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Information Technology and Economic Growth:

A Cross-Country Analysis

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M. P.

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ABSTRACT

This paper explores the impacts of information technology investment on economic growth in a cross-section of 39 countries in the period 1980-95 by applying an explicit model of economic growth, the augmented version of the neoclassical (Solow) growth model. The results based on the full sample of 39 countries indicate that physical capital is a key factor in economic growth in both developed and developing countries. Its influence is even bigger than what is implied by the income share of capital in national income accounts. But neither human capital nor information technology seems to have a significant impact on GDP growth. However, investment in information technology has a strong influence on economic growth in the smaller sample of 23 developed (OECD) countries. Its impact is almost as large as that of the rest of the capital stock. But since the share of IT investment in GDP, although growing, is still much lower than the share of non-IT investment, the net social return to IT capital is much larger than the return to non-IT capital: 60-80 per cent *versus* 4 per cent, respectively. The estimated return is very high; about twice the return to equipment investment and 10-12 times the return to R&D obtained in similar models as the one applied here.

Keywords: information technology; economic growth; productivity paradox; empirics of economic growth

JEL Classification: O11, O14, O41; O47

1. INTRODUCTION

The often-advocated view that information technology will change the world must stem from the basic premise that computing and information processing equipment has a visible impact on productivity and income. While there is substantial evidence that new information technologies are in many ways transforming the operations of modern economies, the impacts on productivity and economic growth have been much harder to detect. Although an increasing number of micro-econometric studies find a positive correlation between IT investment and various measures of economic performance across firms in industrial countries (see, e.g., Brynjolfsson and Hitt 1996, Lehr and Lichtenberg [forthcoming] for evidence on the US, and Greenan, Mairesse and Topiol-Bensaid [forthcoming] for France), disappointment in information technology is chronicled in many macro-economic studies disclosing a non-existing or even negative correlation between IT investment and economy-wide productivity (for a survey, see Brynjolfsson and Yang 1996).

Most of this macro-level evidence is for the US economy, but Motohashi (1997) found that the correlation between productivity and the IT intensity of the capital stock is weak also in five other OECD countries. Given the small number of studies on other countries, it is hard to infer whether the 'productivity paradox' is a feature unique to the US and some other advanced OECD economies or whether it is a more general phenomenon. This concentration of research on the US is quite surprising against the background of the voluminous literature explaining cross-country differences in productivity and economic growth (see, e.g., Durlauf and Quah 1998 for a survey of the field). The reason for the lack of interest in the role of information technology must be the simple fact that IT investment is not a variable included in any of the datasets which have been used in these studies.

Dewan and Kraemer's (forthcoming) recent study is a notable exception. They have estimated an inter-country Cobb-Douglas production function—with GDP as output and IT capital, non-IT capital and labour as inputs—by pooling annual data from 36 countries over the period 1985-1993. Data on GDP and non-IT capital are from the most recent version of the Penn World Table developed by Summers and Heston (1991). A measure of IT capital is constructed from information, provided by International Data Corporation (IDC), on the value of IT shipments, which is the revenue paid to vendors for hardware, data communication equipment, software and computer services. Computer and software price indices are applied in converting these data from current to constant dollars. IT spending flows are aggregated into net capital stocks by using depreciation profiles provided by the Bureau of Economic Analysis.

Dewan and Kraemer's (forthcoming) results indicate that the returns on IT capital are positive and statistically significant for developed countries, but non-significant for developing countries. For developed countries, the output elasticities of IT capital, non-IT capital and labour are 0.057, 0.160 and 0.823, respectively. Thus, a 10 per cent increase in the IT capital stock increases output by 0.57 per cent. This estimate implies that the marginal social product of IT capital lies in the range of 50 to 100 per cent if the share of IT capital in the total capital stock is assumed to be 3-4 per cent and if the value of the capital output ratio is between 2 and 3. For the average values of these variables in Dewan and Kraemer's sample, the return to IT capital is 79 per cent. They further estimate that in 1985-1993 IT capital has accounted for about 53 per cent of the average GDP growth in the developed countries of their sample and for about 41 per cent of GDP growth in the United States.

By contrast, Dewan and Kraemer's (forthcoming) results show that in developing countries non-IT capital investments are quite productive whereas IT investments are not. The output elasticity of non-IT capital is 0.593 but the IT elasticity is statistically indistinguishable from zero. This finding leads the authors to conclude that a substantive base of capital stock and infrastructure is a prerequisite for IT investments to be productive.

