The Aggregate Production Efficiency of IT Investment: a Non-Linear Approach

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Abstract

The rapid diffusion of information and telecommunication (IT) technologies during the recent decennia produced fundamental changes in the economic activity at a global level, resulting in what became coined as the "new economy". However, empirical evidence on the contribution of IT equipment to growth and productivity is at best mixed, with the more or less consistent results on the positive link between the two relating to the United States in the 1990-s. Although the empirical literature on the link between IT investment and economic performance employs a wide variety of methodologies, the overwhelming majority of the studies appears to be employing the assumption of *linearity* of the IT-performance relationship and predominantly explores the *direct* nature thereof. In this study we relax both these assumptions and find that the indirect, or aggregate productive efficiency, effects of IT investment are as important as are the direct ones. The estimated non-linear nature of the indirect relationship between IT investment intensity and productive efficiency accommodates the concepts of critical mass and complementary (infrastructure) capital offered in the literature. Our key finding is that the world economy's average level of IT investment intensity remained below the estimated critical mass. Since in this study we developed a methodology that allows one to explicitly measure the critical mass of IT investment intensity, its individual estimation at a country or industrialsector level may help evaluate the extent to which IT investment activity has to be encouraged or discouraged.

1. Introduction and Motivation

The rapid diffusion of information and telecommunication (IT) technologies during the recent decennia produced fundamental changes in the economic activity at a global level, resulting in what became coined as the "new economy". During the period of 1970-1990 the real spending on IT equipment in the US grew more than two hundred times, leading many to explain the IT investment boom by the productivity returns to increased use of IT equipment in the production process.

However, empirical evidence on the contribution of IT equipment to growth and productivity is at best mixed, with the more or less consistent results on the positive link between the two relating to the United States in the 1990-s. One of the earliest concerns about the positive contributions of IT to growth and productivity was voiced by Robert Solow who stated "We see computers everywhere except in the productivity statistics". For example, the productivity slowdown in the United States that began in the 1970-s and lasted until the beginning of the 1990-s roughly coincided with the rapid growth in the sales of IT equipment (Brynjolfsson, 1993; Roach, 1991), suggesting that the observed boom in IT spending was caused more by the substitution effect due to plummeting computer and related equipment prices rather than due to the productivity returns to IT investment (Oliner and Sichel, 1994; Jorgenson and Stiroh, 1995).

The number of cross-country studies on the relationship between IT investment and economic performance is disappointingly small. Key contributions include Dewan and Kraemer (2000), who estimate an intercountry production function on a panel of 36 countries over the period of fifteen years and find a significant difference in returns to IT investment between developed and developing countries. Another important study is performed by Dedrick and Kraemer (1994) who analyze the link between IT investment growth rates and output growth for a smaller number of countries and years for the Asia-Pacific region. Finally, Kim (2001) follows Dewan and Kraemer's approach by using a very comprehensive dataset of more than eighty countries for the period of twenty eight years, confirming the dichotomy in response to IT investment between the developed and developing countries and concluding in general boosting IT investment should be the governments' policy priority.

Although the empirical literature on the link between IT investment and economic performance employs a wide variety of methodologies, the overwhelming majority of the studies appears to be employing the assumption of *linearity* of the IT-performance relationship. In our view, there is little, if any, theoretical basis to assume such linearity. In fact, one of the key contributions on the matter so far, Dewan and Kraemer (2000), attributes the stronger impact of IT investment on growth in the developed as opposed to developing countries to the factors whose existence implies the inherent non-linearity of the IT-performance relationship. Thus, the authors' argument implies that for IT investment to result in positive returns the IT capital stock itself must reach a certain threshold, or a critical mass level before the positive results to IT are realized, suggesting non-linearity of the IT-performance relationship.

