant throughout. More importantly, the coefficients for IT capital, the main variable of interest, are positive and significant for the different groups of countries. To further test for the difference between developed and developing countries on IT capital stock, we multiply a dummy variable (1 = developed) to IT capital stock and add it to our random effects model for all the countries sampled along with labor, non-IT capital stock, and IT capital stock as regressors. We then test for the restriction that this new coefficient equals zero.[6] This produces a $\chi^2 = 0.34$, $p > 0.05$,

Table 4. Regression Results

	All countries			Developing countries			Developed countries		
	Fixed effects	2D cluster standard errors corrected	Random effects	Fixed effects	2D cluster standard errors corrected	Random effects	Fixed effects	2D cluster standard errors corrected	Random effects
β_L	0.300***	0.300*	0.307***	0.380***	0.380*	0.456***	0.466***	0.466**	0.511***
	(0.070)	(0.141)	(0.063)	(0.120)	(0.173)	(0.105)	(0.090)	(0.133)	(0.082)
β_K	0.352***	0.252*	0.335***	0.353***	0.353**	0.345**	0.451***	0.451**	0.266**
	(0.098)	(0.122)	(0.067)	(0.085)	(0.123)	(0.111)	(0.112)	(0.154)	(0.081)
β_{IT}	0.150***	0.150***	0.145***	0.137***	0.137**	0.125***	0.103***	0.103*	0.104***
	(0.018)	(0.040)	(0.017)	(0.032)	(0.044)	(0.030)	(0.027)	(0.053)	(0.025)
Lagrange			9.59***			6.06**			12.45***
Hausman			2.91			1.05			1.99
N	557	557	557	219	219	219	338	338	338
R^2	0.433	0.433	0.436	0.472	0.472	0.475	0.452	0.452	0.462

Notes: Standard errors are in parentheses. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

indicating there is no significant difference between developed and developing countries regarding the effect of IT capital stock on output. This is in contrast to Dewan and Kraemer's [20] results for 1985–93, which found that IT capital was significantly related to output for developed countries, but not for developing countries. It is also interesting to note that for the sampling period of 1994–2007 used in our analysis, not only was IT capital significant for developing countries but it actually showed a stronger effect than developed countries.[7]

Next, we conducted robustness checks of our results to simultaneity and autocorrelation. A potential problem with endogenous regressors may arise when a shock to annual GDP also triggers contemporaneous adjustments in some of our regressors. This is most likely for labor hours given that it is a "flow" variable and thus most likely to be jointly determined with GDP, as opposed to non-IT capital and IT capital, which are "stock" variables and thus inherently less sensitive to immediate changes in GDP. However, although not likely, given IT capital is our main variable of interest, we would still like to rule out any potential problems with simultaneity and estimate our model by finding instruments for labor and IT capital stock and estimate our regression using two-stage least squares (2SLS). The set of instruments we identified are lagged labor hours (L_{t-1}) and average selling price of a PC (*ASP*). We follow Dewan and Kraemer [20] and use lagged labors as an instrument because past labor hours could not possibly be influenced by a contemporaneous change in GDP. The average selling price of PC works well as an instrument because price is theoretically driven by the supply and demand for computing technology. Average price of PC should affect how much IT stock a country has, but it is unlikely to be correlated with GDP, which is a macro and aggregate measure of economic activities.

Our 2SLS results in Table 5 suggest that the direction and significance of the regressors were not materially different from the results reported in our fixed or random effects model reported in Table 4. The standard errors were higher, but the coefficients remain significant and the R^2s were also in a similar range (from 0.423 to 0.450) for the all countries, developing countries, and developed countries samples. We also tested the exogeneity of the instruments using the Durbin–Wu–Hausmann test. The nonsignificant finding of the Durbin–Wu–Hausmann test suggests that the panel regression is consistent and efficient. Therefore, we conclude that simultaneity is not a major concern in our analysis.