One weakness of the Dewan and Kraemer (forthcoming) study is the fact that human capital is not included in the production function. The results obtained for developed countries are likely to be quite sensitive to its inclusion, since, as will be shown below, investment in information technology is rather strongly correlated with investment in human capital. Dewan and Kraemer's conclusions on the contribution of information technology capital to GDP growth also seem to be grossly at odds with other growth accounting studies. Their estimate of 53 per cent average contribution to growth in developed countries is much higher than what Sichel (1997) has obtained for the US (16 per cent), Niininen (forthcoming) for Finland (20 per cent), Jeong, Oh and Shin (forthcoming) for Korea (34 per cent) and Wong (forthcoming) for Singapore (19 per cent).

Another notable study of the role of information and communication technology in economic growth is the World Bank's (1998a) World Development Report entitled *Knowledge for Development* which argues strongly for the increasing role of knowledge in economic development. The report concludes that the information revolution stimulates the creation of new knowledge by giving inventors and innovators fast access to knowledge. Information technology is also seen to facilitate the production and distribution of a growing number of other goods and services.

A cross-country analysis of economic growth is presented in support of the argument (World Bank 1998a: 157-58). It pools data from the Penn World Table Mark 5.6 and from the World Development Indicators for 74 countries and the averages of economic variables for three decades (1965-75, 1975-85, and 1985-95). In regressing GDP growth rates on a number of independent variables the following three indicators related to knowledge are shown to correlate positively and significantly (at the 5 per cent level) with GDP growth: education, openness to trade, and the availability of communications infrastructure. Education is measured by the average years of schooling in the population, openness by the sum of exports and imports as a percentage of nominal GDP, and communication infrastructure is measured by the number of telephone main lines per one hundred inhabitants. The regression analysis also controls for the real investment ratio, the share of government spending in real GDP as well as for the initial level of GDP and its square. The study finds evidence for the growth rates in different countries to converge to each other, but countries that are far behind catch up very slowly if at all.

The growth regression implies that a country can increase its GDP growth rate substantially by investing in education and in telecommunication as well as by opening up to trade. The growth impact can be as large as 4 percentage points for a country that succeeds in raising all these indicators simultaneously from low to high values, low and high being defined here as values at least one standard deviation below or above the sample average (World Bank 1998a: 23).

The analysis is silent on the impact of information technology on economic growth, but instead it pays attention to the role of the communication infrastructure. This may reflect the lack of data on IT in developing countries rather than the non-existence of such an impact, although it can also be plausibly argued that communications infrastructure may matter more for development than information technology does. The study also suffers from the same weakness as most of similar cross-country regressions do (see, e.g., Durlauf and Quah 1998); namely it is rather *ad hoc* and is not explicitly based on any model of economic growth.

The following analysis is based on an explicit model of economic growth which has recently been applied in a number of studies exploring economic growth impacts of various components of capital. The next section sets out this augmented version of the basic Solow model that includes accumulation of human capital and information technology capital as well as physical capital. Section 3 describes the data, which are obtained from standard sources except for data on IT investment that come from International Data Corporation (IDC), the same source used by Dewan and Kraemer (forthcoming). Section 4 presents the estimation results for a cross-section of 39 countries, developed and developing, over the period 1980-1995. In the concluding section the limitations of the analysis are also discussed.

2. THE MODEL

To study the impacts of information technology investment on economic growth, let us consider an augmented neo-classical model of economic growth *à la* Mankiw, Romer and Weil (1992). In addition to investment in physical capital (i.e. in machinery, equipment and structures) the basic Solow model is extended to include investment in human capital and in information technology. In fact, as shown in Nonneman and Vanhoudt (1996), the model can be extended to cover *m* types of capital by writing the production function in the following Cobb-Douglas form:

(1) $$Y(t) = K_1(t)^{\alpha_1} K_2(t)^{\alpha_2} ...K_m(t)^{\alpha_m} \left[A(t)L(t)\right]^{(1-\sum_{i=1}^{m}\alpha_i)},$$

where K_i denotes capital of type *i* (*i* = 1,2,...*m*), *L* labour, *A* the state of technology, and α_i are constants. Given that all factors are paid their marginal products, the α_i's represent the respective factor shares in total income. Labour is assumed to grow exogenously at rate *n* and technology to progress exogenously at rate *a*.