In this paper we relax the assumption of linearity of the returns to IT investment and analyze two separate channels through which changes in IT investment may affect growth performance. Following Dewan and Kraemer (2000) we consider the IT capital stock as a separate production factor and include the latter into the aggregate production function along with capital and labor. However, we do not limit our analysis of IT investment's impact on growth performance to the direct effect only and assume investments into the IT equipment affect *aggregate production efficiency*. We show the impact of IT on production efficiency to be strongly non-linear, suggesting the existence of the threshold level of IT investment, below which gains to IT investment fail to be realized. It came as a surprise to us that according to our estimates most of the countries in most of the years invested into the IT equipment at the levels falling far short of the IT critical mass. The latter finding entails important policy implications, which we discuss in the concluding section of the paper.

The paper is organized as follows. In Section II we describe the database at our disposal and briefly discuss a few stylized facts that in our view are important for interpreting of our empirical results. In Section III we describe our empirical methodology and discuss our estimates of IT investment effects on the aggregate growth performance. Section IV discusses our empirical results and relates them to the existing findings in the literature as well as to the stylized facts we discuss in Section II. Section V concludes by discussing a few policy implications and summarizing the key results.

2. Database and some stylized facts.

The data at our disposal come from two major sources. The World Bank's World Development Indicators database provides data on the countries' output both in current prices and in real terms, labor force and gross fixed capital formation in terms of the latter's contribution to the GDP. The second data source is the International Telecommunications Union (the ITU) database that contains the estimates of ICT investment in current prices in local currency for 103 countries. For a number of countries and years the ITU database contains missing values. For that reason we had to exclude a number of countries from our analysis and deal with an unbalanced panel of data. Thus we finally ended up with a dataset covering 76 countries and spanning the period of 1975 to 1995[1] (Tables 2 and 3 contain the sample countries). Following the existing literature on cross-country analysis of the effects of ICT investment on growth we make

[1] The year of 1975 appears to be a reasonable starting point since, as some studies argue, the contribution of IT-related equipment to economic growth had been negligible prior to that year (e.g. Jorgenson and Stiroh, 1999).

a distinction between the high-income[2] and lower-income countries by including a dummy for the developed countries into our empirical analysis.

Table 1 presents summary statistics for our dataset. The rate of growth of our sample economy in the period of 1975–1995 is about 3.5% per annum, with the developed countries growing slower compared to the rest of the world. Investment in ordinary capital strongly dominates the IT investment by more than thirty times in terms of the respective GDP shares. This is consistent with the general fact that the IT sector's role in the economy as such is dwarfed by the more conventional industries (see e.g. Table 2 in Jorgenson and Stiroh 1999). The share of IT investment itself appears to be almost the same in the subsamples of developed countries and the rest of the world.

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[2] Also identified by the World Bank as a group of developed countries.

Table 1: Mean values of the key variables

	Pooled	Developed Countries	Rest of the World
Output Growth	3.47%	3.30%	3.58
Gross Fixed Capital Formation	21.99%	22.60%	21.63%
IT Investment Intensity	0.64%	0.63%	0.64%
Labor Force	2.26%	1.29%	2.82%

Note: the means are unweighted ones

As we already mentioned, the data on IT investment in our sample come in the form of shares of the latter in GDP. Just examining the evolution of IT investment shares over time reveals an intriguing empirical regularity. As Table 2 below demonstrates, in the overwhelming majority of the developed countries the shares of ICT investment in GDP contracted significantly during the period of 1975-1995, including the United States where the impact of IT investment on output growth finds the most convincing empirical support.

Table 2: The Evolution of IT Investment Intensity for Developed Countries, 1975-1995

