Telecommunications Capital Intensity and Aggregate Production Efficiency: a Meta-Frontier Analysis

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Abstract

This study explores the link between telecommunications capital intensity and the aggregate production efficiency in the framework of meta-frontier analysis. The latter makes it possible to compare technical efficiency levels between countries operating under different technological frontiers. Our analysis suggests that increases in per capita levels of telecommunication capital will be most helpful in increasing the efficiency with which the existing technological knowledge and production resources are used, but not the technological frontier itself. We thus identify countries where additional investments in telecommunications are desirable as the ones where the technological lag is relatively small and efficient usage of productive resources is a problem. Africa appears to be the region where policies providing incentives for firms and households to purchase more telecommunications equipment will produce the most sizeable effect. In contrast, in the OECD countries where production practices are already the most efficient ones globally and the existing per capita telecommunications capital stock is high, further increases in the latter are not likely to result in any sizable production efficiency gains.

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1. Introduction.

The focus of this study is on the link between telecommunications capital intensity and aggregate production efficiency in the global meta-frontier framework. Capital intensity in general is measured as a ratio of capital stock to labor. A greater extent of the telecommunications capital intensity is associated with the higher levels of labor productivity since better communication tools make workers and their management more efficient (Jorgenson and Stiroh, 2000). We attempt to estimate the effects of telecommunications capital intensity on the levels of aggregate production efficiency in a broad range of countries around the world, putting a specific emphasis on the difference between country group and global stochastic production frontiers.

There are several ways in which investments into telecommunications equipment, such as cables and switches, can render production more efficient. To a large extent, all of these channels are related to the strong network effects that characterize telecommunications capital goods (Creti, 2001). First, firms that are able to quickly gain access to and process large volumes of information on the prospective suppliers of their intermediate inputs are likely to end up with cheaper inputs of higher quality compared to their counterparts that do not have access to a developed information communications infrastructure. Second, such an exchange of information on inputs and outputs to the various production processes that can only be made possible by means of advanced telecommunications networks increases the extent of competitive pressure, which in turn boosts incentives for the firms to use their inputs more efficiently. > Third, the existence of informational superhighways exerts a downward pressure on the time elapsing between conceiving and concluding the deal, urging businesses to act quickly and more efficiently, too.

The main contribution of this study is to employ the meta-frontier framework in order to analyze the link between telecommunications capital intensity as a measure of the informational network effects and aggregate productive efficiency in a worldwide setting. Meta-frontier analysis is different from the conventional stochastic frontier framework in that it allows one to make a distinction between the ‘local’ stochastic production frontier and the ‘global’ one (Battese et al., 2004.) The ‘local’ stochastic production frontiers in our study are defined for the four groups of countries formed according to their geographic proximity, while the 'global' stochastic production frontier is estimated for the whole sample. In contrast to the previous studies on the issue (e.g. Thompson and Garbacz, 2007), we are recognizing the fact that good performance in terms of a 'local' best-practice production frontier is not the same as good performance in terms of the 'global' best-practice benchmark. For that reason the impact of changes in the telecom capital intensity may be different depending on the type of productive efficiency.

We are opting for the telecom capital intensity to represent the extent of development of the telecommunications sector in order to better capture the network effects characterizing the latter. Our basic reasoning is, a person who only has access to a land-line phone can communicate less efficiently (and therefore make less use of communication network effects) compared to the person who in addition can use cell phones, fax machines, satellite networks and the Internet. Thus, we believe that a higher level of telecommunications capital per person (higher levels of telecom capital intensity) makes it more possible to exploit the network effects provided by telecommunications networks. In contrast, the level of telecom capital *per se* (whose growth represents telecom capital widening) is hard to interpret without relating it to the number of people who have access to it. The importance of using the concept of capital intensity as opposed to capital widening has been recognized in e.g. Estevao (2004)[2].

We find that higher levels of telecommunications capital intensity are associated with both higher country group efficiency scores and lower technological gap. However, the marginal effect of increased capital intensity is estimated to be far greater in case of increasing the country group efficiency levels as opposed to the case of reducing the technological gap with respect to the global meta-frontier. In terms of the country group differences in efficiency levels, quite expectedly we find the group of OECD countries to exhibit consistently higher local and meta-efficiency levels compared to countries in the Asian, African and

[2] This study emphasizes the potential importance of the process of capital deepening for the total factor productivity growth. Capital deepening is defined as a growth rate in the level of capital intensity.

Latin American region. Surprisingly, though, we estimate technological gap ratios to be very close to each other.

Our policy implications strongly suggest pursuing economic policies to provide incentives for firms and households to purchase telecommunications equipment in the countries where inefficient production practices are not only manifestly present (low technical efficiency levels relative to the group production frontier), but where they also account for much of the deviation from the deterministic frontier (larger share of the inefficiency term variance in the total variance of the Solow residual). In addition, we advise to pursue IT intensity-boosting policies in the countries with low technological gap ratio together with the policies that improve the technological level itself in order to avoid unnecessary waste of productive resources.

This study is organized as follows. Section 2 provides a review of the literature. Section 3 describes the estimation methodology and the dataset construction. Section 4 presents our empirical results. Section 5 summarizes the results and discusses policy implications.

2. Literature Review

Examining how the development of information and telecommunication technologies (IT) has affected the process of economic growth has been the subject of a significant number of studies including recent contributions by Oliner and Sichel (1994), Schreyer (2000), Dewan and Kraemer (2000) and Jorgenson and Stiroh (2000). Corroborating the initial claim made much earlier in the research by e.g. Jipp (1963) and Hardy (1980), the general conclusion of these studies is that the high extent of telecommunications infrastructure is generally conducive to the high level of economic development.

Recently the research emphasis has shifted away from assessing the direct contribution of IT sector to economic growth and performance and towards the estimation of telecommunications infrastructure on economic efficiency. In fact, given the relatively small contribution of the IT sector itself to the GDP and the variety of indirect (externality) effects outlined above, the key benefit of telecommunications investment is likely to be in the area of aggregate productivity and economic efficiency. Studies that have pursued this line of thinking such as Jorgenson and Vu (2005) and Barry and Triplett (2000) have demonstrated that the indirect effects of IT investment on economic performance are by far no less important than the direct ones. For example, Vu (2005) conducts a detailed growth accounting analysis in a cross-section of more than fifty countries and finds that the IT investment produces a significant impact on economic growth not only as a traditional investment, but also as a factor contributing to economic efficiency.

Since Aigner et al. (1977) have formulated a technique for estimating stochastic production frontiers, several modifications have been put into place, especially in light of the fast increase in the available computing power. Thus, Battese and Coelli (1988) developed an econometric estimation procedure for the individual technical efficiencies given estimates of the stochastic production frontier within a panel data framework. Coelli (1992) provided for a practical way to estimate technical efficiency levels by releasing the Frontier computer program. The useful instrument provided by this program was that it allowed for the *simultaneous* estimation of the inefficiency effects' determinants and the underlying stochastic frontier. The usual practice before that program became available was to run an OLS regression of the estimated technical efficiency levels on a set of determinants. Since there was no way to test whether the estimated efficiency scores were independently distributed, the estimated standard errors for the inefficiency determinants were to be taken cautiously. The simultaneous estimation of efficiency scores *and* their determinants eliminated this problem.