The Solow model also assumes that a constant fraction s_i of output is invested in each type of capital. Defining k_i as the stock of capital of type *i* per unit of effective labour, $k_i = K_i / AL$, and *y* as the level of output per effective labour, $y = Y / AL$, the following differential equations govern the evolution of the capital stocks:

$$(2) \qquad \frac{dk_i(t)}{dt} = s_i y(t) - (a + n + \delta_i) k_i(t), \qquad i = 1,2,...,m,$$

where δ_i's are the rates of depreciation of each type of capital. Rewriting the production function (1) in intensive form as

$$(3) \qquad y(t) = k_1(t)^{\alpha_1} k_2(t)^{\alpha_2} ... k_m(t)^{\alpha_m},$$

the steady-state values of the capital stocks k_i^* can be solved from the following set of equations

$$(4) \qquad k_1^{*\alpha_1} ... k_i^{*\alpha_i} ... k_m^{*\alpha_m} = (a + n + \delta_i) k_i^* / s_i, \quad i = 1,2,...,m,$$

which is linear in the logarithms of the capital stocks. Substituting the solutions in (3) and taking logarithms, the steady-state value of output per effective labour can be written as

$$(5) \quad \ln y^* = \frac{\alpha_1}{1 - \sum \alpha_i} \left[\ln s_1 - \ln(a + n + \delta_1) \right] + ... + \frac{\alpha_m}{1 - \sum \alpha_i} \left[\ln s_m - \ln(a + n + \delta_m) \right].$$

Consequently, the steady-state level of output per labour, i.e. of labour productivity, is positively related to the rates of saving in each type of capital but negatively related to the rates of population growth and depreciation of capital.

As the interest here lies in the impact of information technology on the level and growth of labour productivity, the number of different types of capital is narrowed down to only three: physical capital (K_p), human capital (K_h) and information technology capital (K_τ). Assuming technology to be the same in all countries except for a country-specific shock captured by an error term ε_j, the following empirical specification is obtained for the observable output per worker variable in country *j*:

(6) $$\ln(Y/L)_j = \alpha_0 + \frac{\alpha_p}{1-\beta}\ln s_{pj} + \frac{\alpha_h}{1-\beta}\ln s_{hj} + \frac{\alpha_\tau}{1-\beta}\ln s_{\tau j} - \frac{\alpha_p + \alpha_h + \alpha_\tau}{1-\beta}\ln(a + n_j + \delta) + \varepsilon_j$$

where $\alpha_0 = \ln A(0) + at$, $\beta = \alpha_p + \alpha_h + \alpha_\tau$, and $\beta < 1$ by assumption. The error term reflects differences not only in technology but also in resource endowment, climate and institutions.

The depreciation rate δ is assumed to be the same for all countries and for all types of capital. There do not exist any data that would allow country-specific depreciation rates to be estimated, but there is neither any strong reason to expect depreciation rates to vary greatly across countries. It is, however, much harder to justify the assumption that the depreciation rates are the same for all types of capital. Especially computers and peripheral equipment are known to have much shorter service lives than other types of physical capital (see, e.g., Oliner and Sichel 1994). But, as argued by Temple (1998) in analysing the role of equipment investment, the depreciation rates are likely to be almost perfectly correlated, meaning that the omitted terms should have little effect on the estimates of the parameters of interest.

The augmented Solow model predicts that countries reach different steady states determined by the factors specified in eq. (6). As the convergence to these country-specific steady states is known to be slow, the model can be modified to take the speed of convergence into account by using

(7) $$\ln y_j(t) = (1 - e^{-\lambda t})\ln y_j^* + e^{-\lambda t}\ln y_j(0)$$

where $\lambda = \beta(a+n+\delta)$ denotes the speed of convergence (see Mankiw, Romer and Weil 1992). As pointed out by Durlauf and Quah (1998), this convergence equation is obtained by restricting the parameters of the augmented Solow model in such a way that the depreciation rates on the different types of capital are equal. Otherwise, the local dynamics of income would be dependent on the values of the state variables, i.e. of the capital stocks. The steady-state values specified in eq. (6) may be substituted in (7) yielding an estimable specification:

$$(8) \quad \ln[Y(t)/L(t)]_j - \ln[Y(0)/L(0)]_j = \theta \ln A(0) + at + \theta \frac{\alpha_p}{1-\beta} \ln s_{pj} + \theta \frac{\alpha_h}{1-\beta} \ln s_{hj}$$

$$+ \theta \frac{\alpha_\tau}{1-\beta} \ln s_{\tau j} - \theta \frac{\alpha_p + \alpha_h + \alpha_\tau}{1-\beta} \ln(a + n_j + \delta) - \theta \ln[Y(0)/L(0)] + \varepsilon_j$$

where $\theta = (1 - e^{-\lambda t})$.

