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ICT Equipment Investment and Growth in Low- and Lower-Middle-Income Countries

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Abstract

While production of ICT equipment plays a subordinate role for economic growth in most of these countries, they do benefit from capital deepening arising from falling prices of ICT equipment. Adapting established growth accounting approaches to the data environment of low-income countries, we quantify the growth impacts of absorption of ICT equipment, finding that ICT-related capital deepening contributed 0.2 percentage points to growth in low-income countries, and 0.3 percentage points in low-middle-income countries. The latter is about half the level typically found for industrialized countries.

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I. INTRODUCTION

The paper aims to provide an assessment of the macroeconomic impacts of advances in information and communication technologies (ICTs) in low- and low-middle-income countries. In this regard, it builds on the fact that the use of ICTs is tied to the availability of certain types of equipment, such as computers for information technology, or certain communication devices (phones, or computers, depending on the type of communication) as well as the existence of a telecommunications infrastructure for communication technologies. Thus, the macroeconomic impact of advances in ICTs is linked to the absorption of such equipment.

Our analysis draws from a substantial body of literature on growth accounting and the role that advances in ICTs have played in growth trends in the most advanced countries. Relative to that literature, our framework is adapted to take into account the lack of availability of national accounts or industry data on a level of detail that the most common approaches to assessing the macroeconomic impact of ICTs in the most developed economies are based on.

Specifically, our study focuses on the macroeconomic impacts of ICT-related capital deepening. In the absence of disaggregated investment data, this involves drawing inferences from the observed patterns of trade and – where available – production data regarding the levels of ICT-related investment. Using a set of commonly available macroeconomic variables (e.g., investment rates, underlying growth rates), international data on relative prices of ICT equipment, and a growth-accounting framework inspired by the literature on sources of growth in high-income countries, we estimate the implications of technological advances in ICTs (i.e., falling prices of ICT equipment) for the accumulation of capital and economic growth.

While the production of ICT equipment does not play a macroeconomic role in most low- and lower-middle-income countries, it is a significant contributor to economic growth in a few countries. While the focus of the paper is on ICT-related capital deepening, our analytical framework can also easily be applied to the study of the growth contribution of the production of ICT equipment. The main challenge here is the weakness of the data, as our production data do not identify the role of ICT-related inputs.

A third channel, which we will not attempt to quantify in this study, owing to data constraints, are generalized productivity gains associated with structural changes in the economy enabled by the usage of ICTs. Even for the U.S., (a country with extensive national accounts data regarding the macroeconomic role of ICTs), the empirical evidence for such broad-based productivity gains is weak.[1] As we are dealing with countries with generally

[1] See, for example, discussions included in Gordon (2000) and Oliner and Sichel (2000). Later studies attempted, with some success, to estimate ICT-related productivity gains using micro-economic data.

weaker statistical systems, and a less prominent role of ICT equipment, we are in no position to estimate such generalized productivity effects.

The analysis is structured in 4 sections. We first relate our study to the existing literature on sources of growth, especially to those studies analyzing the impacts of advances in ICTs across countries (Section II), and use this motivates the approach taken in the present study, designed to achieve (near-) complete coverage of low- and lower-middle-income countries. Section III describes the analytical framework, adopting a simple growth-accounting framework with two types of capital (non-ICT-related and ICT-related) in which technological advances in ICTs are identified as falling relative prices of ICT capital. Section IV applies the framework to assessing the growth impacts of ICT-related capital-deepening, offering an analysis for a cross-section of low- and lower-middle-income countries (using 2001-06 averages of key variables), drawing on steady-state properties of the model, and an analysis covering the years 1990-2006, which distinguishes the immediate impacts of falling relative prices of ICT equipment on growth and the "multiplier effects" that arise if a shock to growth results in changes in the rate of accumulation of capital in subsequent periods. Section V complements our analysis of the growth effects of ICT-related capital deepening with an assessment of the contribution of the ICT-producing sector to economic growth, for the limited number of developing countries where this is relevant. Section VI concludes. A data appendix offers a more extensive discussion of the construction of the dataset underlying our analysis.

II. BACKGROUND

The analysis of the impact of advances in ICTs in low- and lower-middle-income countries can draw on a longstanding economic literature analyzing the sources of economic growth in advanced economies, notably the work in the tradition established by Griliches and Jorgenson (1966, 1967). In recent years, particularly in the context of the acceleration in economic growth experienced by the U.S. economy in the latter half of the 1990s, a number of studies addressed the role of ICTs in the "growth resurgence," and identified technological advances in the production of ICTs, as well as capital deepening associated with falling prices of ICT-related equipment, as key factors behind the acceleration in economic growth.[2]

Relatedly, numerous studies have addressed the impacts of ICTs across countries, for example for the G7 economies (Jorgenson, (2003, 2005b), the OECD (see Ahmad, Schreyer, and Wölfl (2004), Colecchia and Schreyer (2002), or Pilat and Wölfl (2004)), or the European Union (see Daveri (2002) or van Ark, O'Mahoney, and Timmer, (2008)). A few studies have analyzed the impacts of ICTs across a larger number of countries, notably

[2] See, for example, Gordon (2000), Jorgenson (2001, 2005a), Jorgenson, Ho, and Stiroh (2005), Oliner and Sichel (2000), Oliner, Sichel, and Stiroh (2007).

Bayoumi and Haacker (2002), for a group of 49 countries, and Jorgenson and Vu (2005a, 2005b, and 2007), who cover 110 countries.[3]

The key challenges regarding the study of the economic impact of ICTs across countries are inconsistencies in national accounts data across countries, and – especially for a study focusing on low- and lower-middle-income countries – lack of disaggregated national accounts data that would identify the production of or investment in ICT equipment in the countries of interest.

Regarding price indices for ICT equipment (crucial as the rate of price decline of a commodity can be interpreted as a measure of the pace of productivity gains in the production of that commodity), most studies referred to above resolve the issue of consistency across countries by constructing "harmonized" price indices, following Schreyer (2000, 2002), based on the difference between prices of ICT equipment and non-ICT equipment in U.S. national accounts.

The more significant constraint for our purposes is the absence of production and spending data from national accounts. Some studies aiming for a wider country coverage have adopted data on ICT-related spending from industry sources (Daveri (2002), Bayoumi and Haacker (2002), and Jorgenson and Vu (2005a, 2005b, and 2007)). The most significant effort so far in developing a global perspective on the macroeconomic impacts of ICTs are the studies by Jorgenson and Vu, using sales data published by the "World Information Technology and Services Alliance,"[4] which are available for 70 countries, and extrapolating spending data based on several secondary data sources for another 40 countries for which complete national accounts data are available from the Penn World Table Version 6.1 (Heston, Summers, and Aten, 2002).

As a key objective of the present study is a comprehensive assessment of the growth impact of ICTs in low- and low-middle income countries, the coverage of which is limited even in the Jorgenson and Vu dataset (although it is the study with the largest coverage of countries so far, it covers only 50 of 103 countries classified as low- or low-middle-income countries by World Bank, 2007), we follow a different track.

First, we construct a database of spending on ICT equipment based on trade data (with some modifications for countries producing ICT equipment), using data reported by countries of interest where available, augmented by data from trade partners where necessary. This yields a dataset of spending on ICT equipment with a complete coverage of all 103 low- and

[3] Owing to the absence of industry-level data for most developing countries, we focus on the economic literature referred on the aggregate impacts of advances in ICTs.

[4] Versions of the same database have also been used by Daveri (2002) and Bayoumi and Haacker (2002). In recent years, the WITSA database has been produced by Global Insight, and presents a subset of Global Insight's *Global IT Navigator* database used in the present study (see Global Insight, 2006).

low-middle-income countries, going back to 1980 (as some countries became independent only after 1980, the number of countries covered is lower for the earlier years).

Second, rather than attempting a complete growth accounting exercise (attributing growth to inputs of labor, different types of capital, and multifactor productivity), we focus on the contributions of the production of ICT equipment and of ICT-related capital deepening to economic growth. As our accounting for the impacts of ICTs relies on the availability of data on investment and, in its crudest form, GDP, our analysis captures between 89 and 97 countries towards the end of the sample period (our analysis of the growth impacts of ICTs covers the years 1990-2006), and 80 countries at the beginning.[5] Notably, our approach does not require an estimation of the contribution to growth of changes in the supply of labor, which is a problematic area for low-income countries as frequently estimates are based on crude demographic models, and findings are difficult to interpret for the purposes of growth accounting if the economy features a large informal sector.

III. Analytical Framework

The purpose of the present section is two-fold: developing a model that will be used to assess the growth impacts of advances in ICTs, and making use of the model to calibrate some key parameters of interest regarding the impacts of ICTs, in addition to those that can be directly obtained from available data or be adapted from other studies. In light of the previous discussion (in the introduction to the present paper), we focus on two areas –

- the growth impacts of rising productivity in the production of ICT equipment, and
- the contribution of ICT-related capital deepening, fueled by declining relative prices of ICT equipment.

After introducing the key components of the model, we first derive the links between advances in ICTs and growth in the steady state. However, as some of the impacts of falling prices of ICTs on economic growth unfold only over time, and the rates of technological advances in ICTs fluctuates, an analysis focusing on the steady-state properties of the model may yield exaggerated estimates of the (immediate) impact of ICTs on growth. We therefore adapt the model in order to track the growth impacts of advances in ICTs over time, interpreting fluctuations in the rate of change of relative prices of ICT equipment as perturbations along the steady-state growth path.

Many of the issues regarding the contribution of ICTs to growth can be captured in a straightforward growth accounting framework with two goods, distinguishing between ICT products (indicated by subscript 2) and any other products (subscript 1). We assume that ICT

[5] The lower coverage at the beginning of the period under consideration primarily reflects the fact that some countries became independent only after 1980, rather than data constraints.

equipment is used as an investment good only,[6] while the other good is used both as consumption good and as investment good. Without loss of generality, we will choose good 1 as the numeraire, so that p_1 is identically equal to 1 (and will be suppressed below), and p_2 represents the relative price of ICT products. Specifically, we assume that the world is populated by economies characterized by an equation that describes output (in terms of the numeraire) as the sum of production of good 1 and 2, with

$$Y = Y_1 + Y_2 = p_1 A_1 F_1(K_{1,1}, K_{1,2}, L_1) + p_2 A_2 F_2(K_{2,1}, K_{2,2}, L_2), \tag{1}$$

where p_i stands for the price of good i, A_i represents total factor productivity in sector i, $K_{i,j}$ stands for capital of type j used in the production of good i, and L_i is the amount of labor occupied in sector i. We assume that $F_1(\cdot)$ and $F_2(\cdot)$ are exhibiting constant returns to scale. Both good 1 and good 2 are traded, so that the use of any commodity does not need to equal production in any economy. We do not impose a global market-clearing condition on either commodity, as we focus on a subset of countries only, and market-clearing is implicit in our dataset (as trade flows – aside from measurement errors – would have to balance out).

Concretely, we adopt a Cobb-Douglas production function, with

$$Y = A_1 K_{1,1}^{\alpha_{11}} K_{1,2}^{\alpha_{12}} L^{1-\alpha_{11}-\alpha_{12}} + A_2 p_2 K_{2,1}^{\alpha_{21}} K_{2,2}^{\alpha_{22}} L^{1-\alpha_{21}-\alpha_{22}}, \tag{2}$$

In this framework, the direct growth contribution of productivity gains in the ICT sector (an increase in A_2) can simply be obtained as the rate of growth of A_2, weighted by the share of the ICT-producing sector 2 in output, i.e.

$$dg_Y = d\left[\frac{\dot{A}_2}{A_2}\right]\frac{Y_2}{Y} \tag{3}$$

However, for the large majority of countries considered in the present study, the primary impacts of advances in ICTs arise from ICT-related capital deepening. To capture those in the present framework, we first make two related (in fact, one can argue, equivalent) assumptions:

[6] Our approach, attributing all spending on ICT equipment to investment, differs somewhat from approaches adopted in key contributions to the literature. It is closest to the framework adopted by Jorgenson and collaborators, who also incorporate all spending on ICT equipment in the analysis. However, they use data that differentiates between investment and spending on durable consumption goods (which include ICT equipment), and adjust GDP figures for the services obtained from durable consumption goods. Other studies, including several studies by Oliner and Sichel, focus on non-farm agricultural output, and correspondingly consider ICT-related investment in those sectors only.

(1) Any productivity gains in the production of ICT equipment (an increase in A_2) beyond the productivity gains in the production of non-ICT products result in a equiproportionate decline in the price of ICT equipment, i.e.,

$$x_2 \equiv \frac{\dot{A}_2}{A_2} - \frac{\dot{A}_1}{A_1} = -\frac{\dot{p}_2}{p_2}. \tag{4}$$

(2) The factor shares of capital of type 1 and 2 are the same across sectors.

The first assumption is consistent with established praxis in the literature on growth impacts of ICTs.[7] (To simplify notation, we use x to denote the growth rate of A_2, as introduced in Eq. (4).) The second assumption is, strictly speaking, implied by the first – if factor shares differ across sectors, then productivity gains in the production of ICT equipment would also result in a change in relative prices owing to ICT-related capital deepening. On a more pragmatic level, in light of the small weight of the ICT-producing sector in the few ICT-producing countries in our sample, and of the lack of availability of industry-level data for our countries of interest, there are no obvious gains from differentiating between factor shares across sectors. On the other hand, the assumption of equal factor shares allows for a considerably simplified presentation of the value of output (in terms of the numeraire), with

$$Y = AK_1^{\alpha_1} K_2^{\alpha_2} L^{1-\alpha_1-\alpha_2}, \tag{5}$$

with $\alpha_1 = \alpha_{11} = \alpha_{12}$, $\alpha_2 = \alpha_{21} = \alpha_{22}$, $K_1 = K_{1,1} + K_{1,2}$, $K_2 = K_{2,1} + K_{2,2}$, $L = L_1 + L_2$, and $A = A_1 + A_2 p_2$, the latter growing at the same rate as A_1 by virtue of Eq. (4).[8]

Using the constant-returns property of the production function, and transforming it into per-capita terms, gives

$$y = Ak_1^{\alpha_1} k_2^{\alpha_2}, \tag{6}$$

where $y \equiv Y/L$, and $k_i \equiv K_i/L$. The accumulation of capital of type *j* ($j \in \{1,2\}$) is governed by

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[7] See, for example, the brief discussion of the "dual approach to productivity measurement" in Jorgenson (2005a), or Schreyer (2002) and Triplett (2004) for a more substantial treatment of the issue.

[8] Note that this representation of the value of output formalizes the point, that productivity gains in ICT-producing sectors, for producer countries, dissipate owing to falling relative prices of these products.

$$\dot{k}_j = \frac{s_j y}{p_j} - (\delta_j + n)k_j , \tag{7}$$

where a dot above a variable indicates a rate of change, s_j is the share of national output invested in capital goods of type j, and δ_j is the physical rate of depreciation of good j, and n the rate of population growth.

