

The Impact of Investment in IT on Economic Performance: Implications for Developing Countries

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Summary. — We review quantitative and qualitative research on the impact of IT on economic performance in developed and developing countries. In general, studies from the developed world have yielded evidence of a strong positive correlation between IT and economic performance, as well as IT-induced changes in workforce composition in favor of highly skilled or educated workers and organizational changes that allow firms to implement IT more effectively. To maximize social returns to IT investment, policymakers in developing countries must address two key deficiencies: (1) a lack of knowledge of “best practices” in IT usage and (2) IT-related skill deficiencies in the workforce.

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1. INTRODUCTION

During the 1990s, there was a rapid diffusion of information technology (henceforth, IT) and the use of the Internet throughout the globe, especially in developed countries. The average household in the USA and other developed countries now contains at least one personal computer with access to the Internet. More importantly, the use of the Internet is pervasive in the private sector in most developed countries. The use of IT and the Internet is also beginning to increase in many developing and transition economies.

A precipitous decline in stock prices starting in 2000, along with a concomitant slowdown in economic growth, has dampened the enthusiasm for IT. Although many policymakers and producers and users of IT continue to be enthusiastic about its long term economic impact, a sober analysis of this question is warranted. A

more comprehensive understanding of the impact of IT and the Internet on productivity in various parts of the world economy requires a synthesis and integration of various studies on the use of IT in e-business processes at various levels of aggregation (e.g., establishments or plants, firms, industries, and countries) and in many countries. This type of assessment might also be useful for policymakers in countries that are producers of IT hardware and

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software. Hence the presentation of evidence on the antecedents and consequences of IT investment and of diffusion of Internet technologies in both developed and developing countries is important.

We believe that a comprehensive review of recent research on this topic is of special interest for developing countries for two reasons: First, these countries have not yet fully reaped the benefits of IT. Second, they have fewer resources to devote to IT and thus have a smaller "margin for error" than developed countries. An objective assessment and resolution of the debate on this subject has important policy implications, since an adjudication of this dispute could allow these countries to formulate an optimal set of IT and e-business strategies that are adapted to local institutions.

Our article begins with a discussion of IT diffusion in various regions of the world. This is followed by an extensive review of the literature on the relationship between IT, the Internet, and productivity growth at the firm, industry, and national levels. Next, we examine international evidence on the widespread phenomenon of skill-biased technological change (henceforth, SBTC) and the organizational dynamics of e-business diffusion in traditional sectors of economy. These include IT-induced organizational changes, such as changes in human resource management practices and organizational structures. The following section provides examples of IT and e-business applications in developing countries. We conclude with a summary of the key findings and policy recommendations. These recommendations may be useful to policymakers who wish to use IT and e-business as a means to bridge the technological gap between the developed and developing world, which might ultimately lead to convergence in economic growth and development across countries.

2. COMPARING IT IN VARIOUS REGIONS

There have been many attempts to measure the e-readiness of countries, in terms of IT use and production and its impact on their economy. Table 1 presents statistics of the intensity of investment in IT, computed as the ratio of IT expenditure to GDP for 51 countries. The relatively low rate of investment in IT in developing countries appears to refute the hypothesis that diffusion patterns

Table 1. *Average annual percentage of GDP devoted to expenditure on ICT (1993–2001)*

Country	Percentage
New Zealand	10.3
Sweden	8.8
Australia	8.7
Switzerland	8.4
Singapore	8.3
UK	8.0
USA	7.8
Canada	7.7
Netherlands	7.5
Denmark	7.3
Hong Kong	7.2
South Africa	7.1
Japan	7.1
Colombia	7.0
France	6.9
Czech Republic	6.8
Israel	6.6
Belgium	6.5
Finland	6.4
Hungary	6.2
Germany	6.2
Norway	6.1
Ireland	5.8
Malaysia	5.8
Korea	5.8
Austria	5.6
Slovakia	5.5
Chile	5.5
Brazil	5.4
Portugal	5.5
Vietnam	4.7
Italy	4.6
Taiwan	4.6
Greece	4.4
Spain	4.2
Venezuela	3.9
Slovenia	3.7
Poland	3.7
China	3.7
Argentina	3.7
Mexico	3.5
Turkey	3.3
Bulgaria	3.1
Philippines	3.1
Thailand	3.1
Russia	2.9
India	2.7
Indonesia	2.1
Egypt	2.2
Saudi Arabia/ Gulf States	1.8
Romania	1.5

Source: Pohjola (forthcoming).

(and perhaps economic growth) are somehow converging, and the digital divide is being reduced. In fact, it is conceivable that such statistics may actually understate the extent of the gulf between developed and developing economies, since developed countries also have more favorable environmental conditions and more robust institutions to support technical advance.

van Ark and Piatcovski (2004) analyzed IT investment patterns and their impact on economic performance in two sets of countries regarded as being at different levels of economic development: the 15 countries of the European Union ("old" Europe) and 10 Central European economies under accession ("new" Europe). They conclude that there is a trend toward convergence in investment in IT between "old" and "new" Europe. Investment in IT capital was also found to be an important source of productivity growth in both sets of countries. Given that the next phase of investment in IT for "new" Europe is likely to be concentrated in the service sector, the authors argue for the establishment of institutions and the implementation of market-oriented reforms that would enhance the effectiveness of IT in services.

Several research organizations have attempted to quantify the extent of investment in IT at the national level, by deriving generalized indexes of IT or "e-readiness." It is important to note that such indexes are not precise measures of this construct, since there are limited data on this phenomenon and some rather heroic assumptions (e.g., perfect competition in input or output markets) must be invoked to derive them.

Some researchers address these difficulties by developing their own taxonomies. For example, van Ark, Frankema, and Duteweerd (2004) divide the economy into three distinct sectors: IT producing industries, IT using industries, and non-IT industries. The second and third categories are defined on the basis of their "IT intensity," or IT capital per worker or per unit of output. Given that such industry-level statistics exist only for the USA, they extrapolate the US data to European countries. Interestingly, they find that non-IT industries constitute two thirds of the US and European economies, and an even higher fraction in emerging economies.