Implicitly the assumption underlying the stochastic frontier estimation procedure (irrespectively of how efficiency scores' determinants were treated) was that the observed production units, be it the individual firms or countries, are rather homogenous in the sense that they are operating under the same (stochastic) production frontier. While that assumption worked well in many cases, it definitely did not hold when the task was to estimate production efficiency scores on the set of the production units that were very different. For example, one cannot seriously believe that the African countries are operating under the same production frontier as the Asian or Latin American countries do. In that case it would make sense to estimate individual production frontiers for every group of the observations and measure technical efficiency levels relative to those. However, the efficiency scores of the units belonging to *different* groups of observations were not directly comparable. For example, a 99% efficiency score of a firm (or country) is not necessarily an indicator of an extremely efficient organization of the production activity since it may well be the case that we are talking about a very 'low' production frontier itself for that group. Alternatively, an efficiency score of 70% in a group of very efficient countries is not necessarily a sign of inefficient production on a global scale.

Recognizing these shortcomings, Battese et al. (2004) have presented a practical way to solve the problem of efficiency scores comparability in a heterogeneous group of observations by estimating the *meta-frontier*. The meta-frontier is defined as an envelope of the country group stochastic frontiers estimated in the conventional way. Meta-frontiers are of the same functional form as the country group frontiers and, since they are envelopes of a group of the individual stochastic production frontiers, an efficiency score relative to the meta-frontier is greater or equal to the efficiency score relative to the individual frontier. In particular, the rankings of observational units within the group and the average efficiency rankings of those groups themselves may well change depending on whether the ranking procedure is based on efficiency scores measured against the individual or the meta-frontier.

The major method so far for estimating the meta-frontiers was to solve a constrained minimization problem with constraints making sure the meta-frontier is in fact an envelope. Battese et al. (2004) offer two ways to specify the objective function to be minimized—the sum of the absolute deviations of the output levels on group frontiers and the meta-frontier or the sum of these deviations' squares. In this paper we follow the approach based on the sum of absolute deviations.

To our knowledge, this is the first study that conducts a meta-frontier analysis of the link between telecommunications capital intensity and aggregate production efficiency. Comparison issues being one advantage of the meta-frontier approach, the identification of the difference between the technological gap and within-the-group inefficiency is another important exercise made possible by this methodology.

3. Estimation Methodology and the Dataset Construction

In this section we explain how we arrived at our empirical results presented in Section 4. We start by describing the production function specification we employ and the way how we calculate technical efficiency levels relative to their respective country group stochastic frontiers. We then explain how we estimate the meta-frontier parameters and reduce the constraints number in the original minimization problem by exploiting the concept of segmented-frontier and by assuming the time-variant coefficients in the meta-frontier. By combining the results of the first two subsections, we show how the meta-frontier efficiency score can be decomposed into the product of country group efficiency score and the technology gap ratio. The final subsection describes the dataset with a special emphasis on the perpetual inventory method that we used to estimate stocks of conventional and telecommunications capital.

3.1 Estimation of country group stochastic frontiers and the levels of production efficiency

For each one of the four geographical regions (OECD, Africa, Latin America and Asia) we estimate a separate country group production frontier. These estimates later serve as a basis for estimating the common meta-frontier. We postulate the basic Cobb-Douglas aggregate production function for each region $k = 1..4$: $Y_{it} = A_{kt} K_{it}^{\alpha_k} L_{it}^{\beta_k}$ where Y_{it} is output, K_{it} is capital and L_{it} is labor in country i in year t and $A_{kt} = A_0 D_k e^{\lambda_k t}$. Technology level A_{kt} is a function of global technological level A_0, geographical group-specific characteristic D_k and the technological time component $e^{\lambda_k t}$ that reflects the fact that the time dimension of our sample is large, especially considering the fast pace of advancements that had taken place in the area of telecommunications in the period between 1981 and 2004. Taking the logarithm of the above specification, we obtain the following expression for our aggregate production function:

$$\ln Y_{it} = \ln\left(A_0 D_k\right) + \alpha_k \ln K_{it} + \beta_k \ln L_{it} + \lambda_k t \quad (1)$$

The empirical stochastic frontier specification of (1) with the technical inefficiency component will assume the following form:

$$\ln Y_{it} = \ln\left(A_0 D_k\right) + \alpha_k \ln K_{it} + \beta_k \ln L_{it} + \lambda_k t + \varepsilon_{it} \tag{2}$$

where $\varepsilon_{it} = v_{it} - u_{it}$ is a stochastic term with v_{it} being standard i.i.d normal and $u_{it} > 0$ distributed as a truncated normal variable and representing the *inefficiency* of the (local) aggregate growth process in the sense that higher values of $u_{it} > 0$ represent *less* efficiency. The efficient production frontier corresponding to (2) will be then represented by

$$\ln Y_{it} = \ln\left(A_0 D_k\right) + \alpha_k \ln K_{it} + \beta_k \ln L_{it} + \lambda_k t + v_{it} \tag{3}$$

or, equivalently, (2) under the condition that $u_{it} = 0$. Technical efficiency of economic growth will then be given by the ratio of the right hand side of (2) to that of (3).

In this study we hypothesize that higher levels of per capita telecommunications capital stock increase technical efficiency of aggregate production relative to the efficient production frontier. In terms of specification (2) we are expecting to find a *negative* association between term u_{it} (representing technical *inefficiency* of aggregate production) and per capita telecommunications capital stock. Using our estimates of (3) we test the hypothesis that u_{it} is a decreasing function of $\frac{K_{IT}}{L}$ where K_{IT} is the real telecom capital stock.

We estimate the effects of telecommunications capital intensity on the *inefficiency* levels by maximizing the following likelihood function:

$$\begin{cases} \ln Y_{it} = \ln\left(A_0 D_k\right) + \alpha_k \ln K_{it} + \beta_k \ln L_{it} + \lambda_k t + v_{it} - u_{it}, u_{it} \geq 0 \\ \mu\left(u_{it}\right) = \delta_{k,1} + \delta_{k,2}\left(\dfrac{K_{IT,it}}{L_{it}}\right) + \delta_{k,3} t \end{cases} \tag{3a}$$

where $\mu(u_{it})$ is the mean of inefficiency term u_{it} conditioned on the level of telecom capital intensity and the time trend term $\delta_{k,3}t$. We avoid running OLS regressions of inefficiency terms u_{it} on the levels of telecommunications capital intensity (the so-called two-stage approach) since it is not clear whether the estimated inefficiency terms in (5) are indeed independent. Denote the levels of technical efficiency estimated from (3a) as TE_{it}^{k}, where superscript k emphasizes the fact that we are talking about a technical efficiency level *relative to the country group, rather than to the meta-, frontier.* It is computed as $TE_{it}^{k} = e^{-\hat{u}_{it}}$. Since only one level of technical efficiency is computed for each observation, index k is not entering the right hand side of the expression for the level of technical efficiency.