From Eq. (2), the rate of growth of output per capita is given by

$$g \equiv \frac{\dot{y}}{y} = \frac{\dot{A}}{A} + \alpha_1 \frac{\dot{k}_1}{k_1} + \alpha_2 \frac{\dot{k}_2}{k_2} . \tag{8}$$

To estimate the contribution of ICT-related capital deepening to growth, it is thus necessary to determine the growth rates of the stocks of non-ICT and ICT capital, and to establish values for the respective elasticities α_1 and α_2. By integrating Eq. (7), we obtain an estimate of the stock of capital, as

$$k_j(t) = \int_{-\infty}^{t} \frac{s_{j,\tau} y_\tau}{p_{i,\tau}} - (\delta_j + n_\tau) k_{j,\tau} d\tau . \tag{9}$$

For ICT equipment, this can be calculated (in a corresponding discrete-time presentation) based on the available data on spending on ICT equipment and the relevant prices, in addition to data on GDP per capita, population growth, and the rate of depreciation of ICT equipment. The rate of growth of the respective capital stocks is then defined as

$$\frac{\dot{k}_j(t)}{k_j(t)} = \frac{\frac{s_{j,t} y_t}{p_{j,t}} - (\delta_j + n_t) k_{j,t}}{\int_{-\infty}^{t} \frac{s_{j,\tau} y_\tau}{p_{j,\tau}} - (\delta_j + n_t) k_{j,\tau} d\tau} . \tag{10}$$

A key aspect of Eq. (10), for the purposes of estimating the growth impacts of ICT-related capital deepening, is the role of the relative price of ICT equipment, p_2. Eq. (10) shows that the faster this price declines, the larger is the growth rate of the stock of ICT-related equipment. The same rate of ICT-related investment in period t as in earlier periods, owing to a lower relative prices at time t relative to earlier periods, translates into larger real increments to the capital stock of ICT equipment. (Vice versa, as ICT equipment was relatively more expensive in the past, the same rate of investment in the past bought little ICT equipment.)

Steady-State Properties of Model

While the general framework just allows for a calibration of the economic impacts of advances in ICTs over time, analyzing the steady-state properties of the model is interesting because it conveys information about the long-term impacts of advances in ICTs, and as it allows for an analytically tractable description of the impacts of ICTs on economic growth. To this end, a key challenge in estimating the growth contribution of ICT-related capital deepening regards the elasticities α_1 and α_2, which cannot be measured directly. To this end, we use the steady-state version of the model spelled out above, in order to obtain a mapping from parameters that can be observed or estimated more directly to α_1 and α_2.

Provided that a steady-state with constant s_j, and constant growth rates of k_j, y, and p_i exists, Eq. (9) can be rearranged as

$$k_j(t) = \int_{-\infty}^{t} \frac{s_j y_t e^{g(\tau-t)}}{p_{j,t} e^{-x_j(\tau-t)}} - (\delta_j + n) k_{j,t} e^{\gamma_j(\tau-t)} d\tau, \tag{11}$$

where γ_j represents the steady-state growth rate of k_j (assumed constant), which simplifies to yield

$$k_{jt} = \frac{s_j y_t}{p_{jt}} \frac{1}{g + x_j} - \frac{\delta_i k_{j,t}}{\gamma_{i,j}}, \tag{12}$$

Rearranging, taking logs, and differentiating through Eq. (12) yields

$$\gamma_j \equiv \frac{\dot{k}_j}{k_j} = g + x_j, \quad \text{i.e.,} \quad \frac{\dot{k}_1}{k_1} = g \quad \text{and} \quad \frac{\dot{k}_2}{k_2} = g + x. \tag{13}$$

Substituting back into Eq. (12) , and solving the capital-output ratios k_1 / y and pk_2 / y, gives

$$\frac{k_1}{y} = \frac{s_1}{g + \delta_1 + n} \quad \text{and} \quad \frac{p_2 k_2}{y} = \frac{s_2}{g + x + \delta_2 + n} \tag{14), (15}$$

Returning to our objective of estimating the elasticities α_1 and α_2, we first note that in a world characterized by constant returns, the elasticities α_1 and α_2 are associated with the factor shares for the respective capital goods. While the factor shares for ICT- and non-ICT-related equipment are not generally available, estimates for the overall factor share of capital (denoted α) are available, and α_1 and α_2 need to satisfy

$$\alpha_1 + \alpha_2 = \alpha \, . \tag{16}$$

A second relationship between α_1 and α_2 can be derived from a no-arbitrage condition – the condition that the rate of returns should be equal across different types of assets, after controlling for changes in relative prices of different assets and depreciation. In our context, this means that

$$\frac{dy}{dk_1} - \delta_1 = \frac{dy}{p_2 dk_2} - x - \delta_2 \, .\text{[9]} \tag{17}$$

Differentiating the aggregate production function (Eq. (6) with respect to k_1 and k_2, this implies that

$$\alpha_1 \frac{y}{k_1} - \delta_1 = \alpha_2 \frac{y}{p_2 k_2} - x - \delta_2 \, . \tag{18}$$

Using Eqs. (14) and (15) to substitute for the (inverse of) the capital-output ratios in Eq. (18) yields

$$\alpha_1 \frac{g + \delta_1 + n}{s_1} - \delta_1 = \alpha_2 \frac{g + x + \delta_2 + n}{s_2} - x - \delta_2 \, . \tag{19}$$

As the variables and parameters, other than α_1 and α_2, can be observed or estimated, it is possible to use the relationship described by Eq. (17) to draw inferences regarding the underlying parameters α_1 and α_2. Using Eqs. (13) and (17) then yields a solution for α_2, for given g, x, δ_1, δ_2, n, s_1, and s_2, with

$$\alpha_2 = s_2 \frac{\alpha(g + \delta_1 + n) + s_1(x + \delta_2 - \delta_1)}{s_2(g + \delta_1 + n) + s_1(g + x + \delta_2 + n)} \, . \tag{20}$$

Using the estimate of α_2 obtained through Eq. (20), it is possible to establish the link between falling prices of ICT-related equipment and growth. Using Eq. (8), and substituting for the growth rates of k_1 and k_2 from Eq. (13), we obtain

$$g \equiv \frac{\dot{y}}{y} = \frac{1}{1-\alpha} \left[\frac{\dot{A}}{A} + \alpha_2 x \right], \tag{21}$$

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[9] This no-arbitrage condition is related to the concept of rental costs of capital used in the tradition of Griliches and Jorgenson (1966, 1967) to calibrate the rates of return on different types of assets, and the notion of the quality of capital (i.e., the services obtained from a unit of capital) used by Jorgenson in more recent publications (see, for example, Jorgenson, 2005a).

which implies that

$$\frac{dg}{dx} = \frac{\alpha_2}{1-\alpha} = \alpha_2 + \alpha_2 \frac{\alpha}{1-\alpha}. \tag{22}$$

In light of Eqs. (8) and (13), this overall impact of changes in the pace of technical advances in ICTs can be broken down into the direct impacts of a change in *x* on the rate of accumulation of ICT capital (Eq. (8)) and thus on growth (Eq. (13), represented by α_2, and the indirect effects that arise as higher growth in turn results in a faster rate of accumulation of capital (see Eq. (8)), represented by $\alpha_2 \frac{\alpha}{1-\alpha}$.

The latter effect, however, arises over time (compare Eqs. (7), (10)). If the economy does not strictly follow a steady-state growth path, Eq. (22) may therefore give a misleading picture regarding the impacts of advances in ICTs over time. Notably, as the rate of price declines of ICT equipment fluctuates (implying shocks that would move the economy away from the steady-state growth path), a steady-state assumption is implausible, and adopting Eq. (22) would result in exaggerated estimates of the impact of changes in the pace of technological advances in ICTs when they occur, while missing out on the lagged impacts that occur through the induced changes in the rate of capital accumulation.

To address these shortcomings of an analysis built on steady-state relationships between key variables, and to gain an improved understanding of the impacts of advances in ICTs over the last years, we will therefore adopt a different approach below, interpreting changes in the rate of technological advances in ICTs as (a series of) one-off shock(s) to an economy moving around the steady-state growth path, and explicitly analyzing the implications of those shocks over time.

Impact of ICT-Related Innovations Over Time

To get a grip on the impacts on economic growth over time of falling prices of ICT equipment, we use perturbation techniques, treating the falling prices of ICT equipment as time-variant disturbances to growth around a steady-state growth path. As it considerably simplifies notation, we adopt a discrete-time version of the model discussed above (with identical properties regarding the steady-state links between advances in ICTs and economic growth).

We denote a shock to growth at time t as γ_t, with

$$\gamma_t = -\alpha_2 \partial p_{2,t} / p_{2,t-1}, \tag{23}$$

where we use "∂" to denote a deviation from a steady-state growth path.[10,11] As we have already accounted for changes in relative prices of ICT equipment through the disturbance term γ_t, we can simplify the analysis considerably by focusing on the capital stock in terms of the numeraire good, which allows us to focus on the evolution of the aggregate capital stock.[12]

We use $\partial y_t / y_{t-1}$ to represent a perturbation to economic growth relative to the steady-state, which is equal to the sum of γ_t and the impacts of the induced perturbations to the accumulation of capital, i.e.

$$\frac{\partial y_t}{y_{t-1}} = \gamma_t + \alpha \frac{\partial k_t}{k_{t-1}}. \tag{24}$$

The accumulation of capital is determined by the difference equation

$$k_t = s y_{t-1} + (1-\delta-n) k_{t-1}. \tag{25}$$

Importantly, this relationship incorporates the behavioral assumption that savings rates remain constant as the growth rates change. For an infinite time horizon, Eq. (25) implies that

$$k_t = s \sum_{i=1}^{\infty} \left[(1-\delta-n)^{i-1} y_{t-i} \right] \tag{26}$$

Differentiating and dividing by k_{t-1}, the induced perturbation to the growth rate of capital follows

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[10] The quality of some of our assumptions rests on the extent to which price shocks are correlated over time. Some of our assumptions implicitly assume that changes in (but not levels of) γ_t are uncorrelated. If this is not the case, price shocks would result in shifts of the steady-state growth path, whereas we analyze them as disturbances around a steady-state growth path.

[11] In the discussion of the steady-state of the model, we derived an explicit solution for the impact of falling prices of ICT capital on growth. For perturbations around a steady-state growth path, the link between a change in relative prices, the induced growth rate of the stock of ICT equipment in real terms, and output growth rests on the need to equate rates of return across different types of capital. A drop in the relative price of ICT equipment implies an equiproportionate increase in the gross rate of return. Under the functional specification we adopt, this results in a reallocation of capital (or a disproportionate share of investment going to ICT equipment) until the nominal weights of ICT capital and other forms of capital are restored to the level at which rates of return are equal across assets. The overall effect on growth of this reallocation of capital is equal to the decline in prices of ICT equipment, weighted by the factor share a_2.

[12] As noted before in a more general context, our analysis assumes that changes in γ_t are uncorrelated over time.

$$\frac{\partial k_t}{k_{t-1}} = s\sum_{i=1}^{\infty}\left[(1-\delta-n)^{i-1}\frac{\partial y_{t-i}}{k_{t-1}}\right], \tag{27}$$

which expands to $$\frac{\partial k_t}{k_{t-1}} = s\sum_{i=1}^{\infty}\left[(1-\delta-n)^{i-1}\frac{\partial y_{t-i}}{y_{t-i-1}}\frac{y_{t-i-1}}{y_{t-1}}\right]\frac{y_{t-1}}{k_{t-1}}. \tag{28}$$

This is the point were the perturbation techniques come in, drawing on properties of the steady-state growth path to approximate the consequences of perturbations. Specifically, we approximate the capital-output ratio by its steady state value $k/y = s/(\delta+n+g)$, and substitute $(1+g)^i$ for y_{t-1}/y_{t-i-1}. Eq. (28) then becomes

$$\frac{\partial k_t}{k_{t-1}} = \frac{(\delta+n+g)}{1+g}\sum_{i=1}^{\infty}\left[\left[\frac{1-\delta-n}{1+g}\right]^{i-1}\frac{\partial y_{t-i}}{y_{t-i-1}}\right]. \tag{29}$$

Using Eq. (24), Eq. (29) yields a difference equation describing the induced perturbation to the growth rate of the capital stock as a function of past disturbances to output growth (γ) and past disturbances to the growth rate of the capital stock,

$$\frac{\partial k_t}{k_{t-1}} = \frac{(\delta+n+g)}{1+g}\sum_{i=1}^{\infty}\left[\left[\frac{1-\delta-n}{1+g}\right]^{i-1}\left[\gamma_{t-i}+\alpha\frac{\partial k_{t-i}}{k_{t-i-1}}\right]\right], \text{ which implies that} \tag{30}$$

$$\frac{\partial k_t}{k_{t-1}} = \frac{(\delta+n+g)}{1+g}\left[\gamma_{t-1}+\alpha\frac{\partial k_{t-1}}{k_{t-2}}\right]+\frac{1-\delta-n}{1+g}\frac{\partial k_{t-1}}{k_{t-2}}. \tag{31}$$

Rearranging and expanding backwards towards an infinite horizon yields a presentation of $\partial k_t / k_{t-1}$ as a distributed lag of past disturbances γ, with

$$\frac{\partial k_t}{k_{t-1}} = \frac{(\delta+n+g)}{1+g}\sum_{i=0}^{\infty}\left[\left[\frac{1+\alpha g-(1-\alpha)(\delta+n)}{1+g}\right]^{i}\gamma_{t-1-i}\right]. \tag{32}$$

For changes to the rate of output growth, Eq. (24), together with Eq. (32), yields

$$\frac{\partial y_t}{y_{t-1}} = \gamma_t + \alpha\frac{(\delta+n+g)}{1+g}\sum_{i=0}^{\infty}\left[\left[\frac{1+\alpha g-(1-\alpha)(\delta+n)}{1+g}\right]^{i}\gamma_{t-1-i}\right]. \tag{33}$$

Eq. (33) represents changes to output growth as the sum of the immediate impact of a disturbance (γ_t), and the transitional impacts on growth of past disturbances playing out through capital accumulation as the economy returns to its steady state.

Regarding the long-term impact of a one-off disturbance to growth at time t, γ_t, Eq. (32) implies that

$$\sum_{i=1}^{\infty}\frac{\partial k_{t+i}}{k_{t+i-1}}=\frac{1}{1-\alpha}\gamma_t, \tag{34}$$

and that the long-term impact of a disturbance γ_t on output is

$$\sum_{i=0}^{\infty}\frac{\partial y_{t+i}}{y_{t+i-1}}=\gamma_t+\alpha\sum_{i=1}^{\infty}\frac{\partial k_{t+i}}{k_{t+i-1}}=\frac{1}{1-\alpha}\gamma_t, \tag{35}$$

or, equivalently (using Eq. (23)),

$$\sum_{i=0}^{\infty}\frac{\partial y_{t+i}}{y_{t+i-1}}=\gamma_t+\alpha\sum_{i=1}^{\infty}\frac{\partial k_{t+i}}{k_{t+i-1}}=-\frac{\alpha_2}{1-\alpha}\frac{\partial p_{2,t}}{p_{2,t-1}}, \tag{35}$$

which closely corresponds to the steady-state presentation in Eq. (22), with γ_t corresponding to the immediate impact of declining prices, weighted by the respective elasticity.

IV. The Contribution of ICT Equipment to Economic Growth

Building on the theoretical framework developed in the preceding section, we are now in a position to assess the growth impacts of technological advances in ICTs in low- and lower-middle-income countries. As most of these countries do not produce ICT equipment, the principal impacts of ICTs may arise through ICT-related capital deepening (in addition to more fundamental transformations in the structure of the global and national economies, which are beyond the scope of this study). The present section evaluates the growth impacts of ICT-related capital deepening, setting out by discussing some key variables and parameters. The middle part of the section provides an analysis of the contributions of ICT-related capital deepening to growth in 2001-06, using the steady-state framework outlined above. The concluding part discusses the contribution of ICT-related capital deepening to growth over the 1990-2006 period, based on the evolution of ICT-related capital stock, and also allowing the role of ICTs (i.e., the elasticity of output with respect to ICT-related capital) to evolve over time.