Based on similar data, van Ark, Inelaar, and McGuckin (2003) conclude that superior relative economic performance in the USA (i.e., relative to Europe) can be partially attributed to

its larger IT-producing sector and faster growth in IT-using service sectors such as wholesale and retail trade and financial brokerage. On the other hand, McKinsey (2004) asserts that a higher productivity in the USA is due to a more favorable regulatory environment, stronger competition, and superior corporate organization in "traditional" sectors.¹

These findings are consistent with evidence presented in van Ark *et al.* (2004), who stressed the importance of accumulation of intangible capital, knowledge, and skilled labor in IT in explaining growth in productivity in services. As noted in Bresnahan, Brynjolfsson, and Hitt (2002), a superior corporate organization is likely to be determined by improvements in communication, networking, and coordination made possible by modern IT.

International organizations such as UNCTAD recognize the lack of hard, systematic data on the information economy in developing and transition economies and are trying to address this problem. Until such information becomes available, UNCTAD is using data generated by other sources, including sister organizations, such as ITU and the World Bank, to derive aggregate IT development data and indices (UNCTAD, *E-commerce and Development Reports 2001-04*). The UNCTAD Index of IT diffusion consists of three dimensions: connectivity, access, and policy environment, with each factor assumed to have an equal weight. The indicators of connectivity are per capita measures of the number of Internet hosts, PCs, telephone mainlines, and cellular subscribers. Proxies for access consist of per capita GDP, the number of Internet users per capita, the percentage of the population that is literate, and the cost of a local call. Indicators for the policy environment are the presence of an Internet exchange and measures of competition in three markets: local loop telecoms, domestic long distance, and the Internet Service Provider market. Each of these indicators is a composite of subindicators that are aggregated by applying the following formula as weights: value achieved/maximum reference value.

Other aggregate indexes measuring the ability of national economies to exploit the economic potential of the Internet and e-commerce yield a similar picture. The two most comprehensive indexes in that respect gauging the e-readiness of approximately half of the countries of the globe are the "E-Readiness Index" (ERI) of the Economist Intelligence Unit of the UK (EIT, 2003) and the "Networked Readiness

Index" (NRI) representing a joint effort by INSEAD, World Economic Forum and the Infodev program of the World Bank. The latest NRI was presented in "The Global Information Technology Report 2002–03" (Dutta, Lanvin, & Paua, 2003).

The NRI consists of three dimensions related to IT: environment, readiness, and usage. The first dimension measures the extent to which a country's markets, political and legal system, and infrastructure (e.g., telecommunication infrastructure) are beneficial to the development and usage of IT. Readiness relates to the ability of three key economic agents: individuals, firms, and government to capitalize on the use of IT. The third dimension measures the incidence of IT usage by these same agents. The authors of the above joint report also relate IT expenditure to the NRI, in an effort to determine how much "bang for the buck" nations are generating from such expense. They conclude that the USA, Finland, and Spain "overperform," while Vietnam, Colombia, and New Zealand underperform. Another lesson they derive from this exercise is that expenditure on IT is not sufficient to guarantee a high NRI score, since New Zealand had the highest rate of investment in IT, while it has a rank of 23 for the NRI.

A comparison of the NRI and ERI indexes and rankings is presented in Table 2. Although they are generally showing similar patterns, the comparison draws attention to some differences and variations. The ERI index is the more extended one and is biased toward higher denominations for the best performers. Thus in the case of the ERI, the variation among 25 best performers is between 8.67 (for the champion, i.e., Sweden) and 6.96 for the 25th country (Israel in this case). For the NRI, the highest rank country is 5.92 (Finland) and the 25th country (Spain) achieved a score of 4.67. Note that the lowest indices for them are, respectively, 2.37 (for the ERI, the 60th country, i.e., Vietnam) and 2.07 (for the NRI, the 82nd country, i.e., Haiti). There are also certain gaps in both systems. Thus, in the ERI, some important countries (from the perspective of "best practices") such as Estonia and Tunisia are missing. The world's second leading IT producer, Japan, is ranked rather low in both systems. While Bangladesh is not included in the ERI, Iran is excluded in the NRI. However, in spite of some gaps, both systems are undertaking an important task of measuring and weighting a large variety of important indicators permitting us

to have an idea of network or e-readiness of the countries.

A key implication of the data presented in this section is that developing nations are likely to fall even further behind the developed world unless appropriate policies are formulated and implemented to reverse the palpable divergence in rates of diffusion of IT and the Internet.

3. IT AND PRODUCTIVITY: A REVIEW OF RECENT EMPIRICAL EVIDENCE

In recent years, numerous scholars have analyzed the relationship between IT and economic performance. Many of these studies examine the impact of IT on productivity growth, although some researchers also examine its effects on firm profitability and stock prices. A summary of several of these papers is presented in Table 3, where each study is presented by its methodology, country of origin of the data, level of aggregation, and by a parsimonious description of the key findings.

These empirical studies have been conducted at all levels of aggregation, that is, at the establishment, firm, industry, and national levels. Many papers present econometric estimates of a simple (Cobb–Douglas) production function, with an additional input representing investment in IT capital, as opposed to conventional physical capital (structures and equipment). Other authors (e.g., Brynjolfsson & Hitt, 1996) have derived estimates of IT labor input (typically the number of employees classified as information systems workers). Siegel (1997) estimated the following reduced-form equation to assess the relationship between computers and productivity:

$$y = \alpha + \beta_1 X_1 + \beta_2 X_2 + u, \quad (1)$$

where y is the growth in total factor productivity (TFP), X_1 is the rate of R&D investment, X_2 is the rate of investment in computers, u is the a classical disturbance term, α is the rate of disembodied external technical change, β_1 is the rate of return on R&D, and β_2 is the rate of return on computers. The author finds that both IT and R&D enhance productivity growth, also reporting evidence of significant complementarities between ICT and R&D capital.