3.2 Estimation of the meta-frontier

Meta-frontier is defined as an envelope of the individually estimated country group frontiers. The basic idea is to find the parameters of a production function $Y_{it} = A^{*}{}_{t} K_{it}^{\alpha^{*}} L_{it}^{\beta^{*}}$ such that the meta-frontier output level exceeds any of the country group output levels (given by the deterministic part of the estimated country group frontiers) for any combination of capital and labor in our sample. We can formalize this idea as follows:

$$\begin{cases} \underset{A_0^{*},\lambda^{*},\alpha^{*},\beta^{*}}{Min} A_0^{*} e^{\lambda^{*}t} K_{it}^{\alpha^{*}} L_{it}^{\beta^{*}} \\ s.t. \\ A_0^{*} e^{\lambda^{*}t} K_{it}^{\alpha^{*}} L_{it}^{\beta^{*}} > A_0 D_k e^{\lambda_k t} K_{it}^{\alpha_k} L_{it}^{\beta_k}, \\ k = 1..K, t = 1..T, i = 1..N \end{cases} \qquad (4)$$

where K is the number of geographical groups, T is the number of years, and N is the number of countries in our sample. Each one of the

$K \times T \times N$ constraints in (4) guarantees that the meta-frontier level of output is greater than any output on any of the country group stochastic frontiers (of course, of their deterministic parts) corresponding to the same combination of capital and labor at any point in time.

Since the constraints' number in (4) is relatively large, we have simplified (4) in two ways. First, we notice that the constraints in (4) are satisfied whenever the meta-frontier output is greater than the *segmented-frontier* output. The latter is defined as the segmented envelope of the country group stochastic frontiers formally defined as $Y_{it}^{s} = \underset{k=1..K}{Max}\, A_0 D_k e^{\lambda_k t} K_{it}^{\alpha_k} L_{it}^{\beta_k}, i = 1..N, t = 1..T$ and s standing for segmented frontier. Each constraint in (4) then becomes $A_0^* e^{\lambda^* t} K_{it}^{\alpha^*} L_{it}^{\beta^*} > Y_{it}^{s}$, and their total number diminishes by four times.

The second way we simplify the constraints in (4) is by assuming that the meta-frontier may evolve over time, which is not unreasonable given the fact that our analysis spans the period of twenty-five years. This assumption modifies both the objective function and the constraints in (4). We are now solving several minimization problems with a smaller number of constraints rather than solving a single minimization problem with a great many constraints. In particular, we are solving a series of problems of the following type:

For each $t = 1..T$, solve:

$$\begin{cases} \underset{A_t^*}{Min}\, A_t^* K_{it}^{\alpha_t^*} L_{it}^{\beta_t^*} \\ s.t. \\ A_t^* K_{it}^{\alpha_t^*} L_{it}^{\beta_t^*} > Y_{it}^{s} \end{cases} \tag{5}$$

where α_t^* and β_t^* are the year-specific factor shares, A_t^* is the year-specific meta-frontier intercept and Y_{it}^{s} is the segmented-frontier output from (4). The number of constraints in (5) is equal to the number of countries in the sample, N.

We reduce (5) by taking logarithms of both the objective function and constraints, ending up with T linear programming problems of the following kind:

For each $t = 1..T$, solve:

$$\begin{cases} \underset{C_t^*, \alpha_t^*, \beta_t^*}{Min} \left[C_t^* + \alpha_t^* (\ln K_{it}) + \beta_t^* (\ln L_{it}) \right] \\ s.t. \\ C_t^* + \alpha_t^* K_{it} + \beta_t^* L_{it} > Y_{it}^s, i = 1..N \end{cases} \quad (6)$$

where $C_t^* = \ln A_t^*$. Denote $Y_{it}^* = A_t^* K_{it}^{\alpha_t^*} L_{it}^{\beta_t^*}$ to be country $i's$ meta-frontier output in year t.

3.3 Technology gap ratio and the country group technical efficiency scores

Technology gap ratios measure how short the observed output levels fall of the meta-frontier. Denoting $Y_{it}^{eff} = \frac{Y_{it}}{TE_{it}^k}$ to be the efficient level of output for country i in year t relative to the *country group frontier* k, the technology gap ratio is defined as $TG_{it} = \frac{Y_{it}^{eff}}{Y_{it}^*}$. The product of the country group efficiency level TE_{it}^k and the corresponding technology gap ratio TG_{it} yields technical efficiency level relative to the meta-frontier TE_{it}^*:

$$TE_{it}^* = TE_{it}^k \times TG_{it} \quad (7)$$

In the right hand side o (7) index k is only serving as a reminder that we are talking about the level of technical efficiency relative to the country group, not meta-, frontier. This country group technical efficiency level is unique for each country in each period of time.

3.4 Construction of the dataset

The data at our disposal come from two sources. The Penn World Table, version 6.2, provides data on real output, labor and investment flows. The International Telecommunications Union world telecommunications database provides us with the total annual investments in telecom defined as capital expenditure in the sector.

In either database we do not have the capital stock levels either for the conventional capital or for the telecom capital. For that reason, before estimating (3a) empirically, we need to estimate stocks of conventional and telecom capital K_{it} and $K_{IT,it}$, respectively.

We estimate the latter two stocks by employing the perpetual inventory method that allows one to estimate capital stocks as a sum of the past real investment flows weighted by the extent to which these investments depreciate over time. Assuming the finite useful lifetime of an investment equal to m (equivalent to saying that an asset becomes useless m years after purchase) and a yearly depreciation rate δ, we obtain the following expression for the value of a stock variable S_{it} that is characterized by investment flow I_{it}:

$$S_{it} = \sum_{\tau=0}^{m-1} (1-\delta)^{\tau} I_{t-\tau} \qquad (8)$$

To use (8) for our computation, we assume the useful lifetime of conventional investment to be equal to thirty years, while that of the telecom investment to be equal to seven years (see Jorgenson and Vu, 2005). Depreciation rates δ that correspond to these values are 7.5% and 20%, respectively.

We obtain real values of investment flows into the conventional capital by combining the information on real GDP per capita (*rgdpl*), investment share of real GDP per capita (*ki*) and population (*pop*) provided by the Penn World table, version 6.2. Flows of investment into the telecommunications capital are defined by the ITU database as the total annual investment in telecom (including mobile service) for acquiring property and plant [3]. Since the deflator for telecommunications investment is not explicitly provided by the ITU database, we employ the National Income and Product Account Tables provided by the U.S. Bureau of Economic Analysis (Table 1.1.4, price index for equipment and software under gross private fixed domestic investment). We then deflate the ITU data on telecom investments in the international U.S. dollars by this index.

To complete this section, a few remarks must be made on the scope of the countries and years covered by this study. As mentioned before, the Penn World Table provides the data on output, capital and labor, while the ITU provides the telecommunications investment data. The World Table data normally cover the period from 1950 through 2004, while the ITU data coverage is only from 1975 through 2004 for telecom investment. Since we take the useful lifetime for conventional capital stock to be thirty years, while that of the telecom capital stock to be seven years, the earliest year for which both conventional and telecom capital stocks could be constructed is 1981, which is the beginning year of the sample.

Since the statistical software we used in order to produce our estimations can deal with unbalanced panels, in principle it was possible to include those countries for which some observations were missing. However, in order to keep the panel reasonably balanced we did not include those countries where capital stocks could be calculated only for a few years such as the Eastern European countries and countries of the Former Soviet Union. For that reason, for example, Germany was not included in the sample. As a result, we ended up with forty-six countries listed below by their geographical location.