Key Variables and Parameters

For our analysis of the growth impacts of ICT-related capital deepening, we need to draw on some macroeconomic and national accounts data. Data on nominal GDP, real GDP growth, and aggregate investment were obtained from the IMF's *World Economic Outlook* database (IMF, 2008). Data on population size and the rate of population growth are based on the estimates by the United Nations Population Division, which are included in and were also downloaded from the *World Economic Outlook* database.

ICT-related investment was estimated following the approach described in the data appendix (Appendix Table 1 includes the average investment rates for the years 2001-05). For most countries, the estimates are based on the level of net imports of IT- and communications-related investment, respectively, applying a mark-up to account for various costs and taxes not included in the data on net imports. For some countries, the investment data are based on available data on spending; for a few countries, adjustment to the data had to be made to account for domestic production of ICT-related equipment.

A crucial variable that affects the magnitude of the growth effects of ICT-related capital deepening is the rate of decline of relative prices of ICT-related equipment (see data appendix for more discussion). The price series we use (Appendix Table 5) are based on prices indices from the U.S. National Income and Product Accounts and Producer Price Indices.[13] For communications equipment, we adopt a modified series based on Doms (2005), which introduces various improvements to the official series regarding the measurement of changes in the quality of communications equipment.[14]

There are three technological parameters that our analysis requires – the overall factor share of capital α (=α_1+α_2) and the rates of depreciation of non-ICT- and ICT-equipment, δ_1 and δ_2. Estimates of α are available from numerous studies, including empirical studies estimating the elasticity of output with respect to capital directly, or (especially for countries with sophisticated national accounts) studies identifying the parameter α as the factor share of capital in GDP, and in growth accounting exercises the parameter α commonly is assumed to take a value of 0.35–0.40. The study with the most comprehensive coverage of low- and lower-middle-income countries, which are the focus of the present study, is Senhadji (2000), providing estimates for α for 24 of the countries covered in our study. Based on his study, we assume a value for the parameter α of 0.5, which is between the median (0.47) and the mean (0.52) of the country level estimates presented by Senhadji (2000) for the 24 countries of interest here.[15]

Our choices for depreciation rates follow the estimates compiled by Jorgenson and Stiroh (2000, also included in Jorgenson, Ho and Stiroh, 2005). For IT equipment ("computers and peripheral equipment"), they propose a depreciation rate of 31.5 percent, and for

[13] See U.S. Department of Commerce, Bureau of Economic Analysis (2008), and U.S. Department of Labor, Bureau of Labor Statistics, 2008.

[14] The work by Doms has been endorsed by prominent researchers in the field, including Jorgenson (2005). The series developed by Doms (2005) do not cover the whole 1990-2005 period that our study focuses on, for the outer years, we adopt an extrapolation.

[15] The numbers regard the model estimated in levels. Senhadji (2000) also provides alternative estimates for a model estimated with first differences, which are very similar.

communications equipment, a depreciation rate of 11 percent (this excludes structures related to telecommunications). For non-ICT capital, we adopt a depreciation rate of 6 percent – while many types of equipment are characterized by depreciation rates in the vicinity of 10-15 percent, our choice reflects that our investment data also include residential and other structures, for which Jorgenson and Stiroh propose depreciation rates mostly between 1 and 5 percent.

Steady-State Analysis

A steady-state analysis based on averages of key variables over a period of time may be a good approximation regarding the stock of ICT capital, as high rates of price decline and physical depreciation imply that investments in previous years carry a low weight in the stock of ICT capital. However, the estimates could be misleading owing to cyclical factors (business cycles, post-conflict recovery) resulting in unusual levels of ICT investment over the period under consideration. Additionally, the role of ICTs in the economy may be evolving over time (with implications for the relation between ICT investment and growth), and a steady-state analysis would not capture these effects.

Setting aside these caveats for the time being, we conduct a steady-state analysis of the contributions of ICT-related capital deepening to growth, for 97 countries for which key macroeconomic data were available over the 2000-2006 period,[16] using the analytical framework described in the preceding section (notably, Eqs. (20) and (22)). In addition to the parameters described above, which are assumed to apply across countries, our estimates of the elasticities of output (see Eq. (20)) with respect to IT equipment and communications equipment are based on country-level estimates of GDP growth and population growth based on IMF (2008).

[16] For a few countries (see Appendix Table 1), overall investment rates were not available. For these countries, we substitute the sample average of investment rates. For Afghanistan, our estimates relate to 2002-06.

Table 1. Impact of ICT-Related Capital Deepening on Growth (Steady-State Analysis), Selected Countries, 2001-06

	IT Equip-ment	Communi-cations Equipment	Elasticity of output w.r.t. IT Equipment	Elasticity of output w.r. t. Communi-cations Equipment	Contribution to Growth: IT Equipment	Contribution to Growth: Communi-cations Equipment	Contribution to Growth: ICT Equipment (=IT+C)
	(Percent of GDP)				(Percentage Points)		
Bangladesh	0.52	0.91	0.004	0.005	0.11	0.09	0.20
China,P.R.: Mainland[1]	0.46	...	0.003	...	0.10	...	...
Egypt	0.23	0.80	0.002	0.004	0.05	0.08	0.14
Ethiopia	0.80	1.52	0.006	0.007	0.17	0.14	0.31
India	0.88	1.76	0.006	0.009	0.19	0.16	0.35
Indonesia	0.41	1.48	0.003	0.008	0.09	0.15	0.24
Nigeria	0.36	1.34	0.002	0.006	0.07	0.11	0.18
Pakistan	0.58	1.20	0.004	0.006	0.13	0.12	0.25
Philippines	0.84	0.96	0.006	0.005	0.18	0.10	0.28
Vietnam	0.58	1.67	0.004	0.008	0.12	0.15	0.28
Memorandum Items							
All countries[2]	0.74	1.39	0.006	0.007	0.16	0.14	0.30
LIC	0.6	1.3	0.005	0.007	0.13	0.13	0.26
LMC	1.0	1.5	0.007	0.008	0.19	0.16	0.35

Source: Author's calculations, as described in text (see discussion of steady-state analysis), based on data from IMF (2008), Global Insight (2006), and UN Statistics Division (2008). The table shows country-level estimates for the 10 most populous low- and lower-middle-income countries. For more details (average investment rates, growth rates of GDP and population), and country-level estimates of the 87 other countries covered, see Appendix Table 1. The totals under memorandum items relate to all countries covered by our analysis, not only the ones shown in the present table.

[1] For China, data on investment in communications equipment were unavailable.

[2] Totals exclude China (as estimates on investment in communications equipment were unavailable) and Paraguay (the latter owing to severe inconsistencies in published trade data).

Table 1 summarizes our findings for the 10 most populous low- and lower-middle-income countries (Appendix Table 1 provides more details and estimates for all 97 countries covered by our analysis). Overall, we estimate that ICT-related capital deepening contributed 0.3 percentage points to economic growth in 2001-06, with just over one-half attributed to IT equipment. While the contribution of IT and communications equipment is about the same for low-income countries, IT equipment plays a larger role in lower-middle-income countries. For the 10 countries covered in Table 1, the contribution of ICT equipment to growth amounts to between 0.14 and 0.35 percentage points (for Egypt and India, respectively). It appears that variations in IT-related investment account for the bulk of cross-country variations in the contribution of ICT equipment to growth, with a contribution from IT investment between 0.05 and 0.19 percentage points, and the contribution from communications equipment ranging from 0.08 to 0.16 percentage points. This reflects a pattern that also applies for the full set of countries covered (Appendix Table 1), for which the variance in the contribution of IT equipment to growth is 60 percent higher than the variance in the growth contribution of communications equipment.

To place our estimates of the growth impacts of ICT-related capital deepening in a global context, it is desirable to compare our estimates for low- and lower-middle-income countries to the impacts of ICTs in the most advanced economies. To this end, we construct estimates of the role of ICTs based on Global Insight's *Global IT Navigator* (Global Insight, 2006), which has a high coverage of high- and upper-middle-income countries. The estimates provided in Global IT Navigator dataset we use extend through 2005 only, and do not identify spending on communications equipment. We therefore need to narrow the focus of analysis to the scale and the impacts of IT-related capital deepening, and change the period under consideration to 2001-05.

Table 2. Impact of IT-Related Capital Deepening on Growth (Steady-State Analysis), Global Insight Dataset, 2001-05

Country Group	GDP per capita (U.S. dollars)	IT-investment: (Percent of GDP)	IT-investment: (Percent of total investment)	Contribution to growth (Percent)
28 high-income countries	26,929	1.18	5.6	0.27
18 upper-middle-income countries	4,478	1.14	5.8	0.25
18 lower-middle-income countries	1,502	0.73	3.3	0.16
5 low-income countries	624	0.72	4.1	0.16
Memorandum items:				
50 lower-middle-income countries[1]	1,748	0.88	3.8	0.20
47 low-income countries[1]	409	0.59	3.0	0.13

Source: See Appendix Table 2, and author's calculations for OECD countries.
[1] Based on the analysis presented in Table 1 for the full set of low- and lower-middle-income countries. Estimates were adjusted to take into account the shorter period covered by Global Insight (2006).

Table 2 summarizes our findings based on the *Global IT Navigator* dataset. It appears the impact of IT-related capital deepening on growth is similar between high- and upper-middle income countries (0.27 and 0.25 percentage points, respectively), whereas the growth impacts are about 0.1 percentage points lower for the lower-middle-income countries and the (few) low-income countries covered by the *Global IT Navigator* dataset, reflecting that IT-related investment is 0.4 percent of GDP lower in these countries, compared to high- and upper-middle-income countries.

Our analysis for the full sample of low- and lower-middle-income countries, however, suggests that the *Global IT Navigator* database may yield misleading results for these countries, owing to limited coverage. Adapting our estimates presented earlier to the shorter period (2001-05) covered by Table 2, we find that the growth impacts of IT-related capital deepening in low-income countries are about half of the impact in high- and upper-middle-income countries, and that the impacts in lower-middle-income countries are about half-way between the impacts in low-income countries and the impacts in high- and upper-middle-income countries.

Figure 1. Contribution of ICT-Related Capital Deepening to Growth

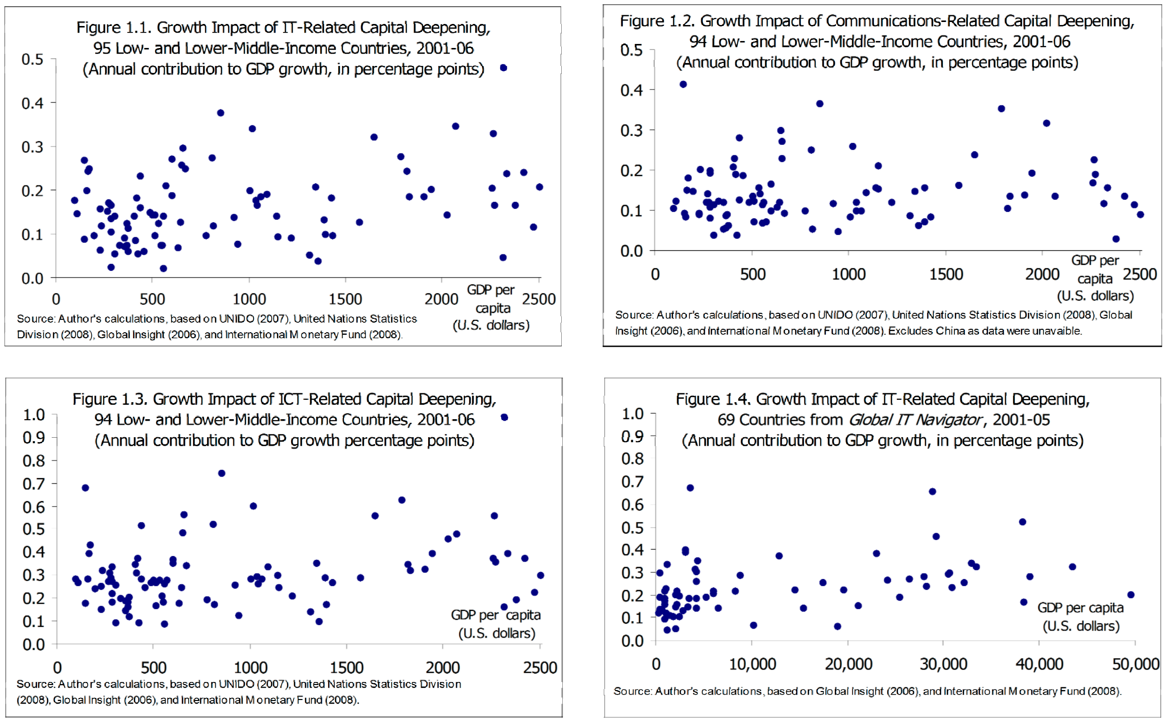

Figure 1 summarizes our findings on the country level.[17] We observe a very substantial variation in the growth impacts of ICT-related capital deepening across low- and lower-middle-income countries with similar levels of GDP per capita. For IT-related capital deepening, the growth impact appears to be correlated with GDP per capita, reflecting the clustering of low-income countries at a growth impact of less than 0.2 percentage points. For communications equipment, the pattern across countries is less clear. Figure 1.4 shows the growth impacts of IT-related capital deepening for the *Global IT Navigator* dataset. While Figure 1.4 suggests a positive link between the growth impact of IT-related capital deepening and GDP per capita, this largely reflects the differences between high- and upper-middle income countries on one hand, and low- and low-middle income countries on the other hand. However, our discussion of growth impacts of IT-related capital deepening across countries (as well as Figure 1.1), suggest that any relations suggested by Figure 1.4 could be misleading, owing to limited coverage of low- and lower-middle-income countries in the *Global IT Navigator* dataset.

[17] To facilitate comparisons between countries, Figure 1.1 and 1.2 are truncated at 0.6 percentage points, and Figure 1.3 does not show estimates exceeding 1.0 percentage points. As a result, the figures do not show estimates of the growth impact of IT-related capital deepening for Kiribati and Paraguay (the latter is also excluded from any averages or aggregates report in the present study, owing to severe inconsistencies in published trade data). Appendix Table 1 provides more detailed data, and also covers the 2 countries not shown in Figure 1.

Contribution of ICT-Related Capital Deepening to Growth, 1990-2006

While a steady-state analysis as presented in the previous section can yield important insights regarding the magnitude of the impacts of advances in ICTs on growth through ICT-related capital deepening, it is not well suited to identify the evolving impacts of ICTs over time, for two main reasons.

- First, the role of ICT equipment in the economy may change over time. Our analytical framework spells out a link between investment rates in ICT equipment and the elasticity of output with respect to ICT equipment. As investment in ICT equipment has generally accelerated over the period 1990, this also points to an increase in the elasticity of output with respect to ICT equipment.
- Second, the pace of innovation in ICTs, as measured by the rates of price decline of ICT equipment, is not constant. Our analysis interpreting innovations in ICTs as perturbations around a steady-state growth path suggests that the full impact of such perturbations evolve over time, and may involve long time lags. Applying a steady-state framework, in this context, results in exaggerations of the immediate impacts of an innovation, while missing out on the lagged impacts of previous innovations.

Data issues

At the outset, we drop several countries from the analysis, owing to data limitations. Afghanistan, Liberia, and Timor-Leste were dropped as GDP data were available only from 2000 (Liberia, Timor-Leste) or 2002. Lesotho, Namibia, and Swaziland were eliminated as the UN Comtrade database subsumes trade data for these countries under the Southern African Customs Union prior to 2000. For Kiribati, Paraguay, and São Tomé & Príncipe, complete data were available, but the countries were dropped from cross-country analysis as the series for ICT-related equipment were characterized by large outliers.[18]

For some countries, investment rates were not available; in these cases, we substitute the unweighted sample averages for investment rates for the respective year.[19] In some cases, macroeconomic data for the early 1990s were not available (largely former Yugoslav and Soviet republics). In these cases, we applied simple extrapolations for the missing data.