Much of the recent *firm-level* evidence suggests that there are "excess" returns to IT, that is, the marginal product of IT capital is

Table 2. Comparison between Network Readiness Index (GITR, 2003) and E-Readiness rankings (EIU, 2003)

Country	NRI score	NRI rank	E-R score	E-R rank
Finland	5.92	1	8.38	6
USA	5.79	2	8.43	3
Singapore	5.74	3	8.18	12
Sweden	5.58	4	8.67	1
Iceland	5.51	5	–	–
Canada	5.44	6	8.20	10
UK	5.35	7	8.43	5
Denmark	5.33	8	8.45	2
Taiwan	5.31	9	7.43	20
Germany	5.29	10	8.15	13
Netherlands	5.26	11	8.40	3
Israel	5.22	12	6.96	25
Switzerland	5.18	13	8.26	8
Korea	5.10	14	7.80	16
Australia	5.04	15	8.20	9
Austria	5.01	16	8.09	14
Norway	5.00	17	8.20	7
Hong Kong	4.99	18	8.20	11
France	4.97	19	7.76	19
Japan	4.95	20	7.07	24
Ireland	4.89	21	7.81	15
Belgium	4.83	22	7.78	17
New Zealand	4.70	23	7.78	18
Estonia	4.69	24	–	–
Spain	4.67	25	7.12	23
Italy	4.60	26	7.37	21
Luxembourg	4.55	27	–	–
Czech Republic	4.43	28	6.52	27
Brazil	4.40	29	5.25	36
Hungary	4.30	30	6.23	29
Portugal	4.28	31	7.18	22
Malaysia	4.28	32	5.55	33
Slovenia	4.23	33	–	–
Tunisia	4.16	34	–	–
Chile	4.14	35	6.33	28
South Africa	3.94	36	5.50	32
India	3.89	37	3.95	46
Latvia	3.87	38	–	–
Poland	3.85	39	5.57	30
Slovak Republic	3.85	40	5.47	34
Thailand	3.80	41	4.22	42
Greece	3.77	42	6.83	26
China	3.70	43	3.75	50
Botswana	3.68	44	–	–
Argentina	3.67	45	5.41	35
Lithuania	3.65	46	–	–
México	3.63	47	5.56	31
Croatia	3.62	48	–	–
Costa Rica	3.57	49	–	–
Turkey	3.57	50	4.63	39
Jordan	3.51	51	–	–
Morocco	3.50	52	–	–
Namibia	3.47	53	–	–

(continued next page)

Table 2—continued

Country	NRI score	NRI rank	E-R score	E-R rank
Sri Lanka	3.45	54	4.13	44
Uruguay	3.45	55	—	—
Mauritius	3.44	56	—	—
Dominican Republic	3.40	57	—	—
Trinidad and Tobago	3.36	58	—	—
Colombia	3.33	59	4.86	37
Jamaica	3.31	60	—	—
Panama	3.30	61	—	—
Philippines	3.25	62	3.93	47
El Salvador	3.17	63	—	—
Indonesia	3.16	64	3.31	53
Egypt	3.13	65	3.72	51
Venezuela	3.11	66	4.75	38
Peru	3.10	67	4.47	41
Bulgaria	3.03	68	4.55	40
Russian Federation	2.99	69	3.88	48
Ukraine	2.98	70	3.28	54
Vietnam	2.96	71	2.91	56
Romania	2.66	72	4.15	43
Guatemala	2.63	73	—	—
Nigeria	2.62	74	3.19	55
Ecuador	2.60	75	3.79	49
Paraguay	2.54	76	—	—
Bangladesh	2.53	77	—	—
Bolivia	2.47	78	—	—
Nicaragua	2.44	79	—	—
Zimbabwe	2.42	80	—	—
Honduras	2.37	81	—	—
Haiti	2.07	82	—	—

Sources: GITR (2003) and EIU (2003).

substantially higher than the marginal product of non-IT capital. There is also some evidence that these private or firm-level returns have become higher in recent years. This is important because there was a lack of a consensus regarding empirical results, at least in some of the early studies. Using country-level data, Oliner and Sichel (1994) concluded that IT did not make a significant contribution to output growth. Catherine Morrison (1997) reached a similar conclusion using industry-level data. Based on estimation of a more elaborate set of cost function equations, including the price and the quantity of IT equipment as separate arguments in the cost function, she reported that IT capital had only a very small impact on technical progress. Berndt, Morrison, and Rosenblum (1992) estimated production functions at the industry level and found that IT was uncorrelated with productivity growth in most industries. Parsons, Gottlieb, and Denny

(1993) also found very low returns on IT investment by Canadian banks. On the other hand, Siegel and Griliches (1992) reported a positive and significant correlation between a manufacturing industry's rate of investment in IT and its productivity growth for all time periods. At the firm level, Lichtenberg (1995) estimated production functions and (as mentioned earlier) found strong evidence of excess returns to information systems equipment and labor.

Most of the recent papers seem to find a strong relationship between IT and improvements in economic performance. Stiroh (2001) and Jorgenson and Stiroh (2000) report some good news regarding the aggregate impact of investment in information technology in the USA. In their early studies (Jorgenson & Stiroh, 1995), the authors reported that computers did not make a large contribution to economic growth, reporting low estimates of the returns to IT that were quite similar to

Table 3. *Recent empirical studies of the impact of ICT on economic performance*

Author(s)	Methodology	Country/sector	Level of aggregation	Results
Dunne <i>et al.</i> (2000)	Regressions of labor productivity on computers	USA/manufacturing	Plant-level	Positive association between computers and labor productivity, which appears to be growing over time
McGuckin and Stiroh (1999)	Cobb–Douglas production function with computer capital	USA/manufacturing and service	Aggregate, major sector, and 2-digit SIC industry-levels	Evidence of “excess” returns to computer capital at each level of aggregation
Gera <i>et al.</i> (1999)	Cobb–Douglas production function with computer capital	USA and Canada/manufacturing	Industry-level	Positive correlation between investment in computers and labor productivity growth
McGuckin <i>et al.</i> (1998)	Regressions of labor productivity on dummies denoting whether the plant uses a computer-based manufacturing technology	USA/manufacturing and service	Plant-level	Plants using advanced computer-based technologies have higher levels of productivity; weaker evidence on the relationship between technology usage and productivity growth
Lehr and Lichtenberg (1998)	Cobb–Douglas production function with computer capital and labor	USA/public sector	Organizational level (government agencies)	“Excess” returns to computer capital
Siegel (1997)	Latent variables model: regressions of parametric and nonparametric measures of TFP growth on the rate of investment in computers	USA/manufacturing 4-digit SIC	Industry-level	When controls are included in the model for measurement errors, computers have a positive and statistically significant impact on productivity