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[3] The term investment means the expenditure associated with acquiring the ownership of property (including intellectual and non-tangible property such as computer software) and plant. These include expenditure on initial installations and on additions to existing installations where the usage is expected to be over an extended period of time. Also referred to as *capital expenditure*. (ITU, Telecom Indicators)

Table 1: The Geographical Coverage

OECD	Asia	Latin America	Africa
1. Austria	1. China	1. Brazil	1. Egypt
2. Belgium	2. Hong Kong	2. Colombia	2. Kenya
3. Denmark	3. India	3. Costa Rica	3. Morocco
4. France	4. Indonesia	4. Ecuador	4.South Africa
5. Greece	5. Malaysia	5. El Salvador	5. Zambia
6. Iceland	6. Philippines	6. Paraguay	
7. Ireland	7. Singapore	7. Uruguay	
8. Italy	8. Taiwan	8. Venezuela	
9. Luxembourg	9.Thailand		
10. Netherlands	10. Korea		
11. Norway			
12. Portugal			
13. Spain			
14. Sweden			
15. Switzerland			
16. United Kingdom			
17. Australia			
18. Canada			
19. Japan			
20. New Zealand			
21. United States			
22. Turkey			
23. Mexico			

Table 1a presents summary statistics for our dataset:

Table 1a: Summary Statistics

	Mean	SD	Min	Max
OECD (552 observations)				
Real GDP (billion USD, constant prices of 2000)	791	1610	4.41	10700
Real capital stock (billion USD, constant prices of 2000)	1640	3160	9.86	21202
Population (million persons)	38.23	57.66	0.23	295.41
Real telecom capital stock (billion USD, constant prices of 2000)	13.300	27.100	0.039	216.000
Real telecom capital stock per capita (USD, constant prices of 2000, per person)	411.16	539.07	16.70	8520.89
Africa (120 observations)				
Real GDP (billion USD, constant prices of 2000)	132	120	7.33	394
Real capital stock (billion USD, constant prices of 2000)	111	88	12.001	305
Population (million persons)	31.57	18.04	5.88	76.16
Real telecom capital stock (billion USD, constant prices of 2000)	1.210	1.540	0.026	6.940
Real telecom capital stock per capita (USD, constant prices of 2000, per person)	32.41	34.89	2.60	163.77
Latin America (216 observations)				
Real GDP (billion USD, constant prices of 2000)	176	331	8.49	1380
Real capital stock (billion USD, constant prices of 2000)	279	561	11.48	2234
Population (million persons)	26.82	47.49	2.26	184.55
Real telecom capital stock	2.110	5.180	0.030	28.700

(billion USD, constant prices of 2000)				
Real telecom capital stock per capita (USD, constant prices of 2000, per person)	70.99	59.83	6.62	300.93
Asia (210 observations)				
Real GDP (billion USD, constant prices of 2000)	787	1160	53.17	6910
Real capital stock (billion USD, constant prices of 2000)	1230	1950	131.89	13241
Population (million persons)	268.67	416.69	2.93	1294.85
Real telecom capital stock (billion USD, constant prices of 2000)	6.760	13.500	0.097	101.000
Real telecom capital stock per capita (USD, constant prices of 2000, per person)	145.14	187.02	0.32	763.24

Expectedly, Table 1a is demonstrating the well-known differences between the OECD and less developed countries. The OECD countries dominate in terms of the real GDP, accumulated conventional and the telecommunications capital. We also observe the mean accumulated real capital stock exceeding the value of mean GDP in all but the African region, the latter apparently being due to the low levels of investment activities in the African countries. The level of real telecommunications capital stock accumulated in all four regions is uniformly a relatively small fraction of the total conventional capital stock, ranging between one-half percent in Asia and a little over one percent in Africa. In per capita terms, we observe levels of telecommunications capital stock per person to be predominantly on the order of several hundred US dollars in the constant prices of 2000. In our view, such low estimates of the accumulated telecommunications capital per person is indicative of both the rapid depreciation rate of the telecom equipment, as well as of the fact that the latter's direct contribution to the economy is likely to be very small compared to the effect it has through its network and spillover effects.

4. Empirical Meta-Frontier Analysis

In this section we are presenting our main empirical findings. We start by discussing the estimation results of the individual production frontiers for the four country groups. Subsection 4.2 continues with the discussion of the country group technical efficiency scores. The next two subsections deal with the meta-frontier estimation results and those of the meta-frontier efficiency scores. Subsection 4.5 analyzes the relative roles distances from the country group frontier and the technological gaps are playing in the determination of the overall meta-frontier efficiency level. The last subsection is dealing with the impact IT capital intensity is producing on both components of the meta-frontier efficiency.

4.1 Country group stochastic production frontiers

We estimate four country group stochastic production frontiers according to (3a) along with the pooled stochastic production frontier for the whole sample. As mentioned in the previous section, comparing technical efficiency levels obtained by estimating the pooled frontier may not be legitimate since different regions might operate under very different country group technologies. Table 2 details the results, the pooled sample estimates are provided for reference only.

Table 2: Country Group Stochastic Frontiers and Technical Efficiency Levels

	OECD	**Latin America**	**Developing Asia**	**Africa**	**World**
Aggregate Production Function: Dependent Variable $Ln(Y_{it})$					
C	2.22 (0.000)	5.24 (0.000)	7.04 (0.000)	-3.97 (0.000)	2.89 (0.000)
$Ln(K_{it})$	0.69 (0.000)	0.44 (0.000)	0.36 (0.000)	0.84 (0.000)	0.66 (0.000)
$Ln(L_{it})$	0.31 (0.000)	0.49 (0.000)	0.49 (0.000)	0.68 (0.000)	0.33 (0.000)
Time Trend	0.01 (0.000)	0.005 (0.001)	0.009 (0.155)	0.002 (0.000)	0.005 (0.000)
Inefficiency Function: Dependent Variable U $(u_{it} = \delta_1 + \delta_2 \left(\frac{K_{ICT,it}}{L_{it}} \right) + \delta_3 t)$					
δ_1	-1.07 (0.000)	-0.97 (0.004)	0.96 (0.010)	0.5 (0.000)	-0.09 (0.529)
$\left(\frac{K_{ICT,it}}{L_{it}} \right)$	-0.004 (0.016)	-0.15 (0.000)	-0.03 (0.000)	-0.05 (0.000)	-0.014 (0.000)
Time Trend	0.025 (0.000)	0.036 (0.000)	-0.007 (0.300)	-0.007 (0.054)	0.009 (0.012)
γ	0.26 (0.09)	0.78 (0.11)	0.55 (0.24)	1.00 (0.000)	0.87 (0.02)
Average Efficiency	96.05% (3.61%)	89.11% (11.07%)	69.93% (18.41%)	84.83% (10.90%)	
Average Efficiency in the World Sample					
# Obs	529	192	210	120	1194

Note: the coefficient for the $\frac{K_{ICT,it}}{L_{it}}$ *variable is entering the* ***inefficiency*** *function, so that the* ***negative*** *value for this coefficient corresponds to* ***increased*** *efficiency. P-values are in parentheses in all cases except for gamma and average efficiencies where in parentheses are their respective standard errors.*

As is evidenced by the pooled frontier estimation, the world on average is operating under constant returns to scale, but there are substantial country group differences with only the OECD countries following the CRS pattern with Africa, Asia and Latin America exhibiting either increasing or decreasing returns to scale. The generalized likelihood ratio test results strongly reject the hypothesis of the world operating under a single production frontier, corroborating the need for the meta-frontier analysis performed in this study.

The time trend is positive and significant at 1% level in all four regions, except for Asia, reflecting the technological progress. Expectedly, the country group frontier shifts out the most in case of the OECD countries, while in Africa it does not appear to do so with the course of time.