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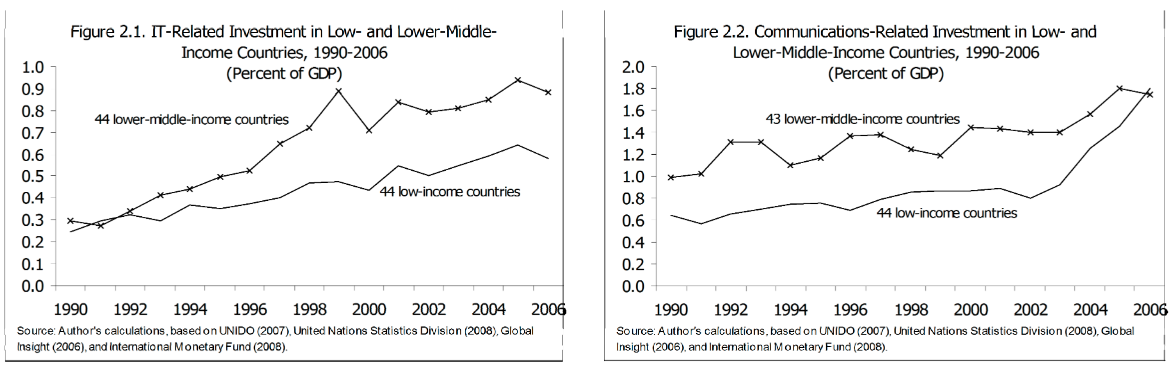
[18] For Paraguay, our estimates of IT equipment (based on net imports) rise from 2.8 percent of GDP to 17 percent of GDP by 2006. Interpretations of these trends are complicated by the fact that published trade data for Paraguay (self-reported or reported by partners in UN ComTrade database, international data like IMF (2008) show very substantial inconsistencies. The series for Kiribati (in 1992) and São Tomé & Príncipe (in 1994) show investment in communications equipment of around 30 percent in isolated years. While these may reflect very large communications investments (bearing in mind the small size of the economies), these outliers would have a dominant impact within the sample for the years indicated.

[19] The sample averages exclude Haiti and Macedonia, where investment rates in the IMF's World Economic Outlook database (IMF, 2008) exceed 100 percent of GDP for some years.

Elasticities of Output With Respect to ICT Capital

Below, we capture the (potentially) evolving aspects of the impact of advances in ICTs over time by allowing the elasticity of output with respect to IT and communications equipment to differ not only across countries, but also over time. Figure 2 illustrates the importance of allowing for changes in the role of ICT equipment over time. Overall, investments both in IT-related equipment and communications equipment roughly doubled as a percentage of GDP between 1990 and 2006. Figure 2 also suggests some notable differences in the evolution of the role of ICT equipment between low-income countries and lower-middle-income countries. Starting at about the same level, investments in IT-related equipment have accelerated markedly in lower-middle-income countries, as compared to low-income countries. At the same time, investment in communications equipment started out lower in low-income countries, but has accelerated markedly, notably since 2002, catching up with low-middle-income countries by 2006.[20]

Figure 2. ICT-Related Investment in Low-and Lower-Middle-Income Countries, 1990-2006



In light of the apparently shifting role of ICT equipment in low- and lower-middle-income countries, we allow for variations in the elasticities of output with respect to IT equipment and communications equipment over time (in addition to cross-country differences). However, some of the variation in investments in ICT equipment appears spurious or related to business cycles, rather than reflecting short-term fluctuations in the role of ICTs in the economy. To capture the variations over time and across countries, we calibrate the elasticities of output with respect to IT and communications equipment as

$$\alpha_{IT,jt} = c_{IT,j} \cdot (\kappa_{IT} + \lambda_{IT,t} \cdot t) \quad \text{and} \quad \alpha_{COM,jt} = c_{COM,j} \cdot (\kappa_{COM} + \lambda_{COM,t} \cdot t)\,. \qquad (36)$$

As a first step towards calibrating $\alpha_{IT,jt}$ and $\alpha_{COM,jt}$ (the elasticities of output with respect to IT equipment and communications equipment for country *j* at time *t*), elasticities were

[20] The increase in investment in communications equipment in low-income countries after 2002 cannot be attributed to specific outliers, but reflects substantial increases in a large number of low-income countries. While investment in communications equipment accelerated by at least 1 percent of GDP in 20 low-income countries between 2002 and 2006, it fell by at least 1 percent of GDP in only one country.

calculated for each country and each period, using the steady-state approximations discussed earlier (Eq. 20). Second, the linear trends $\kappa_{IT} + \lambda_{IT,t} \cdot t$ and $\kappa_{COM} + \lambda_{COM,t} \cdot t$ were obtained through regressions based on the sample averages for each period of the elasticities obtained in step 1. Third, the elasticities generated in step 1 were normalized and detrended by dividing them by the linear trends obtained in step 2. Fourth, the country-specific parameters $c_{IT,j}$ and $c_{COM,j}$ were obtained as the averages for each country of the detrended series obtained in step 3.[21] Concretely, we adopt the following specification:

$$\alpha_{IT,jt} = c_{IT,j} \cdot (0.0025 + 0.00022 \cdot t) \quad \text{and} \quad \alpha_{COM,jt} = c_{COM,j} \cdot (0.006 + 0.00018 \cdot t), \tag{37}$$[22]

which implies that the average elasticity of output with respects to IT capital has grown from 0.0025 in 1990 to 0.006 in 2006. Meanwhile, our estimates suggest that the average elasticity of output with respect to communications equipment has increased from 0.006 in 1990 to 0.009 in 2006.

Fluctuations in Rate of Decline of Relative Prices of ICT Equipment

Regarding the impact of changes in the prices of ICT equipment over time, our analytical framework – interpreting innovations in ICTs as shocks to the prices of ICT equipment – allows us to distinguish the immediate effect of a price shock on the capital stock and the transitional effects as the economy (notably, the capital-output ratio) gradually reverts towards its steady-state growth path following a shock. Figures 3 and 4 illustrate the relevance of this point. The annual rates of price decline for ICT equipment, notably for IT equipment, fluctuate considerably (Figure 3), ranging from 8.8 percent to 26.4 percent for IT equipment, and from 5.6 percent to 10.7 percent for communications equipment. Meanwhile, Figure 4 tracks the impact of a shock to relative prices of ICT equipment over time. The immediate impact accounts for only 50 percent of the long-run effects, and the subsequent adjustment is sluggish, with half of the (remaining) adjustment taking about 13 years. The persistence of the impacts of shocks to relative prices, as well as the fluctuations in the rate of price declines over time, thus validate our point that an analysis of the impacts of ICTs based on steady-state properties of the model may yield misleading results.

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[21] Taking logs and running a panel regression with a time trend would yield similar results. As most of our data are based on net imports, this would have required a reduction in the sample or other adjustments to take account of occasional negative values.

[22] The R^2 of the regressions estimating the linear trend in step 2 of our approach was 0.85 for the elasticity with respect to IT equipment and 0.47 for the elasticity with respect to communications equipment.

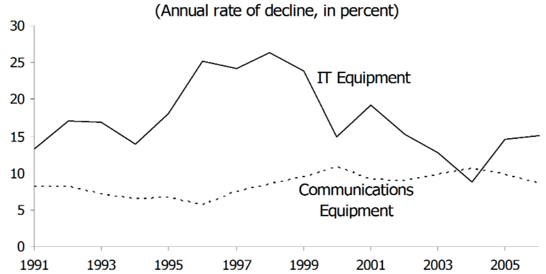


Figure 3. Rates of Price Decline of ICT Equipment, 1991-2006
(Annual rate of decline, in percent)

Source: Author's calculations, as described in text, based on data from U.S. Department of Commerce, Bureau of Economic Analysis (2008), U.S. Department of Labor, Bureau of Labor Statistics (2008), and Doms (2005).

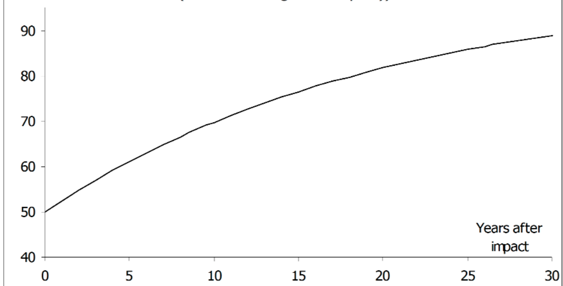


Figure 4. Impact of Shock to Relative Price of ICT Equipment Over Time
(Percent of long-term impact))

Source: Author's calculations, based on model and parameters described in text.

Estimating the Impacts of Advances in ICTs over Time

Our analysis of the impacts of advances in ICTs is based on the perturbation analysis developed above, in particular Eq. (33) and Eq. (23) which are repeated here for convenience.

$$\frac{\partial y_t}{y_{t-1}} = \gamma_t + \alpha \frac{(\delta+n+g)}{1+g} \sum_{i=0}^{\infty} \left[\left[\frac{1+\alpha g-(1-\alpha)(\delta+n)}{1+g} \right]^i \gamma_{t-1-i} \right], \text{ with} \tag{33}$$

$$\gamma_t = -\alpha_2 \partial p_{2,t} / p_{2,t-1}. \tag{23}$$

The validity of this approach rests on the extent to which shocks to relative prices of ICT equipment affect the steady-state growth path. Such changes to the steady-state growth path can occur if agents perceive a decline in the rate of price declines of ICT equipment. This would reduce the user cost of ICT capital, and agents would allocate a larger share of the capital stock to ICT capital. While our perturbation analysis is based on the capital stock in terms of the numeraire good (we account for the change in relative prices separately), such a reallocation would affect the rate of depreciation of the overall capital stock (a weighted average of the depreciation rates of ICT-related capital and non-ICT-related capital). However, the small share of ICT equipment in the capital stock suggests that any changes to the average rate of depreciation and thus the steady-state capital-output ratio (assumed constant in our perturbation analysis) would be very limited.

One issue that we need to address is the fact that our approach requires very long time series for prices of ICT equipment (see Eq. (33), Fig. (4)), beyond the beginning of the period of consideration. For IT equipment, we adopt the price index for "computers and peripheral equipment," a component of private nonresidential investment, from the U.S. National Income and Product accounts, which is available from 1960. For communications equipment, we do not have earlier price series, and apply a rate of price decline of 8 percent for earlier years, roughly in line with our estimates for the early 1990s. Regarding the elasticity of output with respect to ICT equipment (required to translate the original price shock into an output shock, see Eq. 23), extending our estimation backwards to cover years before 1990 increasingly results in problems regarding the availability of data. For this reason, we use our estimates of the respective elasticities for 1990 for the earlier periods.

Figure 5 and Table 3 summarize our estimates for the impacts of declining prices of ICT equipment on economic growth. (Appendix Table 2 provides the estimates for each of the 88 countries covered by our estimates.) The magnitude of the contributions of IT equipment and communications equipment to growth, respectively, are similar, rising from about 0.09 percent at the beginning of the period covered to 0.13 towards the end. While rates of investment in communications equipment are normally considerably higher than investment rates for IT equipment (according to Figure 2, by a factor of about 2 on average), the rates of price declines for IT equipment are higher (on average, exceeding the rates of price decline for communications equipment by a factor of about 2.2 over the 1990-2006 period), so that the magnitude of the growth effects are similar.

One interesting exception to this broad picture regards the years 1996-2000, in which the contribution of capital deepening arising from declining prices of IT equipment to growth peaks (and exceeds the contribution from communications equipment). This is the period which has motivated much of the early work on the economic impacts of advances in ICTs in the United States (e.g., Gordon (2000), Jorgenson (2001), or Oliner and Sichel (2000)). Our estimates are in line with this earlier literature (unsurprisingly, as our international price data are based on U.S. price indices). However, our distinction between the direct effects of shocks to prices of IT equipment and the indirect (and longer-term) effects through capital accumulation, which arise as the economy moves towards the steady-state growth path following a shock, provides a more differentiated picture, as the dampening impact on growth of the slowdown in the rate of decline of relative prices is partly offset by a gradual increase in the induced effects through capital accumulation.

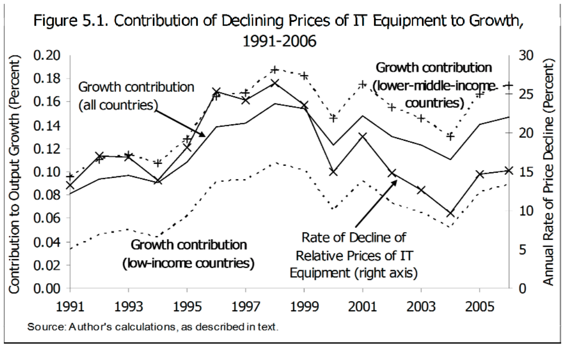
Regarding the role of the direct impacts of declining relative prices of equipment and the indirect effects through an induced acceleration in capital accumulation, we find that the magnitude of the direct and indirect effects is similar, in line with the steady-state properties of the model.[23] Almost all of the variations in the growth impacts of falling prices of ICT equipment on a year-to-year basis reflect the direct effects of changing prices, this is a mathematical necessity as the indirect effects can be represented as a distributed lag of past price shocks with a long memory (for typical parameters, we obtain a half-time of about 13 years). However, changes in the indirect impacts play some role over longer time horizons, and contribute about one-sixth to the acceleration of the growth impacts of advances in ICTs between 1990 and 2006.

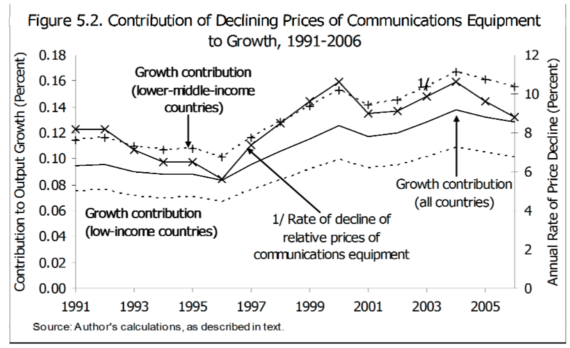
The lower part of Figure 5 (Figs. 5.5 and 5.6) summarize the overall growth effects of falling relative prices of ICT equipment for low- and lower-middle-income countries. Overall, the impacts are about one-third smaller in low-income countries, compared to lower-middle-income countries. Apart from the scale of the impact, the pattern of the impacts over time is similar between low- and lower-middle-income countries, owing to the fact that the

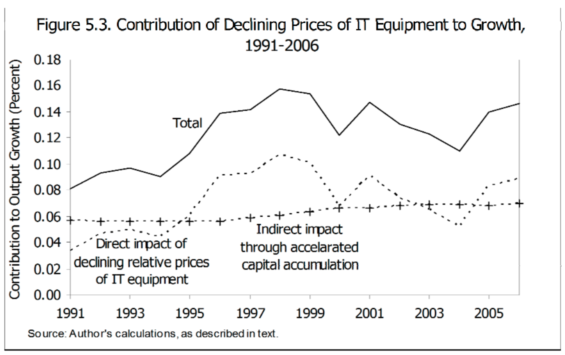
[23] See our discussion of Eq. (22). Our choice of a value of 0.5 for the parameter α implies that the size of the direct and indirect effects is equal in steady state.