Table 3—continued

Author(s)	Methodology	Country/sector	Level of aggregation	Results
Morrison and Siegel (1997)	Dynamic cost function estimation with “high tech” capital	USA/manufacturing	4-digit SIC industry-level	“External” investments in computers by related industries (4-digit industries within a 2-digit sector) enhance productivity
Greenan and Mairesse (1996)	Cobb–Douglas production function with computer capital	France/manufacturing and service	Firm-level	Impact of computers is positive and at least as large as for other types of capital. Returns appear to be higher in services than in manufacturing
Brynjolfsson and Hitt (1996)	Cobb–Douglas production function with computer capital and labor	USA/manufacturing and service	Firm-level	“Excess” returns to computer capital and labor
Jorgenson and Stiroh (2000)	Sectoral growth accounting methods	USA	Aggregate level	The growth contribution of computers increased substantially in the mid-to-late 1990s
Siegel and Griliches (1992)	Correlation between nonparametric measures of total factor productivity and rate of investment in computers	USA/manufacturing	4-digit SIC industry-level	Positive correlation between rate of investment in computers and total factor productivity growth

Source: Link and Siegel (2003, pp. 93–95).

Table 4. *The sources of US economic growth (1959–2001)*

	1959–73	1973–95	1995–2001
Output growth	4.18	2.78	4.07
Contribution of capital	1.77	1.40	2.03
Computers	0.07	0.20	0.49
Software	0.03	0.10	0.27
Communications capital	0.10	0.12	0.17
Other (noncomputer) capital	1.57	0.98	1.10
Contribution of labor	1.24	1.12	1.12
Aggregate total factor productivity	1.16	0.26	0.92

All values are average annual percentage growth rates. Input contributions are real growth rates, weight by average nominal shares (following the convention in this literature).

Source: Jorgenson *et al.* (2002).

those presented by Oliner and Sichel (1994). However, in their recent papers (e.g., Jorgenson, Ho, & Stiroh, 2002), they conclude that the impact of IT on the aggregate economic performance has increased over time, especially in the last half of the 1990s.²

The key figures on sources of economic growth in the USA are presented in Table 4, taken from Jorgenson *et al.* (2002). Based on a comprehensive analysis of IT capital, the authors reported that computer hardware, software, and communication equipment accounted for a much larger fraction of economic growth in the last six years than in earlier periods. This may signify that there are substantial adjustment costs in implementing IT and that policymakers should not expect dramatic improvements in productivity growth in the *short run*. The economic payoff comes only after a substantial increase in IT investment or activity.

In a similar vein, Morrison and Siegel (1997) consider the possibility that conventional empirical studies of the connection between IT and productivity actually underestimate the returns to ICT, because they fail to take account of externalities that arise from investment in ICT. The authors extend the simple Cobb–Douglas production framework by estimating a dynamic, flexible cost function (i.e., a Generalized Leontief functional form) for US manufacturing industries, which takes account of adjustment costs that might arise from IT (and other capital) investment. Their paper is a general critique and extension of various new growth studies that use a simple production function approach to assess the impact of what the authors call *external factors* (investment in R&D, computers, and human capital) on growth. More importantly, they estimate the effects of *external* investment in computers

on the productivity of a given industry, that is, IT investments undertaken by other industries within the same broad sectoral category. The authors report that an increase in investment in IT (and R&D) in a given industry has a positive effect on the productivity performance of other industries (both their suppliers and customers). These results are broadly consistent with the notion that IT and the Internet constitute what leading economists refer to as “general purpose technology” (GPT) (Helpman, 1998), or a technology that has wide applications and productivity-enhancing effects in numerous downstream sectors.

The OECD recently undertook a comprehensive analysis of IT impact on productivity, which was mainly based on data from developed countries. This analysis used indicators such as the share of IT in nonresidential investment, respective contributions of IT and other capital services into the output growth, as well as the impact of IT using and producing sectors as opposed to that of non-IT sectors, to the growth of economy and productivity of labor. The result was fairly conclusive evidence suggesting that IT was a key driver of economic growth in the USA, Canada, Nordic countries, and Netherlands, and also had a substantial positive impact on economic performance in other OECD countries. The USA and Finland were the best performers in terms of labor productivity growth in 1995–99 recording annual growth of 2.5% and 2.75%, respectively. In both countries, 2% of labor productivity growth can be attributed to the IT producing and IT using sectors, while only, respectively, 0.5% and 0.75% were originated from sectors with a low level of IT use (OECD, 2002, pp. 22–24). The evidence on the firm level in those countries also show the importance of time

to accumulate the critical mass of ITs and primarily Internet networks through their extensive diffusion and make them an essential part of everyday practice for workforce thus allowing for further improvements in productivity of labor and corporate organization with requisite efficiency gains (OECD, 2003). The OECD study confirms the findings and policy conclusions of many researchers on the importance of IT investment in enhancing economic growth in most developed economies.

4. EFFECTS OF ICT ON WAGES AND WORK ENVIRONMENT

The IT revolution has also heightened a phenomenon known as “skill-biased technological change” (henceforth, SBTC) or the instance when technological change results in a stronger demand for highly skilled and highly educated labor. This leads to an increase in the relative wages of these workers and shifts in workforce composition in favor of highly skilled and highly educated workers. In the long run, wage competition from skilled labor in less developed countries will diminish the magnitude of SBTC, as companies in developed countries engage in outsourcing to take advantage of lower wage rates. Studies of SBTC are usually based on estimation of wage equations or cost functions, typically including dummy variables that serve as proxies for technological change. The cost function approach is desirable because it allows us to formally test whether technical change is nonneutral, that is, it favors one factor of production relative to another. Note that under SBTC, the assumption is that technological change favors one class of workers (e.g., highly educated workers, at the expense of another class of workers).