	1975	1980	1985	1990	1995	75-95
Australia	100.00%	81.68%	74.79%	89.13%	88.54%	-11.46%
Belgium	100.00%	71.38%	65.85%	61.58%	79.09%	-20.91%
Canada	100.00%	81.85%	58.89%	64.15%	45.83%	-54.17%
Denmark	100.00%	91.08%	73.32%	69.99%	53.46%	-46.54%
France	100.00%	105.93%	95.97%	50.55%	46.41%	-53.59%
Ireland	100.00%	118.30%	67.85%	57.36%	43.11%	-56.89%
Italy	100.00%	75.45%	78.64%	90.00%	51.62%	-48.38%
Japan	100.00%	74.85%	52.80%	54.46%	70.79%	-29.21%
Norway	100.00%	143.18%	119.14%	68.92%	100.13%	0.13%
Singapore	100.00%	79.00%	95.39%	60.27%	46.12%	-53.88%
Spain	100.00%	71.75%	62.38%	134.68%	52.11%	-47.89%
United Kingdom	100.00%	62.33%	60.82%	57.88%	56.90%	-43.10%
United States	100.00%	107.66%	81.32%	54.75%	49.47%	-50.53%
Austria	100.00%	78.83%	105.75%	106.93%	83.60%	-16.40%
Finland	100.00%	65.69%	68.98%	72.47%	83.97%	-16.03%
Greece	100.00%	97.49%	116.86%	87.09%	112.46%	12.46%
Netherlands	100.00%	95.41%	87.80%	120.98%	99.38%	-0.62%
Portugal	100.00%	74.73%	106.70%	149.72%	170.45%	70.45%
Sweden	100.00%	117.47%	191.64%	151.69%	154.80%	54.80%
Switzerland	100.00%	71.48%	88.06%	111.66%	68.30%	-31.70%

Moreover, this contraction is not limited to developed countries alone. Indeed, as shown by Table 3, about seventy percent of the world's countries for which we had data on ICT investment in 1995 and prior to

1981 experience a decline in the share of their IT investment in GDP.

Table 3: The Evolution of IT Investment Intensity in the Lower Income Countries, 1975-1995

Country Name	1975	1980	1985	1990	1995	75-95
Algeria	100.00%	53.73%	53.63%	57.39%	30.75%	-69.25%
Australia	100.00%	81.68%	74.79%	89.13%	88.54%	-11.46%
Austria	100.00%	78.83%	105.75%	106.93%	83.60%	-16.40%
Bahamas, The	100.00%		176.05%	111.68%	84.37%	-15.63%
Belgium	100.00%	71.38%	65.85%	61.58%	79.09%	-20.91%
Botswana	100.00%		54.00%	137.09%	66.94%	-33.06%
Brazil	100.00%	43.49%	40.88%	46.90%	61.22%	-38.78%
Burkina Faso	100.00%			150.31%	151.66%	51.66%
Canada	100.00%	81.85%	58.89%	64.15%	45.83%	-54.17%
China	100.00%	64.07%	127.86%	442.47%	2335.57%	2235.57%
Colombia	100.00%	345.17%	319.96%	551.41%	805.60%	705.60%
Costa Rica	100.00%	52.39%	43.89%	52.33%	102.18%	2.18%
Denmark	100.00%	91.08%	73.32%	69.99%	53.46%	-46.54%
Ecuador	100.00%	171.59%	58.31%	173.83%	201.16%	101.16%
Egypt, Arab Rep.	100.00%	75.45%		140.91%		40.91%
El Salvador	100.00%	31.90%	43.84%	122.41%	125.43%	25.43%
Finland	100.00%	65.69%	68.98%	72.47%	83.97%	-16.03%
France	100.00%	105.93%	95.97%	50.55%	46.41%	-53.59%
Greece	100.00%	97.49%	116.86%	87.09%	112.46%	12.46%
Hong Kong	100.00%	71.63%	102.47%	123.57%	198.31%	98.31%
Hungary	100.00%	94.24%	125.53%	175.63%	419.86%	319.86%
India	100.00%	85.85%	146.12%	233.25%	328.75%	228.75%
Indonesia	100.00%	137.05%	12.57%	43.08%	70.06%	-29.94%
Ireland	100.00%	118.30%	67.85%	57.36%	43.11%	-56.89%
Israel	100.00%	1125.59%	1480.86%	935.10%	824.55%	724.55%
Italy	100.00%	75.45%	78.64%	90.00%	51.62%	-48.38%