We also examined robustness with respect to autocorrelation. Although our variables were already first differenced to achieve stationarity and autocorrelation should not be a concern, we would still like to rule it out. We estimated the AR(1) model on the differenced variables and our results still hold in terms of direction and significance, although the coefficient for IT capital is somewhat lower for the all countries and developed countries samples but slightly higher for the developing countries, and the standard errors were also higher except for developed countries. We conclude that autocorrelation is not a major problem with our estimates and our results are robust.

Because our sampling period of 1994–2007 covers multiple business cycles, it is relevant to examine how the effect of IT capital varies over time for the different country groups. We created an interaction term for each of the production inputs and a

Table 5. Robustness Test

	All countries		Developing countries		Developed countries	
	AR(1)	2SLS	AR(1)	2SLS	AR(1)	2SLS
β_L	0.373***	0.493**	0.223*	0.511**	0.737***	0.352**
	(0.069)	(0.221)	(0.112)	(0.220)	(0.085)	(0.147)
β_K	0.325***	0.389**	0.243***	0.381**	0.257**	0.326**
	(0.084)	(0.119)	(0.049)	(0.164)	(0.087)	(0.096)
β_{IT}	0.099***	0.105*	0.162***	0.129*	0.081**	0.082*
	(0.019)	(0.048)	(0.037)	(0.068)	(0.028)	(0.041)
ρ	0.257		0.301		0.090	
Hausman[1]		0.72		1.27		1.14
N	557	557	219	219	338	338
R^2	0.185	0.423	0.168	0.447	0.290	0.450

Notes: Standard errors are in parentheses. [1] Exogeneity test comparing 2SLS estimates to random effects panel regression estimates. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

dummy variable for each year. We plot the coefficients for IT capital for all countries, developing countries, and developed countries in Figure 2 (the figure starts with 1995 because we are using first differences in the model).

As Figure 2 shows, starting from 1995, the effects of IT capital between the developing and developed countries are similar. The effect of IT capital increases up to 1998, but a sudden drop started after 1998 and persisted until 2000, which corresponds to the bursting of the dot-com bubble. It would appear that during this period, countries were ramping up their IT investments and continuing to build their capital stock. But around this time there was a global slowdown that depressed GDP output, reflected in a low and even negative payoff for IT investments. The effects of IT pick up again in 2001. But it is interesting to see that the effect of IT capital post-2001 appears to be growing more strongly for developing countries than developed countries. This seems reasonable considering that IT is relatively new for developing countries and they are starting from a much lower level of IT capital stock. Therefore, there is more opportunity for IT to spur growth in developing versus developed countries once they have reached the point of seeing positive returns.

Analysis of Moderating Effects of Country Factors

Next we examine the moderating effects of country factors on IT capital. Table 6 presents the regression results relating to human capital measures (tertiary education and immigration). Table 7 presents the results relating to economic openness (net imports and foreign direct investment). Table 8 presents the results for ICT infrastructure (cost of communication, cellular penetration, and Internet penetration). As shown in the first three columns of Table 6, the interaction between level of tertiary education and IT capital is positive and significant for the developing countries only. It was not