A commonly used cost function approach, employed by Berman, Bound, and Griliches (1994), is estimating the following restricted labor cost function:

$$LC_i = f(W_i, TECH, Y, t), \quad (2)$$

where LC is the labor cost, W_i is the wage of the i th type of worker, $TECH$ is a proxy for the technological change, Y is the output, t is the time, and f is assumed to have a translog form. Invoking cost minimization and Shephard's lemma ($S_N = \partial \ln LC / \partial \ln P_N$, where S_N is the share of nonproduction labor in total

employment or labor cost), constant returns to scale, homogeneity of degree one in prices, and taking first differences yields

$$ds_N = \beta_0 + \beta_1 d \ln(W_N/W_j) + \beta_2 d \ln(R/Y) + \beta_3 d \ln(C/I) + u, \quad (3)$$

where the authors include two proxies for technological change: R&D “intensity,” or the ratio of R&D expenditures to sales (R/Y) and the ratio of expenditures on computers to total capital investment (C/I), and u is a classical disturbance term. If $\beta_2 > 0$ or $\beta_3 > 0$, we have evidence of “skill-biased technological change.” Paul and Siegel (2001) extend this framework by estimating a dynamic flexible cost function model. This approach allows for quasi-fixed inputs, a more general functional form for the cost function (than a simple Cobb–Douglas or translog functional form), and also includes measures of trade and outsourcing as independent variables.

A summary of some recent studies of the impact of IT on wages and labor composition is presented in Table 5. Despite the fact that researchers have employed alternative methodologies and analyzed data from different countries at different levels of aggregation (individual, plant, firm, and industry levels), each study reports evidence that is consistent with the existence of SBTC. That is, these researchers generally find that some proxy for technological change (R&D, computers, adoption of advanced manufacturing technologies) is positively correlated with wages and shifts in labor composition in favor of highly skilled or highly educated workers.

Many economists who have studied SBTC ignore the role of organizational change in the implementation of new technologies. In recent decades, many manufacturing firms have adopted new IT-based technologies, such as computer-aided design (CAD), computer-aided manufacturing (CAM), computer numerical control (CNC), and just in time production (JIT) systems. Implementation of these technologies can have a dramatic impact on the work environment since they may simultaneously result in downsizing (labor-saving innovations), retraining of the remaining workforce (“skill upgrading”), and changes in job responsibilities resulting from integration across the functional areas of business (marketing, manufacturing, R&D, accounting/finance, logistics, purchasing, and product design).

Table 5. *Recent empirical studies of the impact of ICT on wages and labor composition*

Author(s)	Methodology	Country	Level of aggregation	Indicators of technical change	Measures of labor input	Results
Bartel and Sicherman (1999)	Estimation of wage equations	USA	Worker data (NLSY) matched to industry-level data	Expenditures on computers, R&D	Nonproduction and production workers	Positive correlation between wages and proxies for technical change, which is stronger for nonproduction workers than for production workers; wage premium attributed to the greater demand for ability in industries experiencing technical change
Haskel (1999)	Regressions of changes in relative wages of workers on computers	UK	3-Digit SIC industry-level	Dummy variable denoting whether a plant introduced new equipment using microchip technology	Skilled and unskilled workers	Positive correlation between relative wages and computers; wage premium for skill rose by 13% in the 1980s in the United Kingdom; computers account for about half of this increase
Paul and Siegel (2001)	Dynamic cost function estimation with “high tech” capital	USA	4-Digit SIC industry-level	Computer capital and R&D	Four types of workers, classified by level of education	Computers and R&D reduce the demand for workers without a college degree and increase the demand for workers with at least some college. Trade has a strong indirect impact on the demand for less educated workers, because it stimulates additional investment in computers

Table 5—continued

Author(s)	Methodology	Country	Level of aggregation	Indicators of technical change	Measures of labor input	Results
Berman <i>et al.</i> (1998)	Crosscountry correlations of within-industry changes in the proportion of nonproduction workers	9 OECD countries	2- and 3-digit SIC industries	Expenditures on computers, R&D	Employment and wage shares for production and nonproduction workers	Positive correlation across 9 OECD countries in within industry changes in shares of nonproduction workers
DiNardo and Pischke (1997)	Estimation of wage equations	Germany	Worker data (NLSY) matched to industry-level data	Dummies for whether a worker sits down, uses a telephone, calculator, pen and pencil	Detailed data on workers: age, sex, race, union status, region	Workers who use a computer earn a wage premium, but so do those who sit down while they work or use a calculator, telephone, pen and pencil
Park (1996)	Regressions of changes in relative wages of skilled and unskilled workers on computers	Korea	2-Digit SIC industry-level	Growth in labor productivity	All workers, excluding unskilled	Positive correlation between labor productivity growth and the proportion of multiskilled workers in Korean manufacturing
Entorf and Kramarz (1995)	Estimation of wage equations	France	Data on workers and firms that employ them	Firm-level data on usage of 3 computer-based technologies	Occupational mix: unskilled and skilled blue-collar, clerks, managers, engineers, professionals	Positive correlation between technology usage and wages; highest wage premiums earned by those with the lowest level of skill
Regev (1998)	Estimation of production function	Israel	Firm-level	Technology index based on quality of labor and capital and R&D investment	No decomposition of labor	Technology intensive firms pay higher average wages, generated new jobs during a period of downsizing

Source: Link and Siegel (2003, pp. 82–87).

Some recent studies have examined the relationship between technical and organizational change. These scholars have found that IT investment is often accompanied by substantial changes in the work environment. For example, Siegel, Waldman, and Youngdahl (1997) analyzed the effects of the adoption of advanced manufacturing technologies on human resource management practices, including proxies for employee empowerment, such as training, changes in job responsibilities, new career opportunities, and enhanced employee control. They report that there is a strong positive correlation between the implementation of certain types of technologies and greater employee empowerment. In a similar vein, Bresnahan *et al.* (2002) present evidence on the connection among technological change, organizational change, and organizational performance. The authors study the effects of declining information technology (IT) prices, increased use of IT, and a rise in the relative demand for highly educated workers. They conjecture that companies need to decentralize decision making and adopt other “high performance” workplace practices, in order to implement new technologies successfully. Such practices include an increased reliance on worker teams and quality circles, where employees can decide the pace and method of work to achieve the best results.

To test these theories, Bresnahan *et al.* (2002) estimate three variants of a regression model with IT demand, human capital investment, and value-added as dependent variables. They report that proxies for workplace organization and human capital are strong determinants of the demand for IT capital, but not other types of capital. This finding is consistent with the argument that there is complementarity among IT, organizational change, and human capital. Similarly, firms with higher levels of investment in human capital, as measured by a greater emphasis on selection, appraisal, and training of employees, tend to have higher levels of IT investment and more decentralized work organization. They report that IT use is positively correlated with enhanced worker autonomy, management’s need and ability to monitor workers, and the firm’s desire to increase investment in human capital.