Japan	100.00%	74.85%	52.80%	54.46%	70.79%	-29.21%
Kenya	100.00%	99.20%	167.15%	279.16%	186.34%	86.34%
Korea, Rep.	100.00%	156.82%	190.43%	156.81%	128.33%	28.33%
Kuwait	100.00%	179.48%			95.60%	-4.40%
Luxembourg	100.00%	118.10%	64.54%	140.35%	108.13%	8.13%
Malawi	100.00%	111.65%	127.06%	94.54%		-5.46%
Mexico	100.00%	61.71%	80.52%	161.64%	117.67%	17.67%
Nepal	100.00%		1245.97%	1111.98%	382.35%	282.35%
Netherlands	100.00%	95.41%	87.80%	120.98%	99.38%	-0.62%
Niger	100.00%			49477.25%	45431.17%	45331.17%
Norway	100.00%	143.18%	119.14%	68.92%	100.13%	0.13%
Oman	100.00%	84.49%	98.03%	10.72%	18.86%	-81.14%
Papua New Guinea	100.00%	143.74%	107.01%	135.33%		
Paraguay	100.00%	119.59%	146.67%	93.18%	141.32%	41.32%
Portugal	100.00%	74.73%	106 70%	149.72%	170.45%	70.45%
Singapore	100.00%	79.00%	95.39%	60.27%	46.12%	-53.88%
South Africa	100.00%	98.57%	178.35%	87.56%	105.65%	5.65%
Spain	100.00%	71.75%	62.38%	134.68%	52.11%	-47.89%
Swaziland	100.00%	117.64%	101.84%	149.22%	171.90%	71.90%
Sweden	100.00%	117.47%	191.64%	151.69%	154.80%	54.80%
Switzerland	100.00%	71.48%	88.06%	111.66%	68.30%	-31.70%
Syrian Arab Republic	100.00%	297.91%	166.85%	41.79%	318.61%	218.61%
Tunisia	100.00%	131.33%		113.45%	227.95%	127.95%
Turkey	100.00%	87.73%	245.77%	193.05%	95.33%	-4.67%
United States	100.00%	107.66%	81.32%	54.75%	49.47%	-50.53%
Uruguay	100.00%	98.55%	212.80%	119.16%	137.79%	37.79%
Venezuela	100.00%		58.05%	54.97%	115.81%	15.81%
Zambia	100.00%	145.10%	122.38%	35.90%	15.08%	-84.92%

Given the astounding speed with which the information and telecommunication equipment has penetrated the world economy since 1975, the contraction of shares of IT investment in such a substantial number of economies is asking for an explanation. In what follows we develop a theoretical and empirical framework that provides a rational for the latter observation. Given the central place the share of IT investment in GDP occupies in our analysis, we further refer to it as an *intensity of IT investment*.

The next section describes the theoretical framework used for the subsequent econometric analysis and discusses the empirical results.

3. Efficiency enhancing effects of ICT: empirical estimates

We follow the framework of Aigner et al. (1997) in order to trace the link between the IT investment and growth through the impact of the former on aggregate productive efficiency. We start with the following specification of a country's aggregate stochastic production function:

$$Y = f(K, L, T) + v - u$$
$$u = d_0 + d_1 s_T + d_2 s_T^{2} \qquad (1)$$

Y is the country's GDP, f stands for the production function relating output to conventional capital K, labor force L and the stock of IT capital T. S_T is the share of IT investment in the country's GDP. (1) captures two effects IT investment may have on growth performance. IT capital stock T entering the production function in (1) represents the direct effect of IT on the level of production. It is namely this direct effect that was mainly the focus of the bulk of empirical literature on the issue. Our contribution is to consider the indirect effect of IT investment, which is represented by the second line in (1). This effect accommodates the idea that while the direct contribution of IT to aggregate output may be small or negligible, its ability to alter the efficiency of production process in general could be substantial enough (the importance of making a distinction between the two effects is very well illustrated in Bosworth and Triplett, 2000).