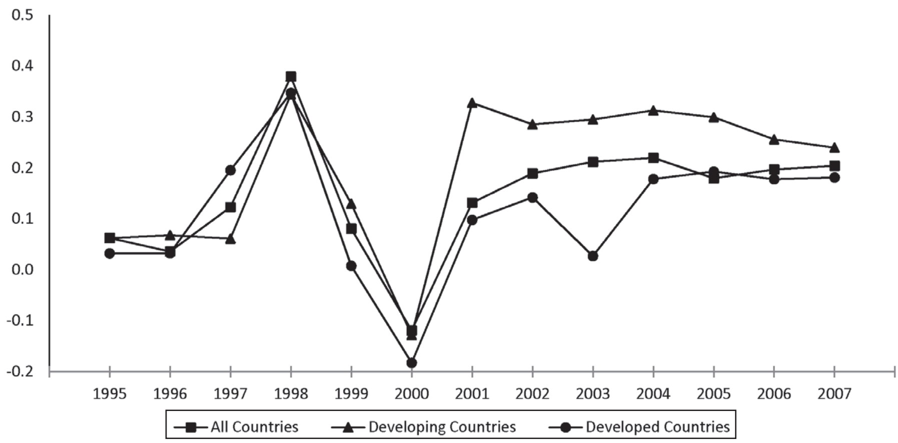

Figure 2. IT Stock Coefficients by Year

Table 6. Random Effects Regression with Human Capital Moderators

	Tertiary education			Immigration		
	All countries	Developing countries	Developed countries	All countries	Developing countries	Developed countries
β_L	0.351***	0.214*	0.571***	0.361***	0.368***	0.303*
	(0.065)	(0.111)	(0.075)	(0.073)	(0.088)	(0.134)
β_K	0.328***	0.320**	0.267**	0.581***	0.407***	0.879*
	(0.069)	(0.107)	(0.079)	(0.105)	(0.116)	(0.355)
β_{IT}	0.128***	0.116***	0.069**	0.113***	0.080***	0.169*
	(0.017)	(0.030)	(0.022)	(0.022)	(0.028)	(0.081)
β_{Edu}	0.036	0.060	0.027			
	(0.024)	(0.043)	(0.024)			
β_{IT*Edu}	0.351	0.809*	–0.016			
	(0.246)	(0.405)	(0.288)			
β_{Imm}				–0.001	0.002	–0.017
				(0.004)	(0.004)	(0.023)
β_{IT*Imm}				0.097	0.043	0.452
				(0.054)	(0.058)	(0.351)
N	518	206	312	334	283	51
R^2	0.438	0.493	0.496	0.464	0.466	0.655

Notes: Variables are mean centered for all countries, developing countries, and developed countries, respectively. Standard errors are in parentheses. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

significant for the developed countries or the combined sample. When comparing the coefficients between the developed and developing countries, we found a significant difference as well ($\chi^2 = 4.23$, $p < 0.05$). This is understandable considering the developed countries in our sample already have high levels of tertiary education and thus possess a stock of workers that are highly trained and leverage the IT investments. It

Table 7. Random Effects Regression with Openness of Economy Moderators

	Net imports			Foreign direct investment		
	All countries	Developing countries	Developed countries	All countries	Developing countries	Developed countries
β_L	0.303***	0.335**	0.461***	0.289***	0.347**	0.469***
	(0.066)	(0.106)	(0.091)	(0.063)	(0.106)	(0.087)
β_K	0.356***	0.363***	0.296**	0.3639***	0.335**	0.301**
	(0.074)	(0.103)	(0.103)	(0.067)	(0.109)	(0.091)
β_{IT}	0.144***	0.120***	0.114***	0.156***	0.137***	0.129***
	(0.019)	(0.033)	(0.029)	(0.019)	(0.034)	(0.028)
β_{Imp}	–0.001	–0.006	–0.000			
	(0.002)	(0.004)	(0.002)			
β_{IT*Imp}	0.011	–0.004	0.017			
	(0.020)	(0.049)	(0.020)			
β_{FDI}				0.003*	0.002	0.002
				(0.001)	(0.003)	(0.001)
β_{IT*FDI}				0.044**	0.058*	0.036**
				(0.014)	(0.030)	(0.013)
N	498	200	298	515	206	268
R^2	0.440	0.480	0.465	0.461	0.485	0.494

Notes: Variables are mean centered for all countries, developing countries, and developed countries, respectively. Standard errors are in parentheses. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

would appear that above a certain point, increasing human capital via tertiary education does not help boost the payoff from IT investments. By contrast, the developing countries as a group have much lower tertiary education. Increasing the workforce education does improve productivity from IT when developing countries are starting from such low levels.

There was no significant main effect for immigration or its interaction with IT stock for all of the samples. While this would suggest that immigration does not play a factor, we suspect this is because many of the immigrants into a country, particularly developed countries where we are getting most of the immigration data, are low-skilled workers seeking better employment opportunities and economic conditions. We suspect that most of these immigrants will be employed in manual labor where IT investments play a less crucial role. Skilled immigrants (e.g., professionals, engineers, scientists) may provide the human capital to boost the productivity of IT investments, but they are relatively small in number compared to other types of immigrants and their effect may be disguised in aggregate statistics.