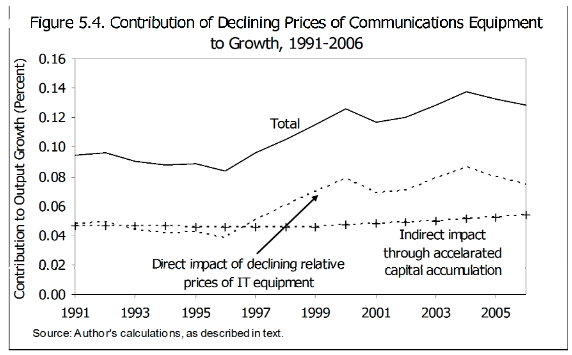
weights of investment in IT equipment are similar across these income groups, and our assumptions regarding the evolving role of ICT equipment, reflected in the modeling of the parameter α_2.

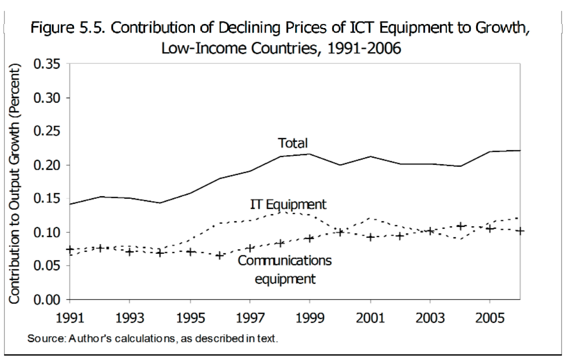
Figure 5. Impact of Declining Prices of ICT Equipment on Growth, 1990-2006











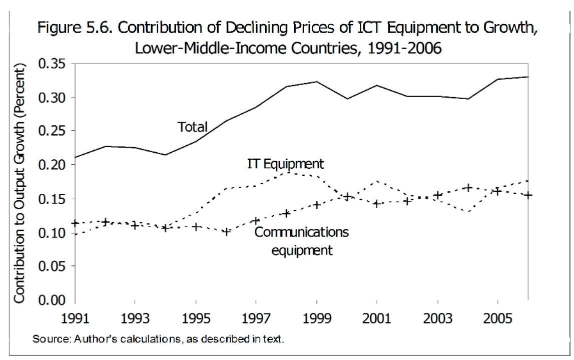


Table 3. Impact of ICT-Related Capital Deepening on Growth, Selected Countries, 1990-2006

Country	IT Equipment 1991-1995	IT Equipment 1996-2000	IT Equipment 2001-2006	Communications Equipment 1991-1995	Communications Equipment 1996-2000	Communications Equipment 2001-2006	Total ICT Equipment 1991-1995	Total ICT Equipment 1996-2000	Total ICT Equipment 2001-2006
Bangladesh	0.04	0.06	0.06	0.03	0.04	0.05	0.07	0.10	0.10
China,P.R.: Mainland[1]	0.14	0.22	0.21	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Egypt	0.03	0.04	0.04	0.07	0.08	0.09	0.09	0.12	0.13
Ethiopia	0.06	0.09	0.09	0.06	0.07	0.08	0.12	0.16	0.16
India	0.08	0.12	0.11	0.10	0.11	0.14	0.18	0.23	0.25
Indonesia	0.05	0.08	0.08	0.14	0.16	0.19	0.19	0.24	0.27
Nigeria	0.05	0.07	0.07	0.06	0.07	0.09	0.11	0.14	0.15
Pakistan	0.05	0.08	0.07	0.05	0.06	0.07	0.10	0.13	0.14
Philippines	0.09	0.14	0.13	0.21	0.24	0.29	0.30	0.39	0.43
Vietnam	0.09	0.14	0.13	0.14	0.16	0.20	0.23	0.30	0.33
Country groups (unweighted averages)									
All countries covered	0.09	0.14	0.13	0.09	0.11	0.13	0.19	0.25	0.26
Low-income countries	0.08	0.12	0.11	0.07	0.08	0.10	0.15	0.20	0.21
Lower middle-income-countries	0.11	0.17	0.16	0.11	0.13	0.15	0.22	0.30	0.31

Source: Author's calculations. See Appendix Table 2 for country-level estimates of all 88 countries covered by our analysis.

Finally, a few more words are in order about differences in the pattern of investment in IT and communications equipment over time, the estimates of the growth impacts of falling prices of ICT equipment obtained from the steady-state analysis, and the estimates from our analysis treating changes in relative prices of ICT equipment as perturbations to an economy moving along (or close to) a steady-state growth path. Conceptually, the key differences are that (1) while the steady-state analysis simply adds up the direct and the indirect impacts (through accelerated capital accumulation) of falling prices of ICTs, the indirect effects occur very slowly in the perturbation analysis, and (2) that the assumptions regarding the elasticity of output with respect to ICT capital differ.

We have already discussed the first of these points at some length. The second point also does have some consequences for our estimates, as a comparison of the results of the steady-state and the perturbation analysis shows. Low-income countries experienced a strong acceleration in investment in communications equipment after 2000. The calibrated elasticity of output with respect to communications equipment in the steady-state analysis, which is based on the behavior of key variables for that period only, reflects this acceleration. In our perturbation analysis, we allow the elasticities of output with respect to ICT equipment to change only slowly over time, allowing for a linear time trend. A temporary acceleration in the rates of investment in ICT equipment (the key determinant of our estimates of the respective elasticities) therefore has a modest impact on the calibrated elasticities in the perturbation analysis. For these reasons, the gap between the growth impacts of falling prices of communications equipment between low- and lower-middle-income countries is closer in the steady-state analysis than it is in the perturbation analysis.

V. ICT Production and Growth

Regarding the production of ICT equipment, the situation in low- and lower-middle-income countries is very different from the situation in OECD countries which has motivated most of the literature on the growth effects of advances in ICTs. While most OECD countries feature at least a small ICT-producing sector,[24] this applies to only a handful of low- and lower-middle-income countries. Partly for this reason, the few studies with a substantial coverage of non-OECD countries (notably, Bayoumi and Haacker (2002) and Jorgenson and Vu (2005a, 2005b, 2007)) have focused on the impacts of ICT-related capital deepening.[25] However, as production of ICT equipment does play an important role in some low- and lower-middle-income countries, an assessment of the growth effects of advances in ICTs in these countries would be incomplete without capturing the productivity gains on the production side.

Conceptually, estimating the (direct) contribution of productivity gains in the production of ICT equipment to growth is relatively straightforward. In terms of the framework developed above, the contribution of productivity gains in the ICT producing sector to growth can be calculated as

$$\frac{Y_2}{Y} \cdot \frac{\dot{A}_2}{A_2},$$

i.e., the rate of productivity gains in the ICT-producing sector (indexed "2") $\dot{A}_2 / A_2$, weighted by the sector's share in the economy Y_2 / Y.

One factor that is complicating the assessment of the contributions of productivity gains in the production of ICT equipment to growth is the fact that we know little about the inputs to the production of ICT equipment, notably inputs of certain ICT-related components which embody most of the technological advances and productivity gains in ICTs. Some of our production data are available on a gross basis only, while others identify value added and the costs of inputs, but not in a form that allows us to identify inputs of interest. In other words, we are not in a good position to distinguish a low-tech manufacturing plant which simply

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[24] See, for example, Bayoumi and Haacker (2002) for production volumes across a large number of countries, including developing economies, Pilat and Wölfl (2004) for the OECD, and Jorgenson (2005a, 2005b) or Jorgenson, Ho, and Stiroh (2005) for the G7.

[25] Additionally, Bayoumi and Haacker (2002) (and Pilat and Wölfl (2004), drawing on the former study), point out that the gains to producers largely dissipate owing to declining prices. This is particularly relevant if the bulk of ICT production is exported, as is the case in low- and lower-middle-income countries with an ICT-producing sector that is large relative to GDP.

assembles imported components, and a high-tech plant that produces electronic components embodying technological advances in ICTs.

To mitigate the problem, we include net exports of electronic microcircuits (SITC 2 category 7764) in our estimates of the production of ICT equipment. The advantages of doing so arise in two areas. First, as microcircuits are an integral part of ICT equipment, and arguably the commodity in which technological progress in ICT is most pronounced and clearly defined, including them in production statistics to measure the contribution of advances in the production of ICT equipment to growth makes sense. Second, as much of the technological advances in ICT equipment are embodied in microprocessors, controlling for net exports allows us to distinguish, to some extent, countries which largely assemble imported components from countries producing the commodities embodying the technological advances. At the same time, focusing on net exports rather than production of electronic microcircuits avoids double-counting of domestically produced electronic microcircuits which are used in the production of ICT equipment.

As explained in some detail elsewhere, and reflecting established practice in the literature, we are using the rate of decline of prices of ICT equipment as a measure of productivity gains in the production of ICT equipment, using data from the U.S. Producer Price Indices and the U.S. National Income and Product Accounts. For communications equipment, the deflators were modified, drawing on the work of Doms (2005).

Table 4 summarizes our findings on the contributions of the production of ICT equipment to growth. In most countries covered by Table 4 the growth impacts are miniscule, reflecting that we placed the bar for inclusion in the Table very low. The growth impact of the production of IT equipment exceeds 0.1 percentage points in only one low-income country (Vietnam), and 4 lower-middle-income countries. In three countries (China, Philippines, and Thailand), the impact of production of IT equipment on growth exceeds ½ percentage point at least in 2001-05.

The role of production of communications equipment is less pronounced, with a growth impact that exceeds 0.1 percentage points in only two countries (India, Indonesia) in 2001-05, although it had a larger impact in the Philippines and Thailand in the 1991-05 period. However, it is important to note that owing to data constraints the estimates on the role of communications equipment exclude China, a country for which informal calculations suggest that the growth impact of the production of communications equipment could also be around 0.2 percent in 2001-05.[26]

[26] China has been a net exporter of communications equipment since 2000, with net exports rising to about 1.5 percent of GDP by 2005. Including plausible values for domestic sales of communications equipment, this points to a level of domestic production of communications equipment that could exceed 2 percent, consistent with a growth contribution of 0.2 percentage points or more.

Table 4. Contribution of ICT Production to Growth, Selected Countries, 1990-2005
(Contribution to Annual GDP Growth, in Percentage Points)

	IT Equipment			Communications Equipment			Electronic Microcircuits (Net Exports)			Total		
Country	1991-1995	1996-2000	2001-2005	1991-1995	1996-2000	2001-2005	1991-1995	1996-2000	2001-2005	1991-1995	1996-2000	2001-2005
Low-Income Countries												
Kyrgyz Republic	0.03	0.01	0.01	0.00	0.01	0.02	0.00	0.00	0.00	0.03	0.02	0.02
Vietnam	0.00	0.23	0.15	0.00	0.10	0.00	0.00	-0.04	-0.09	0.00	0.29	0.06
Zimbabwe	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Lower-Middle-Income Countries												
Albania	0.00	0.03	0.05	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.03	0.04
China,P.R.: Mainland	0.07	0.27	0.51	n.a.	n.a.	n.a.	-0.02	-0.09	-0.21	n.a.	n.a.	n.a.
Egypt	0.00	0.01	0.00	0.02	0.03	0.03	0.00	0.00	0.00	0.03	0.04	0.03
India	0.05	0.06	0.04	0.07	0.09	0.11	0.00	-0.01	-0.01	0.12	0.15	0.14
Indonesia	0.04	0.23	0.20	0.07	0.22	0.20	0.00	0.02	0.01	0.11	0.47	0.41
Iran, I.R. of	0.01	0.03	0.01	0.03	0.10	0.06	0.00	0.00	0.00	0.03	0.13	0.07
Moldova	0.00	0.02	0.01	0.00	0.01	0.01	0.00	0.00	-0.01	0.00	0.03	0.01
Morocco	0.00	0.04	0.00	0.00	0.02	0.03	0.00	0.00	0.00	0.00	0.06	0.02
Peru	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Philippines	0.07	0.84	0.68	0.33	0.00	0.00	0.14	2.70	1.51	0.53	3.54	2.19
Sri Lanka	0.03	0.16	0.06	0.01	0.01	0.01	0.00	0.00	-0.01	0.03	0.16	0.06
Thailand	0.07	0.66	0.60	0.39	0.09	0.00	0.00	0.05	0.05	0.46	0.80	0.66
Ukraine	0.02	0.03	0.03	0.00	0.01	0.06	0.00	-0.02	-0.01	0.01	0.02	0.08
Memorandum Items												
Rate of decline in relative prices	-15.87	-22.99	-14.35	-7.30	-8.36	-9.65	-9.38	-19.77	-10.69	…	…	…

Source: Author's calculations, based on data from UNIDO (2007), Global Insight (2006), and United Nations Statistics Division (2008) for data on production, trade, or spending; IMF (2008) for data of GDP; U.S. Department of Commerce, Bureau of Economic Analysis (2008), U.S. Department of Labor, Bureau of Labor Statistics (2008), and Doms (2005) for data on prices of ICT products.

Incorporating data on net exports of electronic microcircuits in the analysis refines the findings regarding the growth impact of ICT-related production in two areas. First, for some countries (notably Vietnam and China), net imports of electronic microcircuits account for a substantial proportion of the value of production of ICT equipment, which suggests that these countries largely assemble ICT equipment from imported components.[27] Second, including net export of electronic microcircuits, Philippines – by some margin – emerges as the country where the role of production of ICT equipment is largest. In 2001-05, the total contribution of the production of ICT equipment to growth in Philippines amounted to 2.2 percentage points, of which net exports of electronic microcircuits accounted for 1.5 percentage points.

Finally, some notes on interpreting these findings. First, our estimates are based on price indices for the respective commodity categories from the United States. If the composition of production in our countries of interest differs substantially from the commodity bundles underlying the U.S. price indices, this would introduce some margin of error to our estimates. Second, to relate our estimates of the growth contribution of the production of ICT equipment to official data on GDP growth, it is necessary to know which deflators have been applied to the production of ICT equipment in the national accounts data. Only if national price indices fully reflect changes in the quality of ICT equipment is it possible to attribute a share of the growth rate of GDP to our estimated contributions from ICT-related production. If, at the other extreme, the national price indices do not capture changes in the quality of ICT products at all, then it would be necessary to correct the national estimates of GDP growth by adding our estimates of the growth contribution from productivity gains in the ICT-producing sector. Third, as pointed out earlier, it is important to bear in mind that a high contribution of ICT-related production to GDP – literally – does not buy much, as the productivity gains, regarding national income, dissipate owing to the terms-of-trade effect of falling prices of ICT products.

VI. Conclusions and Outlook

The first lesson from our analysis is that capital deepening related to technological advances in ICTs (i.e., falling relative prices of ICT equipment) matters in low- and low-middle-income countries. Overall, we estimate that between 1996 and 2006 the direct and indirect effects of falling prices of ICT equipment added about 0.2 percentage points to economic growth for low-income countries, and 0.3 percentage points for lower-middle-income countries. Relative to high-income countries, a preliminary analysis suggests that the growth impacts of falling prices of IT equipment in low-income countries are about one-half of the level attained in high-income countries, and about three-quarters in lower-middle-income countries. Regarding the relative roles of IT and communications equipment, we find that the

[27] This also applies to Albania, India, Moldova, Sri Lanka, and Ukraine, although the low levels of production there make it more difficult to assess the extent to which ICT production reflects the assembly of imported components.

magnitudes of the contributions to growth are similar – while investment in communications equipment is about double the level of investment in IT equipment, both in low- and in lower-middle-income countries, the relative prices of IT equipment decline at a faster rate, so that the overall impact comes out about the same.