4.2 Technical efficiency estimates with respect to the country group frontiers

According to our estimates, production inefficiency appears to be strongly present in all four regions. The significance of production inefficiency effects is measured by parameter $\gamma = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2}$, which is essentially the share of the stochastic term's variance due to the inefficient production. Low values of γ make the interpretation of technical efficiency scores more difficult since in that case even the role of efficient behavior and organization on the overall performance is small compared to the exogenous random factors. In the context of this study the low values of γ would suggest a smaller extent, to which policy measures aimed at improving efficiency scores relative to the regional frontiers, are important.

Our estimates suggest that in each region the inefficiency component is statistically significant, although its relative importance relative to the purely stochastic disturbance varies depending on geographical location. Specifically, in Africa almost all deviations from the country group stochastic frontiers are explained by the inefficient production rather than exogenous stochastic shocks (e.g. bad weather, world economic crisis, embargoes etc), while in the OECD countries inefficient production explains a much smaller part of these deviations. The average country group efficiency levels are the highest in the group of the OECD countries at 96.05%, followed by the Latin American, African and the Asian regions at 89.11%, 84.83% and 69.93%, respectively.

The time trend variable is either insignificant at the 5% significance level in case of Africa and Asia, or strongly significant at 1% in the OECD and Latin American regions. The sign of the time trend in those cases is positive suggesting that with the course of time production becomes more inefficient relative to the country group frontier. This is natural since, if a country is not aiming to increase its production efficiency levels (e.g. by promoting telecommunications capital intensity, discussed in the next subsection), it will 'relocate' further away from the country group efficient production frontier pushed upwards by the other countries in the group.

As suggested by our estimates, higher levels of telecommunications capital intensity are associated with the higher levels of technical efficiency (evidenced by the *negative* sign on the $\left(\frac{K_{IT,it}}{L_{it}}\right)$ variable (δ_2) in the estimated inefficiency function) in all four regions. The impact of telecommunications capital intensity is estimated to be significant at a 1% level in all regions except the OECD one where it is significant at the level of 2%. The size of telecom capital intensity impact is the highest in Latin America, while it appears to be the lowest in case of the OECD countries with Africa and Asia impacts estimated to be inbetween.

In the absence of meta-frontier estimates we cannot directly compare average efficiency scores obtained for the four regions. For example, the average efficiency score of 89.11% for the Latin American region cannot be sensibly compared to the score of 69.93% for the Asian region since we do not know how the two regions are doing in terms of the distance from the world best-practice meta-frontier. The pooled-sample production frontier cannot substitute for the meta-frontier since it implicitly assumes every four regions are producing according to the same technology. If it turns out that the Asian countries' country group frontier is closer to the meta-frontier compared to the Latin American ones, the direct comparison of the two regions' technical efficiency levels estimated relative to the country group frontiers will be very misleading.

4.3 Meta-frontier production function estimates

We estimate twenty-five meta-frontiers for each year in our sample according to (6). Table 3 presents the results.

Table 3: Meta-frontier estimates

Year	C	K	L
1984	2.132	0.680	0.499
1985	2.159	0.677	0.504
1986	2.191	0.673	0.508
1987	2.208	0.671	0.513
1988	2.228	0.668	0.518
1989	2.249	0.665	0.522
1990	2.267	0.663	0.525
1991	2.296	0.660	0.529
1992	2.334	0.657	0.534
1993	2.391	0.652	0.539
1994	2.451	0.647	0.545
1995	2.518	0.641	0.551
1996	2.564	0.636	0.558
1997	2.594	0.632	0.564
1998	2.591	0.630	0.569
1999	2.586	0.629	0.574
2000	2.57	0.62796	0.5786
2001	2.58	0.6258	0.584
2002	2.63	0.62	0.5904
2003	2.69	0.61	0.60
2004	2.72	0.609	0.606

The intercept of the estimated meta-frontier is continuously growing over time, reflecting the ongoing technological progress in the world. Our estimates also suggest that the marginal product of capital has been decreasing, while the marginal product of labor has been increasing over time. These findings suggest that technological progress has been transforming the world production frontier in the way that was making labor more productive, while “allowing” the returns to capital to follow the path of diminishing returns.

4.4 Meta-frontier efficiency scores estimates

We now use the meta-frontier estimates above to infer the technological gap ratios (TGR) and meta-efficiency levels computed according to (7):

Table 4: Technological gap ratios, country group and meta-frontier technical efficiencies

	1981-1984	1985-1988	1989-1992	1993-1996	1997-2000	2001-2004	Sample Period
Technological Gap Ratios							
OECD	94.43% (1.08%)	94.46% (1.10%)	94.54% (1.16%)	94.53% (1.19%)	94.58% (1.28%)	94.72% (1.39%)	94.56% (1.22%)
Africa	93.57% (1.74%)	93.53% (1.66%)	93.45% (1.76%)	93.17% (1.88%)	92.97% (1.98%)	92.87% (2.03%)	93.22% (1.83%)
Latin America	94.30% (1.53%)	94.18% (1.47%)	94.00% (1.44%)	93.62% (1.36%)	93.33% (1.35%)	93.17% (1.36%)	93.69% (1.44%)
Asia	94.34% (1.07%)	94.07% (1.10%)	93.88% (1.14%)	93.35% (1.20%)	92.93% (1.27%)	92.76% (1.41%)	93.40% (1.32%)
Country Group Technical Efficiencies							
OECD	98.63% (0.34%)	98.16% (0.48%)	97.52% (0.87%)	96.11% (1.86%)	94.48% (3.46%)	92.06% (5.38%)	96.05% (3.61%)
Africa	81.06 (15.47%)	81.50% (12.03%)	86.06% (7.00%)	85.06% (6.76%)	86.42% (8.58%)	88.91% (11.99%)	84.83% (10.9%)
Latin America	88.78% (8.89%)	87.38% (9.93%)	87.08% (10.59%)	89.71% (10.55%)	91.24% (12.07%)	90.48% (13.92%)	89.11% (11.07%)
Asia	52.66% (9.22%)	57.66% (11.29%)	66.84% (15.80%)	74.35% (17.95%)	78.02% (18.08%)	80.71% (17.14%)	69.93% (18.41%)
Meta-frontier efficiencies							
OECD	93.03% (1.24%)	92.72 (1.23%)	92.20% (1.52%)	90.86% (2.42%)	89.38% (3.96%)	87.23% (5.75%)	90.60% (3.90%)
Africa	75.97% (13.96%)	76.33% (11.99%)	80.48% (7.39%)	79.33% (7.57%)	80.44% (9.11%)	82.62% (11.70%)	79.66% (9.95%)
Latin America	82.14% (8.97%)	82.14% (9.25%)	81.68% (9.79%)	83.83% (9.87%)	84.96% (11.23%)	84.11% (12.89%)	83.29% (10.53%)
Asia	51.42% (9.63%)	54.29% (10.90%)	62.83% (15.21%)	69.51% (17.27%)	72.62% (17.36%)	74.96% (16.43%)	66.94% (17.22%)

Note: standard deviations are in parentheses

We do not observe a large amount of variation in the technological gap ratios between the four regions as we did in case of the country group technical efficiencies. OECD is the leader falling short by a little more than 5% of the meta-frontier on average, while the African region is 7% short of the meta-frontier. It is interesting to notice that the four regions' rankings are different with respect to the technical efficiency levels estimated relative to the country group benchmark frontiers and to the technological gap ratio. While the OECD and Latin American regions have the same rankings according to both measures, the African region ranks better according to the country group efficiency, while the Asian region is enjoying a narrower technological gap.