For openness of the economy, there were no effects relating to net imports across all of the samples. But we observed significant interaction between foreign direct investments and IT capital across all of the samples. Furthermore, there was no significant difference in effects between developed and developing economies ($\chi^2 = 0.13$, $p > 0.05$). This signals that countries that received more foreign direct investments enjoyed an additional boost in productivity from IT capital. This makes

Table 8. Random Effects Regression with ICT Infrastructure Moderators

	Cost of communication			Cellular penetration			Internet penetration		
	All countries	Developing countries	Developed countries	All countries	Developing countries	Developed countries	All countries	Developing countries	Developed countries
β_L	0.313***	0.363***	0.499***	0.288***	0.359***	0.493***	0.289***	0.356***	0.517***
	(0.065)	(0.111)	(0.085)	(0.063)	(0.105)	(0.082)	(0.064)	(0.106)	(0.081)
β_K	0.322***	0.318**	0.262**	0.351***	0.358**	0.265**	0.365***	0.349**	0.295***
	(0.069)	(0.120)	(0.086)	(0.070)	(0.116)	(0.082)	(0.068)	(0.115)	(0.077)
β_{IT}	0.143***	0.125***	0.106***	0.164***	0.142***	0.126***	0.170***	0.159***	0.115***
	(0.017)	(0.030)	(0.025)	(0.019)	(0.034)	(0.027)	(0.019)	(0.037)	(0.003)
β_{Cost}	–0.001	0.000	0.005						
	(0.007)	(0.010)	(0.011)						
$\beta_{IT*Cost}$	–0.032	–0.039***	0.041						
	(0.071)	(0.010)	(0.141)						
β_{Cel}				–0.001	–0.003	–0.002			
				(0.001)	(0.002)	(0.004)			
β_{IT*Cel}				0.018*	0.014	0.032*			
				(0.007)	(0.013)	(0.016)			
β_{Int}							0.001	0.001	0.002
							(0.001)	(0.002)	(0.003)
β_{IT*Int}							0.016**	0.017	0.011
							(0.006)	(0.011)	(0.013)
N	539	211	328	557	219	338	557	219	338
R^2	0.427	0.464	0.459	0.442	0.480	0.465	0.444	0.481	0.467

Notes: Variables are mean centered for all countries, developing countries, or developed countries, respectively. Standard errors are in parentheses. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

sense given that foreign direct investment represents the transfer of business practices and know-how from one country to another; in particular, how to leverage IT more efficiently. Also, foreign direct investment may increase a country's external focus, as MNCs have strong ties to the global economy, and their presence via foreign direct investment may increase a country's ability to respond effectively to changing global conditions through the use of IT. This effect could be seen as a parallel to the findings of Tambe et al. [60] that firms with greater external orientation achieve higher returns from IT capital.

Imports, however, do not seem to have the same effects. Although a country can be considered more open if is has a high ratio of imports, such openness does not elevate the effect of IT investments. Some imports are commodity products (e.g., energy, food, raw materials) that do not embody knowledge, and even imports of manufactured goods or capital equipment may not transfer know-how or increase external orientation if they are simply applied within existing organizational structures and processes by domestic firms [5]. While these imports may improve productivity directly, they would not necessarily moderate the impact of IT on productivity.

For ICT infrastructure, we observed a significant negative interaction effect between cost of communication and IT capital for developing countries, but not for developed countries or the full sample. In other words, higher telecom cost lowers the payoff from IT capital in developing countries. Cellular penetration's interaction was positive and significant for only the developed countries, not for the developing countries. But when testing the difference between the coefficients between developed and developing countries, it was not statistically significant ($\chi^2 = 0.19$, $p > 0.05$). Internet penetration was positive and significant only for the full sample, but was not significant when we examined only developing or developed countries. Taking the pattern of effects overall, it appears that widespread diffusion and lower costs of communications and network technologies helped boost the impact of IT capital, albeit to a different degree in developed and developing countries.