The stochastic component of the production function is the difference between the white noise and an inefficiency measure. Thus, in (1) v is white noise and u is distributed as a positive truncated normal random variable. In this framework v accounts for those factors affecting the production process that can not be controlled by the management of the firms that comprise the economy, such as weather conditions for example. u represents the impact of factors that hinder the process of production and that can be influenced by the firms' management through applying more efforts, acquiring new technologies etc. The u term is thus a measure of the extent of the economy's overall inefficiency: *ceteris paribus*, the greater the u the less efficient the production process in the economy is.

We further make two key assumptions. First, we assume that the level of IT investment relative to GDP affects production inefficiency. Using levels of IT investment rather than the GDP share of the latter requires constructing a series of IT capital stock deflators for each one of the 76 countries in our sample, which at this stage appears to be next to impossible given the extent to which such dataset is available. Using the share of IT investment in GDP rather than the level of the former is thus a relatively easy solution to circumventing the IT deflators problem in a large cross-country setting similar to ours.

The second assumption that we make is that the response of productive inefficiency to increases in IT investment intensity is not necessarily linear. In this study we limit ourselves to the quadratic functional form of the inefficiency as a function of IT intensity.

The central issue of this study is the link between IT investment intensity and economic growth. Following Kim (2001), we total differentiate (1) and, dividing both total differentials by the output level, come up with the following growth equation:

$$dY = MPK \quad dK + MPL \quad dL + MPT \quad dT + v - d_1 ds_T - 2d_2 s_T ds_T$$
$$Y = MPK \quad S_K + e_L^Y L + MPT \quad S_T + v - \frac{(d_1 + 2d_2 s_T) ds_T}{Y} \tag{2}$$

Using the discrete analogue of (2) we come up with the following empirical specification:

$$\frac{Y^{t+1} - Y^t}{Y^t} = \frac{\mathrm{D}f^{(t+1-t)}}{Y^t} - d_1 \frac{s_T^{t+1} - s_T^t}{Y_t} - d_2 \frac{\left[(s_T^{t+1})^2 - (s_T^t)^2\right]}{Y^t}$$

$$u = d_0 + d_1 A + d_2 B \tag{3}$$

$$A = \frac{s_T^{t+1} - s_T^t}{Y_t}$$

$$B = \frac{(s_T^{t+1})^2 - (s_T^t)^2}{Y^t}$$

Using the data on the real cumulative indices of output in our sample normalized to unity in the starting year of 1975, we come up with the following empirical specification:

$$\frac{dY}{Y}=\frac{f}{K}\frac{DK}{Y}+e_L^Y\frac{DL}{L}+\frac{f}{T}\frac{DT}{Y}+v-d_1A-d_2B$$

$$A=\frac{S_T^{t+1}-S_T^t}{Y_t} \qquad (4)$$

$$B=\frac{(S_T^{t+1})^2-(S_T^t)^2}{Y^t}$$

Adding the time trend and a dummy variable for the developed countries we come up with the following estimates:

Table 4:

The Direct and Indirect Effects of IT Investment Intensity on Aggregate Production Efficiency (dependent variable: real output growth rate)

	Coefficient	Standard Error	t-ratio
Beta 0	3.52	0.60	5.90
GFCF	0.18	0.02	10.74
Labour growth	0.79	0.07	11.23
IT investment	-0.51	0.20	-2.56
Developed	-3.89	0.42	-9.17
Time trend	-0.003	0.02	-0.16
Inefficiency Estimates			
Delta 1 (linear effect)	3.54	1.26	2.81
Delta 2	-1.35	0.47	-2.90

(quadratic effect)			
Developed	-72.1	2.68	-26.86
Time trend	-0.28	0.15	-1.96
Sigma squared	97.79	11.38	8.60
Gamma	92%	0.01	89.04

Note: Gamma close to 100% indicates at the extent to which inefficiency effects are significant.