In principle, the fact that the Asian countries' country group frontier is 'closer' to the meta-frontier, is potentially conducive to the situation where the Asian meta-frontier efficiencies are on average higher than the African ones. We do not see this happening: the four regions rank in the same way according to both country group efficiencies and the technological gap ratios. However, the meta-frontier approach allows us to avoid the potential misinterpretation of the efficiency scores.

Table 5 below displays two rankings of the countries in our sample according to the average country group and meta-frontier efficiency levels. The richest country in the sample according to its GDP per capita is Luxembourg according to both types of ranking, while the Philippines, Thailand and China are the three poorest *and* inefficient countries according to both country group and meta-efficiency average scores. In general, however, the two rankings are different. Thus, the U.S. ranks number 5 in the OECD group of countries at 97.62% with respect to the country group frontier, while its global (meta-efficiency) ranking is number 15 at 90.65%. Similarly, Iceland ranks number 11 when measured against the OECD frontier, while its global ranking is number 2.

Table 5: Rankings by average country group efficiency and meta-efficiency levels

Ranking	Country	Country Group Efficiency	Country	Meta-Efficiency	GDP per capita
1	Luxembourg	98.09%	Luxembourg	95.53%	$79 400

2	Norway	98.07%	Iceland	94.11%	$40 400
3	United Kingdom	97.89%	Norway	93.51%	$53 300
4	Switzerland	97.77%	Switzerland	92.92%	$40 100
5	United States	97.62%	Denmark	92.29%	$37 200
6	Australia	97.51%	Australia	91.92%	$37 300
7	Denmark	97.10%	Ireland	91.77%	$46 600
8	Sweden	96.94%	South Africa	91.76%	$9 700
9	South Africa	96.93%	Sweden	91.75%	$37 500
10	Austria	96.83%	Austria	91.74%	$39 300
11	Iceland	96.63%	Costa Rica	91.55%	$11 100
12	Japan	96.62%	United Kingdom	91.54%	$35 000
13	Netherlands	96.57%	Netherlands	91.06%	$39 000
14	Ireland	96.55%	Uruguay	90.93%	$10 800
15	Canada	96.40%	United States	90.65%	$45 800
16	Costa Rica	96.39%	Belgium	90.54%	$36 200
17	Uruguay	96.10%	Canada	90.49%	$38 600
18	Brazil	96.02%	New Zealand	90.36%	$27 200
19	Italy	95.89%	Portugal	90.31%	$21 800
20	Belgium	95.87%	Hong Kong	90.15%	$42 000
21	Portugal	95.82%	Japan	90.08%	$33 500
22	France	95.66%	Italy	89.59%	$30 900
23	Hong Kong	95.42%	France	89.36%	$32 600
24	Spain	95.18%	Spain	88.96%	$33 600
25	New Zealand	95.11%	Greece	87.59%	$30 600
26	Venezuela	93.79%	Brazil	87.46%	$9 500
27	Colombia	93.58%	Venezuela	86.93%	$12 800
28	Greece	93.16%	Colombia	86.81%	$7 400
29	Singapore	91.30%	Singapore	86.54%	$49 900
30	Mexico	91.10%	Taiwan	85.32%	$30 100
31	Turkey	90.84%	Mexico	84.03%	$12 400
32	Taiwan	87.53%	Turkey	83.68%	$12 000
33	El Salvador	86.83%	El Salvador	83.25%	$6 000
34	Paraguay	86.41%	Egypt	81.81%	$5 000

35	Morocco	86.16%	Paraguay	80.76%	$4 000
36	Egypt	84.77%	Korea	80.23%	$25 000
37	Korea	83.17%	Morocco	79.62%	$3 700
38	Kenya	79.19%	Kenya	72.81%	$1 700
39	Zambia	77.12%	Zambia	72.28%	$1 400
40	Malaysia	73.43%	Malaysia	69.39%	$14 500
41	Ecuador	63.78%	Ecuador	58.65%	$7 200
42	Indonesia	58.32%	India	54.64%	$2 600
43	India	58.24%	Indonesia	54.03%	$3 600
44	China	55.25%	China	52.44%	$5 400
45	Thailand	54.67%	Thailand	52.31%	$8 000
46	Philippines	53.22%	Philippines	50.30%	$3 200

Source: own calculations and the CIA World Factbook, 2008; the GDP per capita is in U.S. dollars based on the PPP

In general, countries in our sample rank differently according to which frontier their technical efficiency scores are measured against, which underscores the importance of estimating the meta-frontiers for the purpose of comparison of the (average) efficiency scores in the countries belonging to two or several different groups. It is also worthwhile noticing that there is a certain positive correlation between GDP per capita (Table 5, last column), and the average efficiency scores. The correlation coefficient is estimated to be greater in case of the meta-efficiency estimates (64% compared to 61% in case of the country group scores), suggesting richer countries use their productive resources more efficiently.

4.5 Decomposing meta-inefficiency scores into the country group and technological gap components

Taking logs of both sides of (7), we arrive at the following additive decomposition of the meta-frontier efficiency scores:

$$\ln\left(TE_{it}^{*}\right) = \ln\left(TE_{it}^{k}\right) + \ln\left(TG_{it}\right) \tag{8}$$

This decomposition allows us to infer the extent to which the ability to use productive resources efficiently given the available technology in a given country group and proximity to the world technological best practice are contributing to the observed meta-efficiency score. The contribution of the first type is represented by $\frac{\ln\left(TE_{it}^{k}\right)}{\ln\left(TE_{it}^{*}\right)}$, while $\frac{\ln\left(TG_{it}\right)}{\ln\left(TE_{it}^{*}\right)}$ is representing the second-type contribution. Table 6a below presents the decomposition results by country.

Table 6a: Shares of country group efficiency and proximity to the global meta-frontier in the meta-efficiency scores

Country	Mean	Minimum	Maximum	Mean	Minimum	Maximum
	Share of country group efficiency			Share of the proximity to the global meta-frontier		
Australia	30.73% (7.33%)	18.31%	41.60%	69.27% (7.33%)	58.40%	81.69%
Austria	36.11% (14.52%)	20.85%	67.97%	63.89% (14.52%)	32.03%	79.15%
Belgium	41.58% (15.19%)	21.05%	66.38%	58.42% (15.19%)	33.62%	78.95%
Brazil	28.38% (9.64%)	14.82%	45.03%	71.62% (9.64%)	54.97%	85.18%
Canada	35.87% (14.67%)	16.54%	65.25%	64.13% (14.67%)	34.75%	83.46%
China	84.23% (6.74%)	69.90%	91.98%	15.77% (6.74%)	8.02%	30.10%
Colombia	42.73% (15.79%)	11.93%	58.89%	57.27% (15.79%)	41.11%	88.07%
Costa Rica	39.32% (16.79%)	15.35%	59.92%	60.68% (16.79%)	40.08%	84.65%
Denmark	37.32% (10.30%)	21.61%	57.54%	62.68% (10.30%)	42.46%	78.39%
Ecuador	86.93%	85.86%	88.34%	13.07%	11.66%	14.14%