3. THE DATA

Being interested in the impacts of information technology on economic growth, the selection of countries and the time period to be considered is determined by the availability of data on investment in information technology (s_τ). As explained in Pohjola (forthcoming), International Data Corporation (IDC) publishes an annual report on the status of the worldwide information technology market in about 50 countries. The report contains data, based on the revenues of primary vendors, on spending on computer hardware equipment, data communications equipment, computer software and computer services including both professional and support services. The share of this IT outlay in nominal gross domestic product is here used as the measure of IT investment. It might be more informative to consider the real share by excluding the effects of different inflation rates between IT and GDP. But such a breakdown is hard to make if prices do not accurately account for changes in quality, as is likely to be the case for information technology. Lichtenberg (1993) and Nonneman and Vanhoudt (1996) have applied a similar procedure in their analyses of the growth effects of R&D investment.

Data used in estimating equations (6) and (8) are in Appendix 1. Table 1 shows the definition and the basic data source of the variables used. The period considered is 1980-95 covering one and a half decades of the 'information technology' revolution which is often claimed to have begun in the mid-1970s. IT spending data are only available for the shorter period 1989-95. This means that the estimate of the impact of IT investment on economic growth may be biased upwards since IT spending has increased at a faster rate than GDP during the period considered (see Pohjola [forthcoming]). The data on IT spending does not even cover the whole period 1989-95 for all countries. The sample consists of those 39 countries, ranging from India to the United States, for which at least two observations are available from this period. Since the variable s_τ measuring investment in information technology is based on fewer data points than all the other variables, it is probably subject to a greater measurement error. Moreover, these data may not be of the same quality as those produced by official statistical authorities.

TABLE 1
DEFINITION OF VARIABLES

Variable	Definition
$Y(t)/L(t)$ and $Y(0)/L(0)$	Real GDP per working age (i.e. age 15 to 64) population in 1995 and 1980, respectively, measured in purchasing power parities, 1987 international dollars. Source: World Bank (1998b)
n	Compound average annual growth rate of working age population, 1980-95. Source: World Bank (1998b)
s_p	Average of annual ratios of real domestic investment to real GDP, 1980-92. Source: Penn World Table, Mark 5.6 (Summers and Heston 1991)
s_h	Average share of working age population in secondary school 1980-95. Source: UNESCO (1998) and World Bank (1998b).
s_τ	Average of annual ratios of spending on information technology to nominal GDP, 1989-95. Source: International Data Corporation

Following the standard practice of many empirical cross-country analysis of economic growth, investment in physical capital (s_p) is measured as the average share of real investment in real GDP over the period considered. Investment in human capital (s_h) is here approximated by the average annual ratio of pupils in secondary school to working age population, which is a measure of the opportunity cost of investment in education. Two other measures, namely average educational attained in years and the ratio of government expenditure on education to GDP, were also tried, but their explanatory performance was inferior to the performance of the chosen measure. Similar to Mankiw, Romer and Weil (1992), the sum of labour-augmenting technological change and the depreciation rate, $a+\delta$, is set equal to 0.05 in estimating equations (6) and (8). Reasonable changes in this assumption are likely to have little effect on the estimates. Finally, n is the average annual growth rate of the working age population.

Table 2 contains the correlation coefficients between the independent variables. High correlation (0.80) between investment in information technology ($\ln s_\tau$) and the initial level of productivity ($\ln Y(80)/L(80)$) will be seen to create problems in estimating their separate contributions to economic growth.