Several key stylized facts have emerged from the new interdisciplinary literature on the relationship between technological change and organizational change in developed countries. Bresnahan *et al.* (2002) report that IT use in developed countries is associated with a cluster

of complementary organizational practices. These include a transition from mass production to flexible manufacturing technologies, changing interaction with suppliers and customers (mostly resulting in closer relationships with customers and suppliers), decentralized decision making and other organizational transformations, greater ease of coordination, and enhanced communication. Brynjolfsson, Hitt, and Yang (2000) find that these complementary technological and organizational changes enhance the market value of firms.

Thus, it appears as though the way IT is being used is changing organizational structure, design, and control systems. For instance, researchers have reported that back-office jobs are being replaced, while the importance of front-office skills and managerial leadership has increased. Networks of PCs are changing the way people work and the way they are compensated, in the sense that the rewards to multitasking are increasing and employers seem to prefer employees with broad-based education and conceptual and problem-solving skills, which are valued more and more by companies in developed countries.

The end result is that the returns to schooling are high and rising, which appear to be largely due to technological change and concomitant organizational changes that raise the value of knowledge workers to firms and other organizations. Despite this fairly substantial increase in the returns to education, the demand for computer literate workers continues to outstrip supply, which explains part of the wage premium economists have observed for these workers. This also explains why numerous multinational companies have begun outsourcing high-skilled labor to developing countries, as in the case of software programming in India (see Lal, 2002), much as always done with low-skilled labor. Paul and Siegel (2001) report evidence that is consistent with this assertion, as they find that there is a positive correlation between IT investment and the propensity of US manufacturing firms to engage in foreign and domestic outsourcing of mostly business services.

There were other important IT-induced changes in the labor market: improved labor market outcomes for women through higher wages (reducing the gender gap in wages) and greater flexibility in the workplace and the work environment. That is, the diffusion of IT has facilitated the adoption of flexible work practices by firms, which has made it easier

for employees and, especially, women to work from home. Thus, it appears as though technological and social developments are complementary, since the liberation of women has been accompanied by greater freedom to perform work-related tasks at home. This trend is likely to continue, provided, of course, that the infrastructure technology is available in many countries to effectively use IT equipment to perform one's job. In a similar vein, IT and the Internet have led to creation of new industries, especially in business and retail services. This has resulted in an increase in demand for workers who perform tasks that can be accomplished at home and a concomitant rise in women-owned small enterprises.

5. ICT AND INTERNET IN DEVELOPING COUNTRIES: SOME PRELIMINARY EVIDENCE

Despite the existence of *aggregate* indexes on e-readiness, it is difficult to derive systematic evidence of the correlation between ICT use and economic performance at the *sectoral* level in developing countries. However, anecdotal data and case study evidence, especially, are available in traditional export-oriented industries in these countries. Some qualitative studies attempt to assess the impact of B2B markets on export performance and competitiveness. These papers suggest that while traditional export sectors engage in extensive use of e-mail, they are not yet really connected to emerging e-marketplaces. At the same time, however, there is evidence of improved market access and rapidly increasing exports by selected developing and transition economies. It appears as though this is due mainly to outsourcing of business pro-

cesses, including the relocation of back office operations by multinational corporations. This implies that there are promising ICT related niches in global markets for numerous developing countries, especially those endowed with skilled labor and enough bandwidth access to the Internet.

Many papers also stress the importance of ICT related initiatives of developing countries. Thus [Udo and Edoho \(2000\)](#) in their study on ICT initiatives in Africa describe various institutions that have attempted to foster the diffusion of ICT throughout the continent, including the Africa Internet Forum, the African Information Society Initiative (AISI), HealthNet, the Network Startup Resource Center, and SatelLife. Many of these initiatives are public-private partnerships and some are nonprofit organizations. Each is actively involved in the deployment and integration of ICT, especially networking technology.

[Udo and Edoho \(2000\)](#) also present an interesting chart, slightly modified in [Table 6](#), that summarizes what they regard to be innovative uses of ICT in developing nations (not just in Africa). They note that India has been successful in extending the information and communication systems to rural areas. The authors also cite some creative uses of the Internet by the Egyptian government. One is that the government posts the resumes of unemployed workers in a central database and makes this information easily accessible to employers. The Egyptian government has also posted all statutes and regulations online. Both Egypt and Tunisia have organized a Regional Information Technology Development Center, where many useful applications have been developed. They also cite an example of a successful ICT-related industry policy in Chile, which has developed

Table 6. *Examples of innovative initiatives in ICT in developing countries*

Developing country	Description of ICT initiative
India	Developed its own satellites to establish information and communications systems that reach rural areas
Egypt	Initiated several useful IT applications in employment, e-government, and the
Tunisia	Established a Regional Information Technology Development Center
Singapore	Established a Regional Information Technology Development Center
Chile	Use of EDI at harbor—now ranked among the best in the world in the use of IT
Gambia	Developed a successful software industry through a public-private partnership involving firms, universities, and government
	Developed an effective telecommunications infrastructure with several applications

Source: [Udo and Edoho \(2000\)](#).

and nurtured a thriving software industry via a public-private partnership involving firms, universities, and government. The end result is that Chilean software exports are much more competitive internationally. The authors also cite Singapore's very creative use of Electronic Data Interchange (EDI) at their harbor, which is one of the busiest in the world, and a key source of their economic strength. In fact, Singapore has focused so much attention on ICT-related initiatives that it currently ranks number three in the world in the Network Readiness Index presented in Table 5.

The impressive inroads of China as an emerging regional leader in ICT production and use has been discussed in the previous issues of ECDR (UNCTAD, 2001, 2002) and in a comprehensive analysis by Bruno Lanvin, Pamela C.M. Mar, Christine Zhen-Wei Quiang and Frank-Jürgen Richter (Dutta *et al.*, 2003, Chap. 11). Lanvin *et al.* maintain that China has become a highly competitive producer of a wide range of ICT products, from basic electronics and PCs to mobile telephones and high end semiconductors wafers. They stress the role of the government in providing a wide range of support measures such as tax incentives, a conducive climate for foreign direct investment, and infrastructure support. The authors assert that by adapting itself to membership in the WTO, China has transformed itself into an even more attractive location for further expansion of export-oriented ICT production facilities, as well as to local consumption. The rapidly improving skills of local producers and users and the development of innovation clusters (e.g., through science parks) have contributed to China's enhanced productivity and upgrading of ICT production. China has also contributed to the growth of the world economy through its increased demand for imported ICT products and services.