	(0.70%)			(0.70%)		
Egypt	57.55% (31.52%)	0.00%	87.64%	42.45% (31.52%)	12.36%	100.00%
El Salvador	60.64% (27.59%)	13.02%	84.49%	39.36% (27.59%)	15.51%	86.98%
France	37.83% (16.23%)	17.03%	68.37%	62.17% (16.23%)	31.63%	82.97%
Greece	53.55% (14.33%)	28.20%	72.29%	46.45% (14.33%)	27.71%	71.80%
Hong Kong	35.31% (23.59%)	15.66%	79.89%	64.69% (23.59%)	20.11%	84.34%
Iceland	57.54% (18.23%)	11.89%	82.22%	42.46% (18.23%)	17.78%	88.11%
India	86.43% (2.80%)	81.20%	90.30%	13.57% (2.80%)	9.70%	18.80%
Indonesia	87.54% (1.52%)	85.22%	90.39%	12.46% (1.52%)	9.61%	14.78%
Ireland	41.65% (10.38%)	24.33%	65.82%	58.35% (10.38%)	34.18%	75.67%
Italy	36.98% (15.12%)	19.66%	62.09%	63.02% (15.12%)	37.91%	80.34%
Japan	32.49% (11.65%)	19.58%	61.47%	67.51% (11.65%)	38.53%	80.42%
Kenya	73.91% (4.66%)	66.84%	81.00%	26.09% (4.66%)	19.00%	33.16%
Korea, Republic of	52.61% (27.31%)	15.61%	87.83%	47.39% (27.31%)	12.17%	84.39%
Luxembourg	42.98% (8.87%)	33.01%	63.99%	57.02% (8.87%)	36.01%	66.99%
Malaysia	81.10% (10.57%)	66.92%	92.93%	18.90% (10.57%)	7.07%	33.08%
Mexico	51.21% (18.41%)	22.33%	76.88%	48.79% (18.41%)	23.12%	77.67%
Morocco	69.17% (10.27%)	45.82%	79.28%	30.83% (10.27%)	20.72%	54.18%
Netherlands	37.97%	23.04%	53.07%	62.03%	46.93%	76.96%

	(9.70%)			(9.70%)		
New Zealand	46.48% (17.96%)	24.26%	77.98%	53.52% (17.96%)	22.02%	75.74%
Norway	29.13% (8.10%)	14.75%	40.35%	70.87% (8.10%)	59.65%	85.25%
Paraguay	72.76% (6.06%)	59.91%	80.62%	27.24% (6.06%)	19.38%	40.09%
Philippines	91.25% (1.46%)	88.64%	93.16%	8.75% (1.46%)	6.84%	11.36%
Portugal	41.64% (13.24%)	24.41%	69.37%	58.36% (13.25%)	30.63%	75.59%
Singapore	50.84% (20.18%)	31.56%	90.60%	49.16% (20.18%)	9.40%	68.44%
South Africa	37.30% (17.61%)	0.00%	56.51%	62.70% (17.61%)	43.49%	100.00%
Spain	41.00% (16.00%)	21.33%	66.21%	59.00% (16.00%)	33.79%	78.67%
Sweden	36.26% (12.04%)	20.31%	51.63%	63.74% (12.04%)	48.37%	79.69%
Switzerland	30.67% (11.24%)	19.74%	54.17%	69.33% (11.24%)	45.83%	80.26%
Taiwan	48.94% (25.51%)	17.13%	88.20%	51.06% (25.51%)	11.80%	82.87%
Thailand	88.98% (2.58%)	85.81%	93.10%	11.02% (2.58%)	6.90%	14.19%
Turkey	48.54% (22.72%)	17.75%	78.97%	51.46% (22.72%)	21.03%	82.25%
United Kingdom	24.85% (4.86%)	16.39%	31.05%	75.15% (4.86%)	68.95%	83.61%
United States	24.90% (8.98%)	12.86%	45.53%	75.10% (8.98%)	54.47%	87.14%
Uruguay	34.92% (14.24%)	21.30%	68.47%	65.08% (14.24%)	31.53%	78.70%
Venezuela	41.72% (13.10%)	21.18%	62.14%	58.28% (13.10%)	37.86%	78.82%
Zambia	62.40%	0.00%	84.17%	37.60%	15.83%	100.00%

	(20.41%)			(20.41%)		

Note: standard errors are in parentheses, measured in percentage point units

According to our estimates, countries in our sample differ a lot in terms of the relative importance of the technological gap and distance to their country group frontier. In the United Kingdom and the United States (share of the technological gap ratio equal to 75.15% and 75.10%, respectively) most of the meta-efficiency is accounted for by close proximity to the world technological best practice frontier, while the ability to use resources efficiently given the available country group technology contributes the most to the meta-efficiency score in the Philippines and Thailand (share of the country group efficiency equal to 91.25% and 88.98%, respectively). Alternatively, in the Philippines and Thailand, the major source of aggregate production inefficiency is the low level of available technology, while in the U.S. and the U.K. the observed inefficiency is mostly due to the suboptimal usage of productive resources given the available technology in the OECD country group. Table 6b below summarizes the results by four broadly defined groups of countries.

Table 6b: Shares of country group production efficiency and technology development level in the meta-efficiency scores by country group

Country group	Mean	Minimum	Maximum	Mean	Minimum	Maximum
	Share of country group efficiency			Share of the proximity to the global meta-frontier		
Africa	60.06% (22.76%)	0.00%	87.64%	39.94% (22.76%)	12.36%	100.00%
Asia	71.49% (25.05%)	15.61%	93.16%	28.51% (25.05%)	6.84%	84.39%
Latin America	50.93% (24.13%)	11.93%	88.34%	49.07% (24.13%)	11.66%	88.07%
OECD	39.01% (15.77%)	11.89%	82.22%	60.99% (15.77%)	17.78%	88.11%

Note: standard errors are in parentheses, measured in percentage point units

Predictably, the problem of lack of technological knowledge is more of a problem in Africa and in the developing Asian countries where more than three-fifths of the average observed efficiency levels are due to the proximity to the countries' own country group, as opposed to the global, frontier. In the group of OECD countries, by contrast, proximity to the local frontier is only contributing around 40% to the observed average efficiency levels with the rest accounted for by the high extent of technological advancement. In all regions, however, there are countries where the predominant contributor to the observed level of productive efficiency is different from the group average. Thus, in South Africa most efficiency is due to the technological knowledge, while in Iceland around 60% of observed efficiency is caused by the efficient use of productive resources measured against the best practice OECD benchmark frontier.

4.6 The impact of IT capital intensity on technical efficiency levels and the technological gap ratio

In order to identify the impact of IT capital intensity on the levels of technical efficiency relative to the country group frontiers and technological gap ratios, we observe that the estimated technical efficiency levels in the country groups $TE_{it}^{k} = e^{-u_{it}}$ can be transformed as $\ln\left(TE_{it}^{k}\right) = \delta_{k,1} + \delta_{k,2}\left(\frac{K_{IT,it}}{L_{it}}\right) + \delta_{k,3}t$, where coefficients $\delta_{k,1}$, $\delta_{k,2}$ and $\delta_{k,3}$ are estimated from (3a). For the sake of consistency, we are thus choosing to estimate the log-linear specification of the relationship between telecommunications capital intensity and the technological gap ratio. We use the fixed effects model in order to control for the unobserved country heterogeneity. Table 7 below is presenting our estimation results by four country groups. For comparison purposes we are reproducing the part of Table 2 that displays the estimates of the country group inefficiency function.