TABLE 2
CORRELATION MATRIX

	$\ln s_p$	$\ln s_h$	$\ln s_\tau$	$\ln n$	$\ln Y(80)/L(80)$
$\ln s_p$	1.00				
$\ln s_h$	0.38	1.00			
$\ln s_\tau$	0.43	0.44	1.00		
$\ln n$	-0.36	-0.41	-0.63	1.00	
$\ln Y(80)/L(80)$	0.24	0.36	0.80	-0.60	1.00

4. EMPIRICAL RESULTS

Table 3 presents the results of both unrestricted and restricted estimation of eq. (6) for data on all the 39 countries of the sample (columns (1)-(3)) as well as for data on those 23 countries which were OECD members in 1995 (columns (4)-(6)). The estimated equation is the version of the augmented Solow model which assumes that the observed levels of GDP per working age population correspond to the steady state. The restricted estimation imposes on the parameters the constraint that the sum of the coefficients of the logarithm of the investment shares should equal the negative of the coefficient of the logarithm of the sum of population growth, depreciation and exogenous technological change. The F-test is carried out to see whether the restriction is appropriate. As can be seen from the lower panel of the table, the significance level of the F-test is greater than 0.05 in all other versions of the model than in the basic Solow model. This means the data does not reject the restriction for any of the augmented versions.

TABLE 3
STEADY-STATE INCOME REGRESSIONS (EQUATION (6))

Dependent variable: $\ln Y(95)/L(95)$	All 39 countries			23 OECD countries		
	(1)	(2)	(3)	(4)	(5)	(6)
Unrestricted regression						
Constant	3.95** (1.88)	5.09*** (2.07)	10.97*** (2.06)	4.98*** (1.47)	6.57*** (1.45)	9.92*** (1.06)
Physical capital $\ln s_p$	0.81** (0.36)	0.68* (0.37)	0.36 (0.30)	0.48 (0.29)	0.43 (0.26)	0.22 (0.16)
Human capital $\ln s_h$	—	0.30 (0.24)	0.12 (0.20)	—	0.68** (0.27)	0.22 (0.18)
Information technology $\ln s_\tau$	—	—	0.67*** (0.14)	—	—	0.43*** (0.08)
$\ln(a+n+\delta)$	-2.49*** (0.59)	-2.24*** (0.61)	-0.88 (0.56)	-1.99*** (0.46)	-1.89*** (0.41)	-0.91*** (0.30)
Adjusted R^2	0.41	0.47	0.67	0.54	0.63	0.86
Standard error of estimate	0.50	0.49	0.39	0.24	0.21	0.13
Restricted regression						
Constant	7.90*** (0.33)	8.11*** (0.34)	10.24*** (0.49)	8.58*** (0.33)	8.39*** (0.27)	10.04*** (0.31)
$\ln s_p - \ln(a+n+\delta)$	1.35*** (0.26)	0.97*** (0.32)	0.32 (0.28)	0.98*** (0.24)	0.62*** (0.22)	0.23 (0.14)
$\ln s_h - \ln(a+n+\delta)$	—	0.45* (0.23)	0.10 (0.19)	—	0.84*** (0.24)	0.22 (0.17)
$\ln s_\tau - \ln(a+n+\delta)$	—	—	0.65*** (0.13)	—	—	0.44*** (0.07)
Adjusted R^2	0.41	0.45	0.68	0.42	0.62	0.87
Standard error of estimate	0.52	0.50	0.38	0.27	0.22	0.13
F-test of restriction: p-value	0.04	0.15	0.71	0.02	0.22	0.91
Implied α_p	0.57	0.40	0.15	0.49	0.25	0.12
Implied α_h	—	0.19	0.05	—	0.34	0.12
Implied α_τ	—	—	0.31	—	—	0.23

Note: Standard errors are in parentheses. * = significant at 10 per cent, ** = at 5 per cent and *** = at 1 per cent level.

$$(9) \qquad MPK - \delta = \alpha_p \frac{a + n + \delta}{s_p} - \delta \,,$$

The first estimated model (columns (1) and (4) of Table 3) is the standard textbook Solow model including investment in physical capital only. The second version (columns (2) and (5)) is the augmented model proposed by Mankiw, Romer and Weil (1992). It covers investment in both physical and human capital. Both of these variables are statistically significant in the restricted estimation of the model. Physical investment seems to have a rather strong impact on the level of GDP per worker in the full sample of 39 countries. The estimate implies that the output elasticity of physical capital α_p is 0.40. As the steady state value of the marginal product of physical capital, net of depreciation, equals the social net return to investment in physical capital is thus about 8 per cent for a = 0.02, δ= 0.03 and for the sample averages of the other parameters (see Appendix 1). This is well in line with the estimates obtained by Mankiw, Romer and Weil (1992).