A key obstacle to a comprehensive assessment of the economic role of ICTs in low- and lower-middle-income countries is the lack of sufficiently detailed national accounts data for most countries. To address this problem, we construct estimates of investment in ICT equipment based on trade data (and, where necessary, production data), addressing some shortcomings of existing databases in this area, and compiling a database covering essentially all low- and lower-middle-income countries. However, it is important to bear in mind that trade data are a noisy indicator for ICT-related spending, especially for small countries. Additionally, to account for costs which would be included in investment data, but are not captured in trade data, we estimate an mark-up to "translate" trade data into spending figures in a national accounts framework. While a necessary adjustment, this is also an additional source of noise, as we miss out on the variation in these mark-ups across countries.

The most important determinant of the link between falling prices of ICT equipment and the impact on economic growth is the elasticity of output with respect to ICT equipment. We estimate these elasticities based on a steady-state version of our analytical framework, imposing the condition that rates of return to capital be equal between different types of assets, and estimated investment data. A key challenge, to which we do not have a sound answer, is the interpretation of changes in investment rates, which may be spurious, reflect business cycles, or changes in the structure of the economy (i.e., in the elasticity of output with respect to capital). An explicit model deriving appropriate weights is beyond the scope of the present study – we use country fixed effects combined with a linear trend, as this is easily tractable and as we are not primarily interested in idiosyncrasies on the country level; other specifications that are built on an explicit model, giving more weight to year-to-year variations or difference across countries could yield improved estimates of the elasticities.

Finally, it is important to recall the limitations of our analysis. While it is true that benefiting from advances in ICTs does require the use of ICT equipment, and therefore the scale of the absorption of ICT equipment is an important indicator of the scale of the economic role of ICTs in an economy, the economic impacts are much broader, and differ systematically between countries. For example, in high-income countries, spending on IT-related services plays a much higher role than in low-income countries. On the other hand, ICTs have expanded the class of labor-intensive services that is tradable, and it is questionable whether investment in ICT equipment adequately captures the benefits from advances in ICTs in the economies exporting such services. Last, one specific feature of communication technologies (and of some aspects of information technologies) is that utilization of such technologies requires the existence of a related infrastructure (which is partly captured in our investment data), but also subscription to communication services, which means that the structure of the market for telecommunications services, which is characterized by imperfect competition, may affect the way in which advances in ICTs and falling international prices of ICT equipment affect national economies.

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Appendix Table 1. Contribution of ICT-Related Capital Deepening to Growth (Steady-State Analysis), 97 Countries, 2001-2006

	Invest-ment	IT Equip-ment	Communi-cations Equipment	Population growth	Real GDP Growth	Elasticity of output w.r.t. IT Equipment	Elasticity of output w.r.t. Communi-cations Equipment	Contribution to Growth: IT Equipment	Contribution to Growth: Communi-cations Equipment	Contribution to Growth: ICT Equipment (=IT+C)
	(Percent of GDP)			(Annual Growth, in Percent)				(Percentage Points)		
Low-Income Countries										
Afghanistan, I.R. of[1,2]	39.4	0.62	2.67	4.1	11.7	0.004	0.010	0.12	0.20	0.31
Bangladesh	23.9	0.52	0.91	1.9	5.7	0.004	0.005	0.11	0.09	0.20
Benin	18.1	0.43	0.69	3.3	4.1	0.003	0.004	0.09	0.07	0.16
Burkina Faso	17.8	0.42	0.56	3.2	6.1	0.003	0.003	0.09	0.05	0.14
Burundi	10.5	0.79	1.01	3.5	2.7	0.006	0.005	0.17	0.10	0.28
Cambodia	18.5	0.34	1.36	1.8	9.6	0.002	0.006	0.07	0.12	0.19
Central African Rep.	8.0	0.21	0.29	1.7	-0.2	0.002	0.002	0.05	0.04	0.09
Chad	35.4	0.28	0.48	3.6	12.3	0.002	0.002	0.05	0.04	0.09
Comoros	10.0	0.31	1.31	2.7	2.5	0.002	0.007	0.07	0.14	0.21
Congo, Dem. Rep. of	11.1	0.67	1.23	3.0	4.5	0.005	0.006	0.15	0.12	0.27
Côte d'Ivoire	9.9	0.39	0.77	1.7	0.0	0.003	0.005	0.09	0.10	0.19
Eritrea	24.3	1.12	1.75	4.1	2.0	0.009	0.009	0.25	0.18	0.43
Ethiopia	22.7	0.80	1.52	2.6	6.4	0.006	0.007	0.17	0.14	0.31
Gambia, The	24.7	0.62	2.05	3.1	4.6	0.005	0.010	0.13	0.20	0.33
Ghana	26.1	0.84	1.95	2.2	5.3	0.006	0.010	0.18	0.19	0.37
Guinea	12.8	0.25	0.54	1.9	2.9	0.002	0.003	0.06	0.06	0.12
Guinea-Bissau	12.8	0.84	0.69	3.1	-0.1	0.007	0.004	0.20	0.08	0.28
Haiti	27.5	0.24	1.50	1.6	-0.1	0.002	0.010	0.06	0.19	0.24
Kenya	17.3	0.64	1.32	2.6	4.0	0.005	0.007	0.14	0.13	0.27
Kyrgyz Republic	19.8	0.61	1.92	1.0	3.7	0.005	0.011	0.14	0.21	0.34
Lao People's Dem. Rep.	29.8	0.39	2.41	1.6	6.6	0.003	0.012	0.08	0.23	0.31
Liberia	...	1.06	3.15	2.6	-2.6	0.009	0.022	0.27	0.41	0.68
Madagascar	20.2	0.46	0.73	2.8	2.9	0.004	0.004	0.10	0.08	0.18
Malawi	18.6	1.08	1.41	2.6	2.8	0.008	0.008	0.24	0.15	0.39
Mali	18.6	0.35	0.90	3.0	6.2	0.003	0.004	0.07	0.08	0.16
Mauritania	37.5	0.65	1.23	2.9	5.2	0.005	0.006	0.14	0.12	0.26
Mozambique	21.6	0.82	1.35	2.4	8.7	0.006	0.006	0.17	0.12	0.28
Myanmar	11.9	0.44	1.12	0.9	12.8	0.003	0.005	0.09	0.09	0.18

(Continued)

Appendix Table 1. Contribution of ICT-Related Capital Deepening to Growth (Steady-State Analysis), 97 Countries, 2001-2006

	Invest-ment	IT Equip-ment	Communi-cations Equipment	Population growth	Real GDP Growth	Elasticity of output w.r.t. IT Equipment	Elasticity of output w.r.t. Communi-cations Equipment	Contribution to Growth: IT Equipment	Contribution to Growth: Communi-cations Equipment	Contribution to Growth: ICT Equipment (=IT+C)
	(Percent of GDP)			(Annual Growth, in Percent)				(Percentage Points)		
Nepal	19.1	0.73	0.99	2.1	3.4	0.006	0.006	0.16	0.11	0.27
Niger	16.7	0.29	0.94	3.6	5.3	0.002	0.005	0.06	0.09	0.15
Nigeria	25.0	0.36	1.34	2.5	10.2	0.002	0.006	0.07	0.11	0.18
Pakistan	16.4	0.58	1.20	1.8	5.3	0.004	0.006	0.13	0.12	0.25
Papua New Guinea	18.8	1.07	0.80	2.4	1.7	0.009	0.005	0.25	0.09	0.34
Rwanda	17.5	0.73	0.94	2.5	5.4	0.005	0.005	0.16	0.09	0.25
São Tomé & Príncipe[1]	…	1.09	3.04	1.7	6.5	0.008	0.015	0.23	0.28	0.51
Senegal	26.1	1.24	0.95	2.6	4.2	0.009	0.005	0.27	0.10	0.37
Sierra Leone	12.3	0.50	2.03	4.1	12.6	0.003	0.008	0.09	0.15	0.24
Solomon Islands	29.8	0.91	0.64	2.6	2.3	0.007	0.004	0.21	0.07	0.28
Tajikistan	14.6	0.11	2.22	1.2	9.0	0.001	0.010	0.02	0.19	0.22
Tanzania	21.1	0.67	1.24	2.6	7.0	0.005	0.006	0.14	0.11	0.25
Togo	12.5	0.31	1.11	2.9	1.7	0.002	0.006	0.07	0.12	0.19
Uganda	20.5	0.71	1.27	3.2	5.5	0.005	0.006	0.15	0.12	0.27
Uzbekistan	25.1	0.73	1.25	1.5	5.7	0.005	0.007	0.16	0.12	0.28
Vietnam	32.1	0.58	1.67	1.4	7.6	0.004	0.008	0.12	0.15	0.28
Yemen, Republic of	19.0	0.09	0.66	3.0	4.0	0.001	0.003	0.02	0.07	0.09
Zambia	22.0	0.65	1.22	1.9	5.0	0.005	0.006	0.14	0.12	0.26
Zimbabwe	6.5	0.49	0.68	0.7	-5.1	0.005	0.006	0.14	0.12	0.25
Lower-Middle-Income Countries										
Albania	25.3	0.82	1.33	0.5	5.5	0.006	0.007	0.18	0.14	0.32
Algeria	23.5	0.51	1.07	1.5	4.4	0.004	0.006	0.11	0.11	0.22
Angola	11.2	0.50	0.88	2.9	11.7	0.003	0.004	0.10	0.07	0.17
Armenia	24.2	0.82	1.14	-0.4	12.4	0.006	0.005	0.16	0.10	0.26
Azerbaijan, Rep. of	39.8	0.46	1.52	0.5	14.7	0.003	0.006	0.09	0.12	0.20
Bhutan	58.8	0.36	0.53	2.5	8.2	0.003	0.002	0.07	0.05	0.12
Bolivia	13.6	0.87	0.76	2.0	3.3	0.007	0.004	0.20	0.08	0.28
Bosnia & Herzegovina	26.4	1.54	1.26	0.6	4.8	0.012	0.007	0.34	0.13	0.48
Cameroon	18.5	0.52	0.50	2.3	3.6	0.004	0.003	0.12	0.05	0.17
Cape Verde	35.2	1.14	1.07	2.4	6.1	0.008	0.005	0.24	0.10	0.34

(Continued)

Appendix Table 1. Contribution of ICT-Related Capital Deepening to Growth (Steady-State Analysis), 97 Countries, 2001-2006

	Invest-ment	IT Equip-ment	Communi-cations Equipment	Population growth	Real GDP Growth	Elasticity of output w.r.t. IT Equipment	Elasticity of output w.r.t. Communi-cations Equipment	Contribution to Growth: IT Equipment	Contribution to Growth: Communi-cations Equipment	Contribution to Growth: ICT Equipment (=IT+C)
	(Percent of GDP)			(Annual Growth, in Percent)				(Percentage Points)		
China,P.R.: Mainland[3,4]	39.3	0.46	...	0.7	9.8	0.003	...	0.10	...	...
Colombia	17.2	0.91	1.60	1.5	3.9	0.007	0.009	0.20	0.17	0.37
Congo, Republic of	23.3	0.60	1.56	2.4	4.4	0.005	0.008	0.13	0.16	0.29
Djibouti	17.8	1.68	3.59	1.9	3.1	0.013	0.019	0.38	0.36	0.74
Dominican Republic	22.3	0.35	0.83	1.6	4.6	0.003	0.005	0.08	0.09	0.16
Ecuador	21.9	0.74	1.86	1.2	5.2	0.006	0.010	0.16	0.19	0.35
Egypt	17.4	0.23	0.80	1.8	4.2	0.002	0.004	0.05	0.08	0.14
El Salvador	16.1	1.03	1.40	1.5	2.6	0.008	0.008	0.24	0.16	0.39
Georgia	26.3	0.64	1.54	-1.0	7.7	0.005	0.008	0.14	0.15	0.29
Guatemala	18.8	0.90	1.87	2.5	3.4	0.007	0.010	0.20	0.19	0.39
Guyana	25.2	1.39	2.08	0.1	1.2	0.012	0.014	0.34	0.26	0.60
Honduras	24.7	0.86	1.42	2.0	4.9	0.007	0.007	0.19	0.14	0.33
India	27.1	0.88	1.76	1.6	7.0	0.006	0.009	0.19	0.16	0.35
Indonesia	21.5	0.41	1.48	1.3	4.9	0.003	0.008	0.09	0.15	0.24
Iran, I.R. of	28.2	0.21	1.12	1.0	5.6	0.002	0.006	0.05	0.11	0.16
Jordan	23.9	0.68	3.58	3.0	6.2	0.005	0.017	0.14	0.32	0.46
Kiribati[1]	...	3.36	2.72	1.8	2.1	0.026	0.016	0.76	0.30	1.06
Lesotho	34.0	0.64	1.08	0.9	3.6	0.005	0.006	0.15	0.12	0.26
Macedonia, FYR	16.9	1.37	1.88	0.2	1.8	0.011	0.012	0.33	0.22	0.55
Maldives	32.3	2.28	5.70	1.6	6.9	0.017	0.027	0.48	0.51	0.98
Moldova	20.9	1.14	2.19	-1.3	6.6	0.009	0.012	0.26	0.23	0.48
Mongolia	24.9	1.36	2.80	0.9	6.4	0.010	0.014	0.29	0.27	0.56
Morocco	26.5	0.57	1.59	1.1	5.4	0.004	0.008	0.13	0.16	0.29
Namibia	24.9	1.08	1.30	1.4	4.7	0.008	0.007	0.24	0.13	0.37
Nicaragua	26.8	1.19	2.32	1.3	3.3	0.009	0.013	0.27	0.25	0.52
Paraguay[4]	18.6	5.62	1.98	2.0	2.9	0.042	0.011	1.21	0.21	1.42
Peru	18.2	0.93	0.85	1.2	4.8	0.007	0.005	0.21	0.09	0.29
Philippines	16.5	0.84	0.96	2.1	4.6	0.006	0.005	0.18	0.10	0.28
Samoa[1]	...	1.42	2.23	0.7	4.3	0.011	0.012	0.32	0.24	0.55

(Continued)

Appendix Table 1. Contribution of ICT-Related Capital Deepening to Growth (Steady-State Analysis), 97 Countries, 2001-06 (concluded)

	Invest-ment	IT Equip-ment	Communi-cations Equipment	Population growth	Real GDP Growth	Elasticity of output w.r.t. IT Equipment	Elasticity of output w.r. t. Communi-cations Equipment	Contribution to Growth: IT Equipment	Contribution to Growth: Communi-cations Equipment	Contribution to Growth: ICT Equipment (=IT+C)
	(Percent of GDP)			(Annual Growth, in Percent)				(Percentage Points)		
Sri Lanka	24.2	0.76	1.11	0.4	4.5	0.006	0.006	0.17	0.12	0.29
Sudan	15.8	0.32	1.13	2.1	6.9	0.002	0.006	0.07	0.11	0.17
Swaziland	18.3	0.78	1.17	1.2	2.4	0.006	0.007	0.18	0.13	0.32
Syrian Arab Republic	21.7	0.16	0.57	2.7	3.5	0.001	0.003	0.04	0.06	0.09
Thailand	25.5	0.73	0.25	0.7	5.1	0.006	0.001	0.16	0.03	0.19
Timor-Leste[1]	...	0.55	0.52	5.3	0.2	0.004	0.003	0.12	0.06	0.18
Tonga[1]	...	1.15	3.07	0.3	2.3	0.009	0.019	0.27	0.35	0.63
Tunisia	23.9	0.53	1.23	1.1	4.6	0.004	0.007	0.12	0.13	0.25
Turkmenistan[1]	...	0.11	0.21	1.4	15.3	0.001	0.001	0.02	0.02	0.04
Ukraine	21.4	0.94	1.44	-0.8	7.6	0.007	0.008	0.20	0.14	0.35
Vanuatu[1]	...	0.79	0.75	2.6	1.9	0.006	0.004	0.18	0.08	0.26
Memorandum Items										
All countries[4]	22.1	0.74	1.39	1.9	5.1	0.006	0.007	0.162	0.139	0.301
LIC	20.2	0.6	1.3	2.5	4.8	0.005	0.007	0.131	0.128	0.259
LMC[4]	23.8	1.0	1.5	1.4	5.3	0.007	0.008	0.213	0.151	0.364

Source: Authors calculations, as described in text, based on data from IMF (2008), Global Insight (2006), and UN Statistics Division (2008).