Table 7: Technological gap ratio and IT Capital intensity, panel data regression analysis, fixed effects

	OECD		Africa		Latin America		Asia	
Dependent Variable	Ln(TGR)	Ln(TE)	Ln(TGR)	Ln(TE)	Ln(TGR)	Ln(TE)	Ln(TGR)	Ln(TE)
C	-0.06 (0.000)	1.07 (0.000)	-0.05 (0.000)	-0.5 (0.000)	-0.04 (0.000)	0.97 (0.004)	-0.02 (0.000)	-0.96 (0.01)
$\left(\frac{K_{IT,it}}{L_{it}}\right)$	0.00001 (0.002)	0.004 (0.016)	0.0006 (0.000)	0.05 (0.000)	-0.0001 (0.001)	0.15 (0.000)	0.00004 (0.016)	0.03 (0.000)
Time	0.0001 (0.000)	-0.025 (0.000)	-0.0006 (0.000)	0.007 (0.054)	-0.0006 (0.000)	-0.036 (0.000)	-0.001 (0.000)	0.007 (0.300)
R^2 within	31.58%		69.36%		89.56%		90.91%	
R^2 between	21.92%		43.62%		6.63%		0.17%	
R^2 overall	2.59%		20.91%		6.77%		19.55%	
Number of observations	483		105		189		192	

Note: p-values are in parentheses

In all but one case the impact of telecommunications capital intensity on both technical efficiency with respect to the country group frontiers and the technological gap ratios is positive and significant at the 2% significance level. In the case of Latin American countries our estimates suggest that increased levels of telecom capital intensity are associated with a wider technological gap with the world benchmark meta-frontier. While we are puzzled by this finding, we have currently no ready explanation for that.

In the rest of the cases we estimate higher levels of the telecom capital intensity to be associated with both higher efficiency scores relative to the group frontier and a narrower technological gap between the latter and the meta-frontier. The magnitude of the telecom capital intensity's impact, however, varies a lot. Thus, in the OECD countries the impact is the lowest both in terms of increasing the country group technical efficiency score and of narrowing the technological gap. In Latin America increasing levels of the telecom capital intensity appears to have the most potential in terms of pushing the countries towards the Latin

American best practice frontier, while in Africa the effect in terms of reducing the technological gap with the meta-frontier is estimated to be the largest.

In general the effect of telecom capital intensity on the size of the technological gap is much lower than its effect on the technical efficiency score measured against the country group frontier. This finding suggests that more overhead capital in terms of the telecommunications infrastructure works more in the direction of improving the process of managerial decision-making given the available state of technology, while the technology itself is affected much less.

5. Discussion

5.1 General results

The focus of this study is on the link between telecommunications capital intensity and the aggregate production efficiency in the meta-frontier framework. We analyzed forty-six countries over the period of twenty-four years. Our countries were divided into four groups according to their geographical location with the exception of the OECD countries. We applied meta-frontier analysis to the estimation of aggregate performance in order to make comparisons of technical efficiency scores between countries operating under different technologies meaningful.

We found that the division of countries in our sample into four groups was justified in the sense that the difference between the four estimated production frontiers is statistically significant. However, we did not find the distance between the four individual production frontiers and the global meta-frontier to be varying much across the four groups. In fact, the average technological gap ratio measuring this distance was estimated in the range between 93.22% for the African countries and 94.56% for the OECD. The difference between average technical efficiency scores relative to the group country frontiers was found to be much larger. Thus, the Asian countries scored 69.93% on average, while the OECD countries' average technical efficiency levels relative to the group frontier were estimated at 90.60%.

Our empirical analysis has demonstrated that the extent to which telecommunications capital intensity affects the distance towards the global best-practice meta-frontier is different depending on the type of the distance and the region. Thus, while increases in the telecom capital intensity appear to be increasing both technical efficiency scores relative to the country group production frontiers and the technological gap ratios[4], the effect is much larger in the former case compared to the latter. Latin America seems to be able to benefit the most from increased levels of telecom capital intensity in terms of increasing its technical efficiency levels, followed by the African, Asian and the

[4] Note that an increase in the technological gap ratio means decreasing the technological gap itself!

OECD countries. In the latter group, the size of the effect is on the order of one-tenth of that in the other three country groups, however, the OECD is the best performer both in case of the technical efficiency scores with respect to its country group frontier, and in terms of the proximity of the latter to the global meta-frontier.

According to our estimates, increased levels of the telecommunications capital intensity are conducive to the reduction of the technological gap only to a minor extent compared to the effect on the country group frontier technical efficiency scores. We thus infer that an increased ability to communicate faster and over longer distances provided by more telecommunications capital per person is working in the direction of increasing productive efficiency and decision-making *using the existing technology* rather than in the direction of improving or advancing the technology itself.

5.2 Policy implications

The general policy conclusion that can be derived from the previous section is that any policy measures increasing the rate of adoption of telecommunications equipment by firms and households will be most effective in the environment characterized by the following three characteristics:

1) The existing technological knowledge is not employed to its fullest potential, corresponding to low technical efficiency scores measured against the local group frontier
2) Deviations from the deterministic production frontier in a country group are mostly accounted for by the inefficient production practices rather than by stochastic disturbances (in terms of the discussion in subsection 4.2, $\gamma = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2}$ has to be closer to unity
3) The country group frontier is itself close to the global meta-frontier, or active policies are being implemented to improve the existing technological knowledge in the region

Table 8 below groups the countries in our sample according to the three criteria listed above.

Table 8: Ranking of country regions according to the effectiveness of policies increasing IT intensity

Effectiveness of IT policy (1=most effective)	γ (efficiency versus stochastic deviation)		Technological gap ratio		Technical efficiency relative to group frontiers	
1	Africa	100%	Africa	93.22%	Asia	69.93%
2	Latin America	78%	Asia	93.40%	Africa	84.83%
3	Asia	55%	Latin America	93.69%	Latin America	89.11%
4	OECD	26%	OECD	94.56%	OECD	96.05%

It is remarkable how the group of OECD countries is consistently placed in the end of the list. This should not be, however, erroneously interpreted as evidence of lack of importance of the telecommunications capital in these countries. Rather, due to the fact that this group of countries is most advanced technologically, the relevance of the IT-intensity boosting policies is low compared to the other regions because most countries are producing efficiently already.

Africa appears to be the region where policies providing incentives for firms and households to purchase more telecommunications equipment will produce the most sizeable effect. While the African countries' deviations from the African production frontier are overwhelmingly the result of the inefficient management and production practices, its technical efficiency levels relative to the group frontier are the second lowest in the sample, preceded by the Latin American countries.

With respect to Asia and Latin America, it is rather hard to compare the two regions since the Asian countries are estimated to be least efficient according to the country group frontier, while in the Asian countries the deviations from group frontier are more the result of the inefficient behavior compared to Latin

American countries. Referring to the difference in the technological gap ratio does not help much since the two average values for the regions are very close to each other. We conclude thus that in both Latin America and in Asia the policies of increasing the level of IT capital intensity will produce an improvement, although the size of this improvement is likely to be smaller than that in the African countries.

Finally, since we do not find nearly as much variation in the technological gap ratios across the regions compared to that in the country group technical efficiency levels, we infer that pursuing economic policies aimed at improving the existing level of technology equally desirable in each one of the four regions. This conclusion seems to be the only uniform one for the four country groups we have arrived at in this study.

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