As is to be expected the output elasticity of physical capital is smaller (0.25) in the subsample of 23 OECD countries than in the larger sample (0.40). On the contrary, investment in human capital has a stronger impact on output in the OECD than in the larger group of countries, the elasticities being 0.34 and 0.19, respectively. In both cases, however, the output elasticities of physical and human capital sum up to approximately 0.6, which again is well in line with Mankiw, Romer and Weil (1992).

The third model of Table 3 (columns (3) and (6)) shows the results obtained by estimating the augmented model when also investment in information technology is included in it. This augmentation improves the explanatory performance of the model and shows that IT investment has a large and statistically very significant impact on the level of GDP per worker. This impact is surprisingly large, the implied output elasticity of IT capital α_τ being about 0.31 in the full sample of countries and 0.23 in the OECD subsample. Such a high elasticity means that the social return to IT investment is also large. From eq. (9) it is seen to equal 140 per cent in the steady state for a = 0.02, δ= 0.03 and for the sample averages of the other parameters in all the 39 countries. For the OECD countries the estimated return is considerably lower: 80 per cent. Another surprising feature of this model is the fact that neither physical nor human capital investment has any statistically significant explanatory power.

The steady-state regressions reported in Table 3 yield consistent estimates of the output elasticities if the initial level of GDP per working age population is randomly distributed around steady-state productivity. Estimation of the dynamic version of the augmented Solow model specified in eq. (8) may yield consistent estimates of production function parameters even if initial productivity is not evenly distributed. Table 4 presents the results. Investment in human capital is no longer statistically significant in any of the models estimated, but investment in physical capital and the initial level of productivity are significant in all of the models. The estimates imply that in the full sample of 39 countries the output elasticity of physical capital α_p is about 0.6 and that the speed of convergence λ of output per worker to the steady state is 2 per cent a year.

Investment in information technology does not have any significant explanatory power in the larger sample, but, rather interestingly, it is strongly significant in the case of the OECD countries. The results imply that the elasticity of output with respect to IT capital is 0.21, which is of the same size as the elasticity with respect to physical capital (0.26). The social net returns to these two types of investments are 80 per cent and 4 per cent, respectively. The net return to IT capital is, of course, lower than estimated here if a higher rate of depreciation is applied. But even if the depreciation rate is 20 per cent, the resulting 60 per cent net return is very high. Investment in IT seems to have a much stronger impact on economic growth than, for example, R&D investment has. Using a similar approach, both Lichtenberg (1993) and Nonneman and Vanhoudt (1996) found that the output elasticity of R&D capital is about 7-9 per cent in the OECD.

Both the steady-state income regressions (Table 3) and the growth regressions (Table 4) give a consistent view of the impact of IT investment on GDP per capita: it is statistically significant and very strong, implying that the output elasticity of IT capital is about 0.2. The results obtained from the two models, however, differ in the larger sample of 39 countries. IT is significant in the steady-state regression but insignificant in the growth regression. The strong correlation (0.80) displayed in Table 2 between the initial level of productivity and investment in information technology may lie behind the difference between these results.

TABLE 4
GROWTH REGRESSIONS (EQUATION (8))