Conclusion

This study revisits the issue of whether IT investment leads to greater economic output, looking across a large sample of developed and developing countries. With 45 countries over 14 years, this is the largest study of IT and productivity at the national level that we are aware of, and the first to include data from the post-2000 period. During the period covered by this study, 1994–2007, the nature of IT changed significantly with the widespread adoption of the Internet, electronic commerce, PCs, client–server computing, and a variety of enterprise and interorganizational systems. Also, IT investment in the developing world grew at a rapid pace, lessening the gap in IT capital between developing and developed countries. These changes were accompanied by rapid globalization of manufacturing and services as well as greater flows of capital and labor across borders. In such a changing environment, we might expect to see new relationships between IT and productivity, compared to older studies, and we did.

Discussion

The findings in this study include two important new results. First, there is strong evidence that developing countries are now enjoying productivity growth associated with IT investment. This addresses one of the major concerns raised by prior studies of IT and productivity (with the exception of Papaioannou and Dimelis [51]), which had failed to find such a relationship and thus raised questions about whether the majority of the world's population was being left out of the IT productivity story. There is now strong empirical evidence that the positive effects of IT at the country level extend to both developed and developing countries.

Second, we find evidence that three sets of country factors influence the relationship of IT investment to productivity. The relationship of IT to productivity is moderated for the full set of countries by levels of foreign investment, cellular phone penetration, and Internet penetration. In developing countries, the relationship is moderated by education levels, foreign investment, and cost of telecommunications services. In developed countries, the significant moderators are foreign investment and cellular penetration. This suggests that the effects of IT depend not only on the level of use but also on the presence of resources and favorable policies to support IT use. Such relationships had been posited in the literature previously, and these factors had been found to influence IT investments [18] and to directly influence productivity [51]. However, this study provides the first empirical evidence linking them with productivity gains from IT investment.

Implications

The results of this study have both academic and policy implications. For IS researchers, they reduce concerns that the relationship of IT investment to productivity at the national level was true for only the richest countries and thus limited in applicability. The finding that developing countries only began to realize measurable payoffs from IT investment in more recent years suggests that there may be some critical level of IT capital stock or some minimum level of accumulated experience [41] required before such gains become evident. Indeed, our finding that IT had a greater effect in developing countries after 2000 is consistent with the capital stock explanation and with previous research on the history of IT and productivity in the United States [8, 36].

There are other possible explanations for the delayed effect of IT investment on productivity in developing countries. One explanation is that the long-term spillover effects of IT investment on total factor productivity are greater than short-term effects, as found by Han et al. [27]. These spillover effects, associated with organizational change and creation of IT-enabled organizational capabilities, are likely to be realized only after significant periods of learning and adjustment [10, 43]. Another explanation is that the greatest effects of IT are realized when IT investment is aimed at economic growth rather than cost reduction. This was found to be true at the firm level in a study showing that IT investments led to greater profitability when focused on revenue growth rather than cost reduction [43]. The same may be true for productivity in the broader economy. In the early stages of IT adoption, most investment is aimed at automation for cost reduction. It is usually only later that the focus shifts to using IT to expand markets and transform industries, and it may be that developing countries only reached this stage in more recent years.

Our finding of a moderating effect of education is consistent with other research that examined productivity differences among countries. Kyriacou [40] concluded that economic growth was associated with an abundant stock of human capital and that convergence of developing and developed countries occurs only if sufficient levels of human capital are accumulated. Barro's [2] panel study of 80 developed and developing countries concluded that education and other institutional factors such as rule of law and improved terms of trade go hand in hand with faster rates of economic growth. Our results suggest that education not only has these direct effects but it also moderates the relationship of IT to output.