Another interesting study was conducted by Lal (2002), who examined comprehensive data from 51 Indian firms on numerous aspects of performance and other firm characteristics, including data on ICT investment, wages, exports, imports, profits, and the extent to which firms adopt e-business methods. These companies were located in a newly developed industrial town near New Delhi called the New Okhla Industrial Development Area. The firms in this new industrial region had access to two private sector Internet Service Providers (ISPs) and two public sector ISPs. The author estimated firm-level Tobit regressions of the determinants

of export performance. The regressions included many control variables and a measure of the nature of the firm's use of e-business methods. The three types of e-business technologies were email, url, and portal. Lal concluded that firms that adopted more advanced e-business tools generated higher levels of exports. This finding on a key dimension of performance for companies for a cluster in India might be valuable for smaller developing countries where domestic markets are often quite small. Thus, it appears that the adoption of sophisticated e-business technologies may improve economic performance. Another critical factor is that ICT labor costs are substantially lower in India than in developed countries. For instance, the average systems analyst was earning \$48,000 in the USA and \$34,000 in the UK in 1995, while their counterparts in India were earning \$14,000. In addition, there is a growing interest in open source software developments, which are fostering a greater degree of open exchange of software under innovative licensing arrangements.

Moodley (2002) conducted an in-depth quantitative and qualitative analysis of the use of B2B e-commerce by manufacturing firms in South Africa. His study is based on 120 firm-level interviews and 31 interviews with industry experts. His evidence indicates that the incidence of use is fairly low. Although 87% of the firms had access to the Internet, only 49% of the firms had a corporate website and only 22% were using the Internet for order taking. He concludes that e-commerce is not yet an important strategic objective for most South African firms. The author also hypothesizes that e-commerce is an evolutionary technology, not a revolutionary technology, as some of its strongest advocates have asserted. Moodley states that his evidence shows that B2B e-commerce is in the early stages of its evolution and is likely to follow path-dependent patterns.

Masten and Kandoole (2000) examine IT patterns of investment in Malawi. They find that the government has focused a great deal of attention on assisting small- and medium-sized enterprises (SMEs) in using IT to increase employment and income. This may be because there is no large amount of foreign direct investment by large, multinational firms in this country. Malawi is an interesting country to study because its institutions involved in promoting IT investment among small businesses received at least some support either from developed countries (e.g., the USA, Britain, or Germany), or from international organizations (e.g., the

World Bank or the United Nations), or NGOs (e.g., World Learning and the Women's Village Banking). The authors conclude that there is a very large and extensive support system for companies implementing IT in this country. Not surprisingly, they find an unusually high level of satisfaction with these services, and they suggest that these resources have been used quite effectively. The end result appears to be a dynamically growing small business sector, given that Malawi is a very poor country (ranked 157 out of 174 countries, in terms of economic well being, according to UNDP, 1996).

Humphrey, Mansell, Paré, and Schmitz (2003) also examined the B2B e-commerce experiences of firms in the horticulture and garments sectors in Bangladesh, Kenya, and South Africa. This empirical study was based on field interviews with 74 enterprises. An additional 37 key informant interviews with industry experts, business associations, e-commerce solution providers, and government officials were conducted across the three countries. The enterprise interviews were conducted with individuals in senior management positions. These individuals were well positioned to provide useful information on the scale and impact of IT use to support B2B e-commerce. Their findings so far challenge the view that the mere low cost of transfer of information makes B2B e-commerce a particularly advantageous proposition for the firms from developing and transitional economies given the current technological divides, organizational and awareness level within and between firms, as well as the institutional setup on the level of facilitation and regulatory framework. In some cases, B2B e-commerce can reduce the costs of making firms known to one another. But many implementations of Internet applications do not offer packages of services such as payment and settlement mechanisms, insurance, logistic systems, inspection, certification of quality, and customs clearance. According to the authors, without low cost access to such services, developing country firms may find it prohibitively expensive to exploit new external markets.

Many developing and transition economies are launching various IT initiatives. The success stories of India and Costa Rica have been well documented by UNCTAD (2002). Estonia's success was examined by GTR 2002-03. A recent study by McKinsey (2004) on prospects for IT services and the software sector in Armenia also reveals some interesting evidence and suggests some original conclusions. According

to the authors, this "Silicon Valley"-like region of the former Soviet Union passing through a painful phase of deindustrialization in the 1990s still managed to retain a highly skilled and highly educated workforce and started since the second half of the 1990s to develop IT services and the software sector, which is now accounting around 2% of the economy (which is a relatively high indicator by international standards). At the same time, the productivity here is on the level of half of the comparable sector in India. As the report noted, the main impediments to continued progress are the connectivity, monopolistic position of the foreign owned telecom carrier, lack of supporting environment, and a right set of government policies (McKinsey, 2004).

As the above analysis suggests, it is the interaction among connectivity, access, network security, capability/skills, market structures and firm governance, as well as the regulatory and facilitation environment, which determine whether firms from developing countries can participate effectively and efficiently in the information economy and compete in global e-marketplaces. The increasing differentiation between the developing countries in their access to the Internet, in IT investment levels, and in adaptation of labor to the requirements of information economy suggest that the trend of the digital divide might become quite persistent also between different groups of developing countries, unless adequate global and regional initiatives are implemented to offset this negative trend.

6. TENTATIVE CONCLUSIONS

The empirical findings on IT and economic performance reviewed in this paper are fairly robust, in the sense that the overwhelming majority of researchers have found a positive correlation between some proxy for IT investment and some proxy for economic performance at each level of aggregation (e.g., plant, firm, industry, and country). Furthermore, there was evidence suggesting that complementary investment in IT-related labor and organizational factors that provide a supportive work environment for maximizing the returns on IT investment also contribute to improvements in productivity growth. It also appears that the social returns to IT might exceed the private returns, which provides further fuel to the argument that governments should explore all possibilities to sup-

port investment in IT. The evidence suggests that the dissemination of this general purpose technology will have a sustained, long-lasting impact on productivity and economic growth, provided that policymakers implement policies that facilitate a faster rate of diffusion and a better allocation of resources.