Dependent variable: $\ln Y(95)/L(95) - \ln Y(80)/L(80)$

	All 39 countries			23 OECD countries		
	(1)	(2)	(3)	(4)	(5)	(6)
Unrestricted regression						
Constant	3.17*** (0.78)	3.39** (1.33)	3.65** (1.36)	0.24 (0.76)	0.49 (1.01)	3.54** (1.57)
Physical capital $\ln s_p$	0.73*** (0.15)	0.72*** (0.16)	0.69*** (0.16)	0.24* (0.12)	0.24* (0.13)	0.20* (0.11)
Human capital $\ln s_h$	—	0.02 (0.10)	0.01 (0.11)	—	0.06 (0.15)	0.04 (0.13)
Information technology $\ln s_\tau$	—	—	0.10 (0.10)	—	—	0.18** (0.08)
$\ln(a+n+\delta)$	-0.28 (0.29)	-0.27 (0.31)	-0.22 (0.31)	-0.81*** (0.22)	-0.83*** (0.23)	-0.71*** (0.21)
Initial productivity $\ln Y(80)/L(80)$	-0.28*** (0.05)	-0.29*** (0.08)	-0.29*** (0.08)	-0.21** (0.08)	-0.23** (0.09)	-0.44*** (0.12)
Adjusted R^2	0.55	0.54	0.54	0.43	0.40	0.53
Standard error	0.21	0.21	0.21	0.10	0.10	0.09
Restricted regression						
Constant	2.36*** (0.46)	2.20** (0.92)	2.20** (0.93)	1.07 (0.72)	1.57* (0.86)	4.56*** (1.25)
$\ln s_p - \ln(a+n+\delta)$	0.62*** (0.12)	0.63*** (0.14)	0.60*** (0.15)	0.39*** (0.11)	0.36*** (0.11)	0.26** (0.10)
$\ln s_h - \ln(a+n+\delta)$	—	-0.02 (0.10)	-0.03 (0.10)	—	0.15 (0.15)	0.08 (0.13)
$\ln s_\tau - \ln(a+n+\delta)$	—	—	0.06 (0.10)	—	—	0.21*** (0.07)
$\ln Y(80)/L(80)$	-0.31*** (0.05)	-0.30*** (0.08)	-0.30*** (0.08)	-0.15* (0.08)	-0.21** (0.10)	-0.46*** (0.12)
Adjusted R^2	0.54	0.53	0.52	0.32	0.32	0.52
Standard error of estimate	0.21	0.21	0.21	0.11	0.11	0.09
F-test of restriction: p-value	0.22	0.23	0.16	0.04	0.08	0.30
Implied α_p	0.67	0.68	0.63	0.72	0.50	0.26
Implied α_h	—	0.00	0.00	—	0.21	0.08
Implied α_τ	—	—	0.06	—	—	0.21
Implied λ	0.02	0.02	0.02	0.01	0.01	0.03

Note: Standard errors are in parentheses. * = significant at 10 per cent, ** = at 5 per cent and *** = at 1 per cent level.

5. CONCLUSIONS

Physical capital is a key factor in economic growth in both developed and developing countries. Its influence is even bigger than what is implied by the income share of capital in national income accounts. But neither human capital nor information technology seems to have a significant impact on GDP growth. The conclusions concerning the strong growth impact of physical capital and the weak influence of human capital confirm the findings of many previous cross-country analyses (including DeLong and Summers 1991; Levine and Renelt 1992; Benhabib and Spiegel 1994, and Hamilton and Monteagudo 1998). But the poor performance of IT investment in explaining cross-country growth differences contradicts many popular views on the influence of the information technology revolution.

Investment in information technology has, however, a strong influence on economic growth in developed (OECD) countries. Its impact is almost as large as that of the rest of the capital stock. But since the share of IT investment in GDP, although growing, is still much lower than the share of non-IT investment, the net social return to IT capital is much larger than the return to non-IT capital: 60-80 per cent *versus* 4 per cent, respectively. The estimated return is very high indeed; about twice the return to equipment investment and 10-12 times the return to R&D obtained in similar models as the one applied here (DeLong and Summers 1991; Lichtenberg 1993; Nonneman and Vanhoudt 1996).

The results confirm Dewan and Kraemer's (forthcoming) conclusion that information technology plays a significant role in the current economic growth of developed countries but that it does not yet seem to have made a substantial contribution in developing countries (see also Kraemer and Dedrick (forthcoming)). This may simply reflect the fact that developed countries have already built up a mature stock of physical infrastructure and human capital which enhance and amplify the effects of investments in information technology. Developing countries on the other hand lack such IT-enhancing complementary factors making it much more difficult for them to benefit from modern advances in technology which enable redesign of production, work well as business management practices.

On the other hand, the same hypotheses, which have been used to explain the 'productivity paradox' at the national level, could as well here be applied to explain why IT investments do not seem to have paid off in all countries. Among these hypotheses are, for example, mismeasurement of IT investment, long delay in the diffusion of new technology and small share of IT investment in GDP (see, e.g., Pohjola (forthcoming)). But at the same time one should be able to explain why in the empirical estimations reported in Table 4 investment in physical capital has a larger impact on economic growth than is suggested by its factor share in income.

Investment-specific technological change can be argued to lie behind the important role that physical capital plays in economic growth (see, e.g., Greenwood and Yorukoglu 1997; Greenwood and Jovanovic 1998). The basic Solow model and its augmented version applied in this chapter treat capital and labour as homogenous factors of production. Technological progress is like 'manna from heaven' and improves the productivity of all factors of production, old and new alike. In reality, however, advances in technology tend to be embodied in the latest vintages of capital. The fast technological improvement of computers and the resulting rapid decline in their prices are a case in point. In such a world productivity does not increase if no new investments are made.