[1] Investment rates were unavailable. Elasticities and contributions of ICT equipment to growth were estimated based on the sample average for investment rates (22.0 percent).

[2] For Afghanistan, data relate to 2002-2006

[3] For China, data on investment in communications equipment were unavailable.

[4] Totals exclude China (as estimates on investment in communications equipment were unavailable) and Paraguay (the latter owing to severe inconsistencies in published trade data).

Appendix Table 2. Contribution of ICT-Related Capital Deepening to Growth, 88 Countries, 1990-2006

Country	IT Equipment			Communications Equipment			Total ICT Equipment		
	1991-1995	1996-2000	2001-2006	1991-1995	1996-2000	2001-2006	1991-1995	1996-2000	2001-2006
Albania	0.14	0.22	0.20	0.03	0.03	0.04	0.17	0.25	0.24
Algeria	0.07	0.11	0.10	0.06	0.07	0.08	0.13	0.18	0.18
Angola	0.09	0.13	0.12	0.09	0.10	0.12	0.17	0.23	0.24
Armenia	0.07	0.11	0.10	0.10	0.12	0.14	0.17	0.22	0.24
Azerbaijan, Rep. of	0.06	0.09	0.08	0.27	0.31	0.37	0.33	0.40	0.46
Bangladesh	0.04	0.06	0.06	0.03	0.04	0.05	0.07	0.10	0.10
Benin	0.05	0.08	0.07	0.05	0.06	0.07	0.10	0.13	0.14
Bhutan	0.12	0.19	0.17	0.12	0.14	0.17	0.24	0.33	0.35
Bolivia	0.09	0.13	0.12	0.11	0.13	0.15	0.20	0.26	0.28
Bosnia & Herzegovina	0.14	0.21	0.20	0.08	0.10	0.12	0.22	0.31	0.32
Burkina Faso	0.07	0.11	0.10	0.04	0.05	0.06	0.11	0.16	0.16
Burundi	0.11	0.17	0.15	0.07	0.08	0.10	0.18	0.25	0.25
Cambodia	0.04	0.06	0.06	0.07	0.08	0.10	0.11	0.14	0.15
Cameroon	0.05	0.08	0.08	0.03	0.04	0.04	0.09	0.12	0.12
Cape Verde	0.17	0.26	0.24	0.12	0.14	0.17	0.29	0.40	0.41
Central African Rep.	0.05	0.07	0.07	0.04	0.05	0.06	0.09	0.12	0.12
Chad	0.04	0.07	0.06	0.04	0.05	0.06	0.08	0.11	0.12
China,P.R.: Mainland	0.14	0.22	0.21	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Colombia	0.12	0.18	0.17	0.10	0.12	0.14	0.22	0.30	0.31
Comoros	0.11	0.17	0.16	0.13	0.16	0.19	0.25	0.33	0.35
Congo, Dem. Rep. of	0.06	0.08	0.08	0.07	0.08	0.09	0.12	0.16	0.17
Congo, Republic of	0.09	0.14	0.13	0.07	0.08	0.10	0.16	0.22	0.23
Côte d'Ivoire	0.07	0.11	0.10	0.05	0.06	0.07	0.12	0.17	0.17
Djibouti	0.15	0.23	0.21	0.20	0.23	0.27	0.35	0.46	0.48
Dominican Republic	0.07	0.11	0.10	0.07	0.08	0.10	0.14	0.19	0.20
Ecuador	0.10	0.15	0.14	0.09	0.10	0.13	0.19	0.26	0.27
Egypt	0.03	0.04	0.04	0.07	0.08	0.09	0.09	0.12	0.13
El Salvador	0.13	0.20	0.19	0.08	0.10	0.12	0.21	0.29	0.30
Eritrea	0.08	0.12	0.12	0.09	0.10	0.12	0.17	0.22	0.24
Ethiopia	0.06	0.09	0.09	0.06	0.07	0.08	0.12	0.16	0.16
Gambia, The	0.11	0.17	0.16	0.15	0.17	0.21	0.26	0.34	0.37
Georgia	0.07	0.10	0.09	0.08	0.10	0.11	0.15	0.20	0.21
Ghana	0.09	0.14	0.13	0.09	0.11	0.13	0.19	0.25	0.26
Guatemala	0.11	0.17	0.16	0.10	0.11	0.13	0.21	0.28	0.30
Guinea	0.04	0.06	0.05	0.05	0.05	0.07	0.09	0.11	0.12
Guinea-Bissau	0.13	0.20	0.19	0.08	0.09	0.11	0.22	0.30	0.30
Guyana	0.21	0.31	0.29	0.19	0.22	0.27	0.40	0.54	0.56
Haiti	0.03	0.05	0.05	0.06	0.07	0.09	0.10	0.12	0.13
Honduras	0.14	0.22	0.20	0.09	0.10	0.12	0.23	0.32	0.33
India	0.08	0.12	0.11	0.10	0.11	0.14	0.18	0.23	0.25
Indonesia	0.05	0.08	0.08	0.14	0.16	0.19	0.19	0.24	0.27
Iran, I.R. of	0.03	0.05	0.05	0.10	0.12	0.14	0.14	0.17	0.19
Jordan	0.10	0.16	0.15	0.14	0.16	0.19	0.24	0.32	0.34
Kenya	0.08	0.12	0.11	0.09	0.10	0.12	0.16	0.22	0.23
Kyrgyz Republic	0.10	0.16	0.14	0.11	0.13	0.16	0.22	0.29	0.30
Lao People's Dem.Rep	0.04	0.07	0.06	0.10	0.12	0.15	0.15	0.19	0.21
Macedonia, FYR	0.21	0.31	0.29	0.13	0.15	0.18	0.34	0.46	0.47
Madagascar	0.06	0.09	0.08	0.05	0.05	0.07	0.11	0.14	0.15
Malawi	0.13	0.19	0.18	0.10	0.12	0.14	0.23	0.31	0.32
Maldives	0.22	0.33	0.31	0.29	0.33	0.41	0.51	0.66	0.72

(Continued)

Appendix Table 2. Contribution of ICT-Related Capital Deepening to Growth, 88 Countries, 1990-06

Country	IT Equipment 1991-1995	IT Equipment 1996-2000	IT Equipment 2001-2006	Communications Equipment 1991-1995	Communications Equipment 1996-2000	Communications Equipment 2001-2006	Total ICT Equipment 1991-1995	Total ICT Equipment 1996-2000	Total ICT Equipment 2001-2006
Mali	0.04	0.06	0.06	0.04	0.04	0.05	0.08	0.11	0.11
Mauritania	0.07	0.11	0.10	0.07	0.08	0.10	0.14	0.19	0.19
Moldova	0.18	0.27	0.24	0.09	0.11	0.13	0.28	0.38	0.37
Mongolia	0.12	0.18	0.17	0.16	0.19	0.22	0.28	0.37	0.39
Morocco	0.09	0.14	0.13	0.10	0.11	0.13	0.19	0.25	0.26
Mozambique	0.10	0.15	0.14	0.08	0.09	0.11	0.17	0.24	0.25
Myanmar	0.05	0.08	0.08	0.07	0.08	0.10	0.12	0.16	0.18
Nepal	0.08	0.13	0.12	0.05	0.06	0.07	0.14	0.19	0.19
Nicaragua	0.17	0.26	0.24	0.13	0.15	0.18	0.30	0.41	0.42
Niger	0.05	0.08	0.08	0.04	0.04	0.05	0.09	0.12	0.13
Nigeria	0.05	0.07	0.07	0.06	0.07	0.09	0.11	0.14	0.15
Pakistan	0.05	0.08	0.07	0.05	0.06	0.07	0.10	0.13	0.14
Papua New Guinea	0.16	0.24	0.22	0.06	0.07	0.08	0.22	0.31	0.30
Peru	0.12	0.18	0.17	0.07	0.08	0.10	0.19	0.26	0.27
Philippines	0.09	0.14	0.13	0.21	0.24	0.29	0.30	0.39	0.43
Rwanda	0.06	0.09	0.09	0.06	0.07	0.08	0.12	0.16	0.17
Samoa	0.21	0.32	0.30	0.15	0.17	0.20	0.36	0.49	0.50
Senegal	0.11	0.17	0.16	0.06	0.06	0.08	0.17	0.24	0.24
Sierra Leone	0.14	0.21	0.19	0.12	0.14	0.17	0.26	0.35	0.36
Solomon Islands	0.13	0.20	0.19	0.08	0.09	0.11	0.21	0.29	0.29
Sri Lanka	0.09	0.14	0.13	0.09	0.10	0.12	0.18	0.25	0.26
Sudan	0.04	0.06	0.06	0.05	0.05	0.07	0.09	0.11	0.12
Syrian Arab Republic	0.02	0.03	0.03	0.04	0.05	0.05	0.06	0.08	0.08
Tajikistan	0.01	0.02	0.02	0.08	0.09	0.11	0.10	0.12	0.13
Tanzania	0.08	0.12	0.11	0.07	0.08	0.10	0.15	0.20	0.21
Thailand	0.09	0.14	0.13	0.17	0.20	0.24	0.27	0.34	0.38
Togo	0.06	0.10	0.09	0.08	0.09	0.10	0.14	0.18	0.19
Tonga	0.17	0.26	0.25	0.15	0.17	0.20	0.32	0.43	0.45
Tunisia	0.11	0.16	0.15	0.07	0.08	0.09	0.17	0.24	0.25
Turkmenistan	0.02	0.03	0.02	0.05	0.05	0.07	0.06	0.08	0.09
Uganda	0.07	0.11	0.11	0.05	0.06	0.07	0.13	0.17	0.18
Ukraine	0.13	0.20	0.18	0.09	0.11	0.13	0.23	0.31	0.31
Uzbekistan	0.06	0.09	0.08	0.08	0.09	0.11	0.14	0.18	0.19
Vanuatu	0.17	0.26	0.24	0.11	0.13	0.16	0.28	0.39	0.40
Vietnam	0.09	0.14	0.13	0.14	0.16	0.20	0.23	0.30	0.33
Yemen, Republic of	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.07	0.08
Zambia	0.13	0.20	0.19	0.08	0.09	0.11	0.21	0.29	0.30
Zimbabwe	0.13	0.19	0.17	0.11	0.13	0.15	0.24	0.32	0.33
Country groups (unweighted averages)									
All countries covered	0.09	0.14	0.13	0.09	0.11	0.13	0.19	0.25	0.26
LIC	0.08	0.12	0.11	0.07	0.08	0.10	0.15	0.20	0.21
LMC	0.11	0.17	0.16	0.11	0.13	0.15	0.22	0.30	0.31

Source: Author’s calculations.

DATA APPENDIX

Production of ICT Equipment

Where not stated otherwise, data are based on the UNIDO *Industrial Statistics Database* (UNIDO, 2007), which provides data on industrial output and value added by ISIC category. The categories of interest are ISIC 3 (i.e., ISIC, Rev. 3) category 3000 ("manufacture of office, accounting, and computing machinery") and the earlier ISIC 2 (i.e., ISIC, Rev. 2) category 3825 (with the same label) for IT equipment, and ISIC 3 category 30 ("manufacturing of radio, television, and communication equipment and apparatus").[28] For some countries, the data are available in ISIC 3 classification from the early 1990s; for most low- and middle-income countries the transition occurred in the late 1990s. While the categories coincide by title, merging ISIC 2 and ISIC 3 series is not a trivial exercise – for countries where the series overlap, discrepancies may occur between the "matching" categories.

While the UNIDO *Industrial Statistics Database* may include the major producers of ICT equipment, the limited coverage of low-income countries (and, to a lesser extent, lower-middle-income countries) is problematic for or purposes. For this reason, we also analyze trade data (from United Nations Statistics Division, 2008) in order to identify additional countries which may produce ICT equipment. This analysis of trade data points to three countries not covered by UNIDO (2007) that could be producers – China, Thailand, and Tunisia. In two cases, production data from UNIDO (2007) are inconsistent with trade data – for Indonesia, UNIDO (2007) shows trivial quantities of production of IT equipment, even though trade data show significant net exports of IT equipment since 1994. Conversely, UNIDO (2007) shows production of ICT equipment for Macedonia exceeding 4 percent of GDP in 1997-2000, even though the country does not export such equipment (exports of less than 0.02 percent of GDP). In both cases, our estimates are based on trade data (as these are also validated by partner countries).

Appendix Tables 3 and 4 summarize the production data used in our analysis for the years 1990-2005. Gaps between annual observations in UNIDO (2007) data were filled by intrapolation (data in italics). For China and Indonesia, data on production of ICT equipment are based on trade data from United Nations Statistics Division (2008) and data on domestic spending from WITSA (2001) and Global Insight (2006).

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[28] Alternative sources of data on the production of ICT equipment are the *Yearbook of Electronics Data* by Reed Electronics Research (2008), providing data well aligned with our objectives, but only for a small number of low- and low-middle-income countries, and UNIDO (2008). Regarding the latter, a key commodity of interest, IT equipment, is available only included in the wider category "office, accounting, and computing machinery" (ISIC, Rev. 3, category 3000). While this wider category is dominated by IT equipment in recent years, the share declines as we go back in time, and this would introduce an additional source of error to our analysis.