Although many of these results are derived from developed economies, this evidence provides important lessons for developing and transition countries. First, developing countries should not lose sight of the big picture, with regard to the payoff to investment in technology. These countries should focus on implementing technology policies that foster long-run economic growth. Furthermore, these policymakers should not misinterpret the recent financial boom and bust in financial markets (which is reversing itself as this article is being written) as indicating a decline in the social rate of return on investment in IT and the Internet. Instead, the recent financial market experience should temper any unreasonable expectations about achieving astronomical, virtually instantaneous improvements in economic performance. Even in the developed world, where organizations encounter substantially more favorable institutional conditions and better technological and physical infrastructure, it has taken several decades for the benefits associated with ICT investment to result in substantial improvements in economic growth.

There are two key deficiencies that policymakers in developing countries must address, in order to stimulate higher social returns to investment in IT, particularly in the realm of B2B e-commerce. The first is a lack of knowledge of "best practices" in the use of IT. Thus, governments should foster an improved understanding by local firms on the best methods of using IT in their respective sectors, so that optimal choices can be made regarding the most efficient use of this technology. A second deficiency is underinvestment in IT-related technology. By establishing an investment friendly environment, the policymakers will enable firms in establishing their own IT investment priorities. By supporting the development of infrastructure technology, they will also help us to provide a greater access to low-cost, high-bandwidth Internet connections and the use of affordable software as an open source. Speedy and reliable connections will help us to build trust in what are essentially faceless and impersonal transactions. Currently, there is still a reluctance on the part of players from

many developing countries to share information online, which is a major barrier to the successful adoption of B2B and B2C e-commerce.

States should also play a leading role in addressing another major obstacle: IT-related skill deficiencies in the workforce. This can be achieved in several ways. One approach is to provide training and skill development, or at least, to encourage state-run educational institutions to shift their priorities accordingly. Another avenue is to provide incentives to firms to engage in such training themselves, through tax policy or through subsidies.

As noted in the previous sections, it appears that the magnitudes of the market failures are sufficiently high that the public sector in an *individual* country alone cannot effectively overcome them. This is especially true for the smaller, developing countries. Our review of the literature suggests that a wide range of collaborative arrangements can be used to address these market failures, including public-private partnerships, alliances, and consortia. These partnerships would be useful for (a) providing a better access to financial capital to stimulate investment in IT, (b) enhancing the development of human capital to facilitate implementation of the new technologies, (c) stimulating the development and extension of networks, which serve to increase the private (firm-level) and social returns to IT and e-business, and (d) allaying concerns regarding sharing proprietary information.

National governments, the private sector, society at large, and especially the R&D community in developing and transition countries must realize that IT should not be treated as a homogenous phenomenon. As discussed in the previous sections of this article, a large body of empirical evidence indicates that the antecedents and consequences of IT vary according to the type of IT investment. That is, there is considerable heterogeneity in the challenges and policy issues associated with each type of IT. Still, the empirical evidence suggests that the potential for investment in IT to generate substantial productivity gains may actually be greater for firms in developing countries than those in developed countries. Of course, this is partially due to the fact that developing countries start from a much lower economic base than highly industrialized countries. However, their roadmap toward the information economy could be streamlined, giving an opportunity to catch up by adopting the latest IT technologies such as wireless solutions to leapfrog

infrastructure bottlenecks or open source software to improve low cost access to the Internet mediated information flows. It is still important to note that the vast potential of IT cannot be exploited without considerable attention being devoted to understanding sector-specific characteristics relating to market structure (i.e., the extent of consolidation in the industry), the state of the supply chain, and resources available to firms to support their businesses. Voluminous evidence has been presented in this article on these sector-specific factors.

In developing countries, these characteristics are likely to be different from those in developed countries, even within the same industry. Developing countries have relatively weak risk management systems in place and fewer resources to invest. They simply cannot afford to waste their limited technical, financial, and human resources on IT investments that do not yield a high social return. To make the wisest IT investment decisions, businesses must rely on the support of their public authorities and financial intermediaries, as well as on various kinds of international public-private partnerships.

It is critical for research organizations, such as UNCTAD, to enhance their efforts to document the current state of IT usage and implementation in developing and transition countries. In the meantime, there is still little systematic evidence on the economic consequences of IT in these countries, as well as on how institutional and regulatory factors interact with IT and influence economic outcomes. It is important to note that ITs and their applications remain a costly investment for most firms in developing countries, because of the need to achieve far more than simply connectivity to global networks. IT applications must be embedded within organizations in a way that does not yield substantially increased costs of coordination both within the firm and between buyers and sellers in the supply chain. Analyzing the experience of the use of ITs and various

implementations of e-commerce by firms in developing and transition economies and relating them to the best practices in a given field, might help us to identify the key bottlenecks and critical success factors in a particular country. This would enable researchers to provide much more specific recommendations.

We conjecture that IT and the Internet will generate high social returns in countries that invest in these technologies and use them wisely. The pace of technological progress in IT goods and services is showing no signs of slowing down. As a result, these products are becoming more affordable to businesses and households in countries with lower per capita incomes. The bottom line is that there exists a critical opportunity for developing countries striving to improve their global competitiveness and enhance economic growth through IT-related investment. Thus, it is incumbent upon policymakers in these countries to ensure that domestic firms encounter an environment that is conducive to such investments and that they have sufficient incentives to undertake them. This will enable them to improve their export competitiveness through participation in local, regional, and global e-marketplaces.

In the context of developing countries, an important caveat must be mentioned: the *opportunity cost* argument, that is, other forms of public support/investment, such as increasing access of women to primary education, might generate higher social returns.³ This also underscores the realistic notion that developing and transition countries face a different set of challenges than do developed countries. Although it is impossible to directly refute the opportunity cost argument in this context, it is likely that IT and primary education are complements anyway. Furthermore, the evidence suggests that developing countries can increase the probability of catching up to more advanced countries through well-targeted investment in IT and Internet-related technologies.

NOTES

1. In contrast to van Ark *et al.* (2003), the McKinsey report categorized retail and wholesale trade as traditional sectors, not “new economy” sectors.

2. See Gordon (2000) for a more skeptical view of the “new economy” and computers as a general purpose technology.

3. We are indebted to an anonymous referee for raising this astute point.

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