The standard Solow model can be adjusted to take into account technological progress embodied in the form of new capital goods. In such a vintage model of economic growth, the output elasticity of capital stock exceeds the share of capital in income (see, e.g., Hamilton and Monteagudo 1998). Thus, the estimation results obtained above could be argued to support the view that technological improvements are indeed incorporated in physical capital. But if this is the case, then the argument should apply even more strongly to information technology capital. This is because technological progress most likely has been much faster in information technology than in other fields in the past two or three decades. For example, on average, the real price of new equipment has fallen at the annual rate of 4 per cent and the real price of computing at the rate of 20 per cent in the United States over the post-war period (Greenwood and Jovanovic 1998). If IT is the engine of the current phase of economic development, one would thus expect empirical estimations to produce a strong relationship between output growth and IT investment as, indeed, they do for the subsample of the 23 OECD countries in 1980-95.

A final caveat is in order. Although investment in IT in this chapter has been interpreted to cause economic growth, it has not been possible to fully test this causality because sufficiently long time series do not exist. This testing remains a useful avenue for future research.

APPENDIX 1
DATASET

Country	Y(95)/L(95)	Y(80)/L(80)	s_p	s_h	s_τ	n
Argentina	11617	12780	0.1416	0.0981	0.0044	0.0145
Australia	22973	19093	0.2615	0.1326	0.0208	0.0154
Austria	24301	20530	0.2499	0.1620	0.0146	0.0076
Belgium	25191	21298	0.2122	0.1317	0.0184	0.0029
Brazil	7268	8758	0.1655	0.0403	0.0081	0.0245
Canada	24852	21572	0.2549	0.1280	0.0175	0.0122
Chile	13474	9062	0.2171	0.0820	0.0093	0.0194
China (PRC)	3506	1172	0.2245	0.0806	0.0034	0.0218
Colombia	8798	7396	0.1519	0.1176	0.0077	0.0235
Denmark	25223	20616	0.2110	0.1381	0.0208	0.0041
Finland	20881	17415	0.3078	0.1320	0.0176	0.0036
France	24970	21421	0.2531	0.1498	0.0173	0.0068
Germany	22896	19813	0.2469	0.1412	0.0161	0.0055
Greece	13828	12857	0.1983	0.1222	0.0049	0.0087
Hong Kong	25571	13682	0.1935	0.1216	0.0089	0.0161
Hungary	7683	7678	0.2464	0.0867	0.0141	0.0003
India	1939	1262	0.1419	0.1004	0.0037	0.0236
Indonesia	4007	2258	0.2550	0.0906	0.0049	0.0254
Ireland	21109	13418	0.2315	0.1600	0.0130	0.0099
Italy	22183	18867	0.2436	0.1340	0.0116	0.0053
Japan	24621	17787	0.3447	0.1243	0.0172	0.0068
Korea (Rep of)	13406	5512	0.3135	0.1664	0.0105	0.0200
Malaysia	13620	7831	0.2890	0.1405	0.0097	0.0265
Mexico	9713	12702	0.1590	0.1447	0.0062	0.0324
Netherlands	22395	18981	0.2102	0.1470	0.0216	0.0081
New Zealand	20648	18616	0.2384	0.1697	0.0244	0.0116
Norway	26560	19833	0.2629	0.1373	0.0193	0.0059
Philippines	4335	5222	0.1618	0.1113	0.0063	0.0282
Portugal	15241	11604	0.2072	0.0853	0.0096	0.0034
Singapore	27205	12680	0.3593	0.1124	0.0158	0.0210
South Africa	9421	12137	0.1612	0.1496	0.0200	0.0263
Spain	16948	13991	0.2461	0.1721	0.0110	0.0089
Sweden	23203	20428	0.2106	0.1201	0.0238	0.0037
Switzerland	28111	27177	0.3077	0.1352	0.0227	0.0090
Thailand	7458	3672	0.2022	0.0754	0.0054	0.0275
Turkey	6842	5755	0.2123	0.0884	0.0037	0.0303
UK	22961	18263	0.1708	0.1427	0.0206	0.0036
USA	32279	26774	0.2066	0.1292	0.0249	0.0087
Venezuela	11052	14087	0.1532	0.0260	0.0092	0.0298
Average	17136	13949	0.2263	0.1212	0.0133	0.0144

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