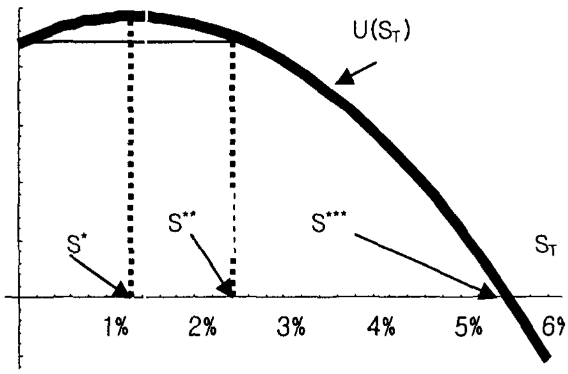
Both coefficients on conventional production inputs come out with the expected positive signs and are statistically significant. However, Table 1 is challenging one with the negative marginal product of ICT investment. We offer an explanation for this finding below based on our estimates of the non-linear relationship between the aggregate production efficiency and the ICT investment intensity.

Our estimated one-sided inefficiency component of the composite error term in (1) is given by the following (t-statistics are in parentheses;):

$$u = d_0 + \underset{(2.81)}{3.54}\frac{DT}{Y} - \underset{(-2.9)}{1.35}\left(\frac{DT}{Y}\right)^2 \qquad (5)$$

The estimates in (5) suggest the relationship between aggregate production inefficiency and the ICT investment intensity is strongly non-linear since both coefficients *delta1* and *delta2* are statistically significant at a 1% level. Figure 1 below represents the relationship graphically:

Figure 1: The response of aggregate production inefficiency to increases in the IT investment intensity



Note: This graph is constructed on the range of the actual data on ICT investment intensity; delta0 in (5) is chosen such that the inefficiency component u is not negative on the observed levels of $\frac{DT}{Y}$.

In what follows, we suggest an interpretation of the empirical estimates described above that may serve as an explanation for the observed decreases in ICT investment intensity in a substantial number of countries as well as a lack of convincing worldwide empirical evidence on the positive link between ICT investment and (total factor) productivity growth.

4. The critical mass, efficiency gains and overinvestment: interpretation of the empirical estimates

According to our estimates, while the share of ICT investment in the GDP is relatively low, increasing that share does not result in a higher aggregate production efficiency but rather in decreases thereof. However, beyond a certain threshold value of s^* further increases in that share lead to increases in aggregate efficiency of production. We call s^* a critical mass point, thus drawing a parallel with the part of the literature on ICT investment that claimed the existence of a threshold level of ICT capital stock that must be reached before the productivity gains of the ICT investment can be captured statistically. Similarly to that literature, we do not attempt to explain the mechanisms behind the existence of such a threshold. Instead, our contribution is to redefine the 'critical mass' point in terms of the ICT investment's *share* in GDP rather than its level, thus making it possible to estimate the 'critical mass' of ICT investment empirically even in the absence of consistent ICT deflators.

The fact that by definition the inefficiency component cannot be negative and our estimates in (5) imply that there exists a level of IT investment intensity s^{**} such that countries whose GDP share of ICT investment exceeds s^{**} enjoy higher levels of aggregate production efficiency relative to those that did not invest in the ICT equipment at all (respectively, countries with s_T=0). In our framework, it is namely the countries with $s>s^{**}$ that can be classified as the ones that truly benefited from investing into the ICT equipment.

Since inefficiency is by definition non-negative, (5) implies increasing the extent of ICT investment intensity stops resulting in increased efficiency of the aggregate production beyond point s^{***} (see Figure 1). The threshold point s^{***} is important since it can be viewed as the level of ICT investment intensity at which the efficiency-enhancing potential of further increasing the ICT investment intensity is exhausted. Thus, s^{***} may be viewed as a sort of an 'overinvestment' point[3]. Unfortunately, the dataset at our disposal makes it impossible to estimate the exact magnitude of s^{***} since

[3] The concept of *complementary capital* offered by the ICT literature allows to redefine s^{***} as the threshold beyond which no efficiency enhancing effects of further increasing the ICT intensity are possible, *given* the current level of ICT capital.

empirical specification (3) that we are employing only allows for estimating two of the three parameters in specification (1) of the inefficiency component of the composite error term in the aggregate production function. Obtaining consistent and comparable data on ICT capital stock would resolve the estimation problem, thus allowing to provide estimates of the 'overinvestment' thresholds.