For policymakers in developing countries, as well as international development agencies, the findings provide evidence that IT investments are likely to lead to productivity gains and thus to higher sustainable economic growth rates. These economic effects provide an argument for policies to support IT use and to avoid policies that discourage use, such as raising taxes or tariffs on computing equipment. They also argue for avoiding policies that raise telecommunications prices or create barriers to Internet use. The findings also point to the importance of policies to increase tertiary education and to reduce telecommunications costs. Finally, they argue for greater openness to foreign investment in order to realize greater benefits from IT investment. These policies may be desirable on their own merits, but the fact that such resources enhance the value of IT is another reason to pursue them.

In terms of specific policies to enhance the productivity effect of IT, our findings, as well as those of Dewan et al. [22] and Kiiski and Pohjola [38], suggest that countries should consider creating IT "clusters" for greater effect in places such as schools, libraries, or community centers. Consideration should be given to providing a package of ITs, infrastructure, and training for users. Such integrated efforts are likely to have a greater effect on IT-related productivity than simply distributing technologies such as laptops or mobile phones in developing countries. Our findings about the value of FDI with respect to productivity suggest that countries should not only encourage FDI in general but they should also try to attract companies and industries that are more IT intensive, as these are more likely to bring more productivity-enhancing IT knowledge and practices. Finally, policies that encourage diffusion of low-cost communications technologies and services, such as encouraging competition, are likely to have a positive effect on IT-related productivity gains.

Future Research

This study has identified critical areas for future research. Our study includes only upper-income developing countries because of data availability for IT capital. It would be valuable to include lower-income countries, perhaps as a separate group as Lee et al. [41] did. It would be interesting to see if those countries are able to realize gains from IT investment earlier in the development process with the availability of lower-cost mobile technologies that may not require the accumulation of capital stock and experience that older technologies did.

The significant moderating effect of country characteristics on the productivity effects of IT shows that better models need to be developed to capture other factors that might influence IT productivity. There are rich opportunities for further research in quantifying the cumulative effects of IT investment and experience, and in identifying other country-level resources that might affect the relationship of IT to productivity.

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Notes

1. An exception is Papaioannou and Dimelis [51], discussed below.

2. An exception is Pohjola [54], who incorporates human capital in an empirical study of IT and productivity across 39 countries.

3. Figures showing this relationship are available from the authors. Unlike other studies such as Papaioannou and Dimelis [51], which include telecommunications equipment as part of ICT investment, we include only data communications in our IT investment measure and treat telecommunications equipment as part of the communications infrastructure.

4. The developed countries used in our sample have been classified as developed countries by the IMF throughout the sampling time frame. The only exceptions are South Korea and Taiwan, which gained developed country status in 1997. Because the majority of our sampling time frame for these two countries were classified as developed countries, we choose to leave their classification as developed instead of developing. However, in Dewan and Kraemer [20], who sampled the countries from 1985 to 1993, Taiwan and South Korea were classified as developing, as were Greece and Portugal.

5. Although there is considerable debate in the literature with regard to what is the appropriate depreciation rate for capital stock, the general consensus is that the depreciation rate will vary depending on country and types of industry and capital assets in question. However, at the macro level, which is the level of analysis we are dealing with, generally a lower aggregate depreciation rates is recommended (e.g., 5 percent [3, 28]).

6. This is the same as a Chow test if applied to the fixed effects model. We also conducted this test for the fixed effects model, and the results were the same as for the random effects model. For simplicity, we report only the findings for the random effects model since it is the more appropriate model for our data set.

7. As an alternative specification to address heteroskedasticity, we perform the same analysis with per capita variables. After conducting the panel unit root test, the per capita variables were all first differenced. The results suggest that there is not a substantial difference between panel regression using per capita variables and aggregate values. Furthermore, there was no significant difference between the developed and developing countries ($\chi^2 = 0.09$, $p > 0.05$). The results are available upon request from the authors.

Because our sample contains more countries than in previous work, we also conducted analysis with a subsample of countries examined by Dewan and Kraemer [20] as a robustness check. The results were similar to our full sample. The results are available upon request from authors.

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