Appendix Table 3. Production of IT Equipment in Low- and Lower-Middle Income Countries, 1990-2005 (Percent of GDP)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Low-income countries																
India	0.20	0.28	0.30	0.17	0.31	0.29	0.27	0.29	0.12	0.14	0.22	0.23	0.20	0.24	*0.24*	*0.24*
Kyrgyz Republic	0.06	0.05	0.14	0.17	0.02	0.04	0.03	0.04	0.03	0.02	0.11	0.09	0.07	0.02	0.02	*0.02*
Vietnam	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	1.14	*1.37*	1.60	0.53	0.66	0.99	1.04	*1.04*
Zimbabwe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Lower-middle-income countries																
Albania	*0.00*	*0.00*	*0.00*	0.00	0.00	0.00	0.00	0.00	0.19	0.16	0.13	0.73	0.10	0.12	0.17	*0.17*
China,P.R.: Mainland	*0.26*	*0.26*	*0.32*	*0.20*	*0.41*	*0.52*	*0.64*	*0.83*	*0.96*	*0.98*	*1.31*	*1.62*	*2.20*	*3.39*	*4.33*	*4.70*
Egypt	0.00	0.02	0.00	0.02	0.02	0.01	*0.03*	0.06	0.05	*0.04*	*0.03*	*0.02*	0.01	*0.01*	*0.01*	*0.01*
Indonesia	*0.03*	*0.08*	*0.15*	*0.14*	*0.23*	*0.32*	*0.42*	*0.46*	*0.70*	*0.83*	*1.95*	*1.42*	*1.29*	*0.92*	*1.14*	*1.01*
Iran, I.R. of	*0.00*	0.00	0.01	0.01	0.06	0.03	0.05	0.08	0.08	0.08	0.10	0.08	0.05	0.03	*0.03*	*0.03*
Macedonia, FYR[1]	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Moldova	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	0.05	0.10	0.05	0.09	0.04	0.04	0.08	0.12	0.07	*0.07*
Morocco	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	0.19	0.17	0.10	0.12	0.00	0.00	0.00	0.00	0.01	*0.01*
Peru	0.04	0.09	0.02	*0.02*	0.03	0.00	0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Philippines	0.02	0.04	0.06	0.40	0.47	0.80	0.92	1.18	3.77	4.21	*4.37*	4.53	*4.10*	3.66	*3.66*	*3.66*
Sri Lanka	0.01	0.00	0.00	0.12	0.14	0.29	0.00	0.54	0.52	0.94	0.53	0.31	*0.31*	*0.31*	*0.31*	*0.31*
Thailand	0.00	0.07	*0.08*	0.09	0.01	*1.37*	2.73	*1.99*	1.25	*2.26*	3.28	*3.89*	*3.31*	*3.21*	*3.20*	*3.90*
Ukraine	*0.00*	*0.00*	0.77	0.21	0.16	0.10	0.05	0.13	0.07	0.11	0.23	0.18	0.21	0.18	0.28	*0.28*
Memorandum items:																
Share of IT production in ISIC Rev. 3 category 3000[2]	78.6	77.9	75.2	82.5	77.0	85.4	85.4	86.2	87.2	86.4	88.5	86.4	89.5	90.2	89.9	89.8
Macedonia, FYR: Production of IT and office equipment (UNIDO, 2007)						0.00		4.03	4.28	4.00	3.89	3.59	1.57	1.13	0.99	
Macedonia, FYR: Exports of IT Equipment				0.03	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.03	0.01

Source: Author's calculations, based on data from UNIDO (2007), UN Statistics Division (2008), and IMF (2008), except for China (1990-2005) and Thailand (2001-2005), which are not covered by UNIDO (2007). For these two countries, estimates have been constructed based on data on net exports from UN Statistics Division (2008), and spending data from Global Insight (2006) and WITSA (2001).

[1] For Macedonia, trade data (both reported by Macedonia and corresponding data from partner countries were inconsistent with production data in UNIDO 2007). Our estimates follow the trade data, assuming that the level of production is equal to zero. Source data for production and trade are shown under memorandum items.

[2] The assumed share of IT equipment in production in ISIC Rev. 3 category 3000 (IT and office equipment) for each country is based on the share of IT equipment (SITC 2 categories 752 and 7599) in gross exports in SITC category 75 (office machines and automatic data processing equipment) for that country. For orientation purposes, we show the unweighted average of these shares (which was also used to scale the estimates for Peru, as no trade data were available for that country).

Appendix Table 4. Production of Communications Equipment in Low- and Lower-Middle Income Countries, 1990-2005 (Percent of GDP)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Low-income countries																
India	0.80	0.84	0.99	0.83	1.05	1.02	0.90	1.11	1.04	1.00	0.98	0.82	1.18	1.06	*1.06*	*1.06*
Kyrgyz Republic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.15	0.15	0.17	0.19	0.10	0.18	*0.18*
Vietnam	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	1.54	*1.58*	1.63	0.00	0.00	0.00	0.00	*0.00*
Zimbabwe	0.21	0.22	0.20	0.16	0.19	0.20	0.14	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Lower-middle-income countries																
Albania	*0.00*	*0.00*	*0.00*	0.11	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*
China,P.R.: Mainland	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Egypt	0.16	0.24	0.34	0.31	0.28	0.41	*0.35*	0.29	0.36	*0.33*	*0.30*	*0.28*	0.25	*0.25*	*0.25*	*0.25*
Indonesia	0.49	0.43	0.86	0.81	1.06	1.41	1.65	2.16	2.35	2.16	3.11	1.59	1.72	1.96	*1.96*	*1.96*
Iran, I.R. of	*0.34*	0.34	0.34	0.35	0.40	0.23	0.39	0.65	0.89	1.26	1.65	1.47	0.47	0.39	*0.39*	*0.39*
Macedonia, FYR	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	0.00	*0.00*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*
Moldova	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	0.65	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.15	*0.15*
Morocco	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	0.16	0.21	0.20	0.02	0.40	0.23	0.23	0.25	0.28	*0.28*
Peru	0.31	0.28	0.42	*0.24*	0.05	0.03	0.03	*0.03*	*0.03*	*0.03*	*0.03*	*0.03*	*0.03*	*0.03*	*0.03*	*0.03*
Philippines	3.07	3.92	4.08	3.78	4.15	4.87	0.00	0.00	0.00	0.00	*0.00*	0.00	*0.00*	0.00	*0.00*	*0.00*
Sri Lanka	0.07	0.13	0.07	0.03	0.10	0.10	0.10	0.08	0.10	0.13	0.11	0.09	*0.09*	*0.09*	*0.09*	*0.09*
Thailand	3.51	6.62	*5.87*	5.13	2.62	*3.51*	4.41	*2.20*	0.00	*0.00*	0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Ukraine	*0.00*	*0.00*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.54	0.49	0.51	0.66	*0.66*

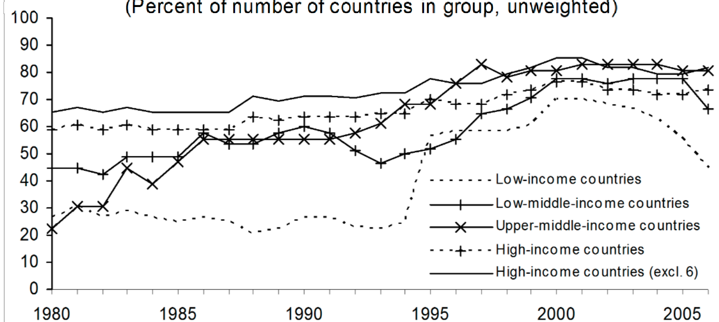
Source: Author's calculations, based on data from UNIDO (2007) and IMF (2008).

Data on Trade in ICT Equipment

In the absence of national accounts data on ICT-related spending, and the limited coverage of other databases on ICT-related spending across developing countries, trade data (taken from United Nations Statistics Division, 2008) are the principal source of data for constructing a dataset on absorption of ICT-related equipment in low- and lower-middle-income countries. However, the availability of trade data from low-income countries is also limited, and time series of trade data often exhibit missing years. Where data are unavailable, we therefore construct data based on partner country trade records.

As measures of IT equipment, we focus on SITC 2 categories 752 (automatic data processing equipment) and 7599 (parts and accessories pertaining equipment in category 752), corresponding to HS 2002 categories 8471 and 847330.[29] For some purposes (the discussion of gains in the production of ICT-related equipment), we also look at SITC 2 category 7764 (electronic microcircuits). The measure of communications equipment we adopt is SITC 2 category 764 (telecommunication equipment, parts and accessories).

Figure A1. Availability of Trade Data by Country Group, 1980-2006
(Percent of number of countries in group, unweighted)



Sources: Author's calculations, based on UN Comtrade database. "High-income countries (excl. 6)" excludes 6 small economies for which trade data are reported as part of the statistics of the surrounding economies. Countries are included in the denominator from the first full calendar year after independence.

The availability of detailed trade data for low- and low-middle-income countries has improved substantially in recent years. Figure A1 illustrates the availability of trade data (SITC 2 classification) from the COMTRADE database (United Nations Statistics Division, 2008). Most notably, the availability of data for low-income countries has increased dramatically around the mid-1990s (a trend that owes much to improved access to ICTs in developing countries), from around 30 percent for which data are available to over 60 percent. However, data reporting for these countries appears to be subject to delays, as

[29] Most countries now report data in "HS 2002" or "HS 1998" format. We adopt the older "SITC 2" classification, because it captures the categories of IT equipment we are interested in fairly well, and allows us to construct a dataset that extends back to 1980. Some studies (e.g., Caselli and Coleman, 2001) focus on SITC category 752 only, presumably because category 7599 is considered an intermediate input. This interpretation, however, is inconsistent with observed trade patterns, with (net) commodity flows in categories 7599 broadly parallel to trade flows in category 752.

evident from the drop in the number of countries for which data are available in the later years. Also, data series are frequently incomplete, especially for low-income countries.

One method researchers have attempted to get around breaks in trade data is the substitution of partner country data for missing country observations. This principle has been applied by Feenstra and others (2005) to construct a data set of bilateral trade flows for 1962-2000. However, the dataset constructed by Feenstra and others has several shortcomings regarding our purposes. Most substantially, it is based only on trade data from only 72 countries accounting for 98 percent of overall world exports. While these include the largest trading countries, the coverage of low- and lower-middle-income countries is limited. Second, we focus on a much narrower set of trade data than Feenstra and others (2005), which gives us an opportunity to scrutinize the data of interest in more detail. Third, as evident from Figure A1, the data of interest are now available through 2006 for most countries.

In summary, in light of the available data, our dataset is constructed as follows:

- We use data as reported by countries of interest (low- and lower-middle-income countries) where available; and
- For non-reporting countries, we use proxies created by adding up the corresponding trade flows from reporting countries, but scale them to account for the share of non-reporting countries in recorded trade (compare Fig. A1).[30]

Spending on ICT Equipment

In order to determine the contribution of ICT-related equipment to capital deepening, we need data on investment in ICT-related equipment consistent with aggregate national accounts data. For countries we identified as **non-producers** of the respective categories of ICT equipment, our measures of ICT equipment investment are based on trade data. However, investment data would include components which are not included in trade data. First, the trade data we use are available on a fob ("free on board") basis, and do not include insurance, freight, and related costs. Additionally, the importer bears the costs of customs clearance, and would be liable to pay import tariffs. Additionally, other indirect taxes may apply (value added tax, sales tax, and excise taxes), and final expenditure data would also include costs incurred on the retail level, in addition to any profit margins.

To obtain estimates of applicable mark-ups to transform trade data into expenditure figures, we compare data on spending on IT equipment from Global Insight (2006), available

[30] Scaling the proxies to account for the share of non-reporting countries removes trends in estimates constructed from partner country data that simply reflect an increase in the share of directly reported trade in global trade flows. However, it is worth noting that our scaling method implies an assumption that for non-reporting countries the share of trade with reporters and non-reporters is the same as the corresponding shares for reporting countries.

for 14 low- and low-middle-income countries we classify as non-producers,[31] with net imports of IT equipment for these countries. On average, spending on IT hardware from Global Insight (2006) exceeds net imports of IT equipment by 72 percent, and this is the mark-up we will be adopting both for IT equipment and communications equipment.[32] To obtain estimates of ICT equipment investment for **non-producers** of such equipment, we therefore apply the following rules:

- For IT equipment, we adopt data from Global Insight (2006) and WITSA (2001) on IT equipment spending where available. For other countries, we generate estimates of spending on IT equipment by applying a markup of 72 percent to net imports in SITC categories 752 and 7599.
- For spending on communications equipment, where domestic spending figures are unavailable, we apply the same mark-up of 72 percent to imports in SITC 2 category 764.

For **producers** of ICT equipment, this approach need to be modified somewhat

- We adopt data from Global Insight (2006) and WITSA (2001) on spending on IT equipment where available.[33]
- For spending on communications equipment, or spending on IT equipment for the countries where spending data are unavailable,[34] we apply the same mark-up as for non-producers (72 percent) to net imports of IT equipment.
- We obtain estimates of ICT-related spending as the sum of the relevant net imports (plus markup) and of estimated production levels at face value.[35]

Prices of ICT Equipment

Hedonic price indices are widely regarded as the preferred method for constructing price indices for ICT products, owing to the rapid technological change in the sector and the

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[31] Bangladesh, Bolivia, Cameroon, Colombia, Ecuador, Honduras, Jamaica, Jordan, Kenya, Pakistan, Peru, Senegal, Tunisia, Zimbabwe.

[32] Data on spending on communications equipment are not available from Global Insight (2006); the relevant category there also includes services.

[33] This applies to China, Egypt, India, Indonesia, Iran, Morocco, Philippines, Sri Lanka, Thailand, and Ukraine.

[34] For 1999-2005, this applies to Albania, Kyrgyz Republic, and Vietnam. For 1990-1998, it applies to the same three countries, as well as Iran, Moldova, and Peru.

[35] The zero mark-up applied to domestic production reflects two considerations. Some mark-up would need to be applied to translate domestic production figures into domestic spending. At the same time, our net import data may include some intermediates, which would necessitate a deduction from the production values in order to avoid double-counting.

evolving specifications of ICT products. Working Party on Indicators for the Information Society (2005) recommends the use of hedonic indices for ICT equipment, and U.S. National Income and Product Accounts and Producer Price Indices employ hedonic indices for key categories of IT equipment, although less so for communications equipment (see Grimm and others, 2005).

Following common practice in cross-country studies of the impact of ICT-related capital deepening, our data on the decline in relative prices of ICT equipment are generally based on U.S. national accounts data (Appendix Table 5), and are measured by the relevant price indices relative to the CPI. However, for the underlying price indices for communications equipment, we follow Doms (2005), a study that has been recognized (e.g., by Jorgenson, 2005) as a major improvement in measuring changes in prices of communications equipment.

Appendix Table 5. Relative Prices of ICT Equipment, 1990-2006 (1990=100)

Year	NIPA: Investment: Computers and peripheral equipment	PPI: Communication and related equipment	Communication and related equipment (based on Doms, 2005)	PPI: Integrated microcircuits
1990	100.0	100.0	*100.0*	100.0
1991	86.7	97.7	*91.8*	85.3
1992	71.9	95.4	*84.3*	73.4
1993	59.7	94.3	*78.3*	70.1
1994	51.4	93.8	73.2	69.7
1995	42.1	92.9	68.4	61.1
1996	31.5	91.6	64.6	46.4
1997	23.9	90.9	59.8	34.4
1998	17.6	90.2	54.7	25.0
1999	13.4	87.6	49.5	22.7
2000	11.4	83.9	44.2	20.3
2001	9.2	81.4	*40.2*	16.1
2002	7.8	78.8	*36.6*	14.3
2003	6.8	75.8	*33.0*	13.6
2004	6.2	72.3	*29.5*	12.5
2005	5.3	69.7	*26.6*	11.5
2006	4.5	67.7	*24.3*	10.4

Source: Author's calculations, as described in text, based on data from U.S. Department of Commerce, Bureau of Economic Analysis (2008), U.S. Department of Labor, Bureau of Labor Statistics (2008), and Doms (2005). Underlying indices have been divided by the CPI and scaled so that 1990 values = 100. Estimates from Doms (2005) were available for 1994-2000 only. For 1990-93 and 2001-06 (numbers shown in italics), the series were extrapolated, assuming that the price index for communication equipment declines at a rate that is 6 percent faster than in the PPI statistics.

Other data and country coverage

Data on **GDP** (in millions of U.S. dollars) and **GDP per capita** (in U.S. dollars) were obtained from the IMF's *World Economic Outlook* database (IMF, 2008).

The definition of **country groupings** into low-, lower-middle-, upper-middle-, and high-income countries adopted in this study is based on the World Bank's country classification for 2007 (World Bank, 2007). In our discussion of availability of trade data, we refer to a group of high-income countries excluding six countries for which trade data are included in the trade statistics of another country (Isle of Man, Liechtenstein, Monaco, Puerto Rico, San Marino, and U.S. Virgin Islands). While our dataset on trade in and spending on ICT products includes all 49 countries classified as low-income countries and all 54 countries classified as low-middle-income countries, the analysis is largely confined to a group of 95 countries for which a minimum set of data are available from IMF (2008), and excludes Democratic People's Republic of Korea, Liberia, Somalia, Federated States of Micronesia, Iraq, Marshall Islands, West Bank and Gaza, and Timor-Leste.