In our sample, we observe almost no cases of s exceeding s^*, not to mention s^{**}. Indeed, the overall average ICT investment intensity in our sample (0.64%) falls far short of the threshold level of s^* (=1.3%) beyond which the efficiency gains become realized.

We are now ready to offer an explanation of why we have been observing stagnating and in many cases decreasing shares of ICT investment in the countries' GDP-s for the sample period of 1975-1995. The reason appears to be both economic agents' rationality and their ignorance of the existence of the threshold, or 'critical mass' level of ICT investment. Since, according to our estimates, most of the countries' ICT investment fell far short of the critical mass point beyond which more ICT investment would result in more efficient production, they observed *decreased* levels of productive efficiency as a result of more GDP channeled into the ICT investment. Thus, rationality dictated a reduction of the rate of growth of the ICT capital stock so that the ICT investment share in GDP would decrease. However, this type of rationality is a constrained one since it does not take into account the non-linearity of the relationship between the speed of growth of ICT capital stock and productive efficiency.

This line of argument is also explaining why the marginal product of ICT investment came out negative in our estimates. The reason is, of course, not that the ICT equipment 'harms' production efficiency. Our analysis suggests that there exists a tradeoff between the ICT-induced efficiency gains and the costs associated with the foregone production that could have taken place if the ICT investment resources were channeled into the traditional sectors of the economy. It remains to be explained why at the low penetration rates of ICT the forgone production costs outweigh the efficiency-enhancement benefits of ICT investment, but that issue is beyond the scope of this paper.

5. Policy implications and further research avenues

Our empirical results suggest the indirect, or aggregate productive efficiency, effects of IT investment are as important as are the direct ones. The estimated non-linear nature of the indirect relationship between IT investment intensity and productive efficiency accommodates the concepts of critical mass and complementary (infrastructure) capital offered in the literature. Our key finding is that the world economy's average level of IT investment intensity remained below the estimated critical mass. In terms of our framework that implies the *reduction* of levels of IT investment intensity was generally resulting in increasing growth rates of output during the past twenty-five years. While at this stage we can offer no theoretical explanation of this finding, developing one is definitely an interesting and rewarding research agenda.

We do not find evidence of the distinction between the response of output growth to the intensity of IT investment in developed and developing countries. Namely, after including the dummy for developed countries into the production function and the inefficiency specification we find the growth effect of IT investment to be statistically significant in both groups of countries.

Since in this study we developed a methodology that allows one to explicitly measure the critical mass of IT investment intensity, its individual estimation at a country or sector level may help evaluate the extent to which IT investment activity has to be encouraged or discouraged. If aggregate production efficiency is the policy makers' objective, our research provides the direct answer on the minimum level of IT investment intensity that must be achieved before production efficiency gains start taking place.

Our findings may be of particular relevance for the less developed countries that are contemplating investments into the IT viewing them as one of the means to move closer to the best practice production possibilities frontier. Indeed, our study implies realizing immediate productivity gains may be difficult for the countries whose investments constitute a relatively smaller fraction of their GDP-s since those gains will necessitate rapid accumulation of IT capital stock so that its share of GDP grows beyond the critical mass point. That growth will have to be achieved at the expense of the more conventional investments, resulting in a short-run decline of the rates of output growth. The Government, therefore, should be very careful to undertake a thorough analysis of the long-run productivity benefits brought about by a boost in IT spending versus the short-run costs associated with it. It might well be that incurring the latter proves to be unjustifiable from the point of view of the society's welfare, even in the anticipation of the coming productivity benefits.

6. References

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