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**Working Paper**

## Benchmarking Efficiency Telecommunication Industries US and Major European Countries: A Stochastic Possibility Frontiers Approach

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**621**

**Georg Erber**

**Benchmarking Efficiency of Telecommunication  
Industries in the US and Major European Countries**

**A Stochastic Possibility Frontiers Approach**

**Berlin, September 2006**

Opinions expressed in this paper are those of the author and do not necessarily reflect views of the institute.

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**Discussion Papers 621**

Georg Erber\*

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in the US and Major European Countries**

A Stochastic Possibility Frontiers Approach

Berlin, Februar 2006

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## 1 Introduction

Productivity growth and in particular the significant acceleration of productivity growth in the US economy in the second half of the 1990's, raised high expectations that the massive investment in ICT-capital goods had finally had its impact on the whole US economy. Numerous growth accounting studies found that the large investments in the 1990's were the key factor contributing to this development (see, e.g., OLINER & SICHEL, 2000; JORGENSON & STIROH, 2000; JORGENSON 2001, 2003; GORDON 2000A, 2000B; COUNCIL OF ECONOMIC ADVISORS, 2001). This new dynamism led – after two decades of debate about the persistent productivity slowdown since the mid-1970's – to a catchword of a “new economy”. Information processing via computers everywhere and the rapid global dissemination of data using digital communications over the Internet and new digital wireless networks were contributing in the make- as well as in the use-industries to a significant surge in US productivity growth.

The US, which had been trailing most OECD countries in productivity growth during the previous decades, suddenly became revitalized by this event (the end of the Solow Paradox). In the wake of this shift attributed to the New Economy, most other OECD countries were left trying to catch up to the dominant high level of US productivity. The roles of the game had changed and the pendulum swung to a US economy forging ahead, leaving *old Europe* in particular behind.

The EU countries' hope that they were simply lagging behind the US with regard to the rapid diffusion of ICT and therefore could expect a surge of higher productivity growth at the beginning of the new millennium (see, e.g., the Lisbon summit declaration of Spring 2000) has not materialized and is expected not to do so in the near future.<sup>1</sup> Massive investments in most OECD countries similar to the US in ICT capital goods at the aggregate level have not the same impact as in the US.<sup>2</sup>

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<sup>1</sup> According to an EIU Report, a survey in the EU member countries found that 30% of the companies included reported that more than 50% of the targeted efficiency gains in ICT projects did not materialize and led to heavy cost overruns. See EIU (2004) p.5. EIU estimated that during the period of 1995 until 2001, in the EU-member countries 1.9 trillion Euros were invested in ICT equipment. See *ibid.* p. 7.

<sup>2</sup> Anecdotal evidence on major failures of heavy ICT investments illustrates that the risks of failure in this area are significant. In Europe, the UMTS mobile phone networks have not led to rapid use of a mobile Internet, as was expected in 2001, when telephone carriers spent about € 100 billion to have a first-mover advantage over the rest of the global carrier industry. The recent significant delay of the road pricing system, TollCollect, led to significant



This raises a number of questions concerning the previously-proposed explanation of the US productivity rebound.

- Is ICT investment really the key to explaining US development (see, e.g., CARR 2003, 2004)?
- Are still-significant differences in the measurement of quality changes by hedonic methods in the US and other OECD countries distorting comparative analysis (see, e.g., WYCKOFF, 1995; OECD 2001, MOCH & TRIPLETT 2001, MOCH 2001, HARTWIG & SCHIPS, 2005)?
- Are there hidden complementarities to ICT investments which would help explain the differences in efficiency in ICT investments in the US and most other OECD countries (GRILICHES 1969, MELKA & NAYMAN ZIGNAGO MULDER 2003, ERBER & HAGEMANN 2004)?
- Is ICT capital therefore only an enabler, a necessary but insufficient input to raise productivity, and does the whole environment of its application matter much more than simple growth accounting exercises could reveal (see e.g. ABRAMOWITZ 1985)?

The standard methodology in growth accounting based on production or cost functions cannot distinguish adequately between efficient and inefficient use of input factors. A key assumption is that a cost minimizing or profit maximizing firm always uses factor inputs efficiently. The possibility of inefficient use of resources is therefore ruled out by assumption.

The aggregate analysis, however, also rests on the assumption that all firms have access to the same technology pool, meaning the representative firm is not limited by barriers to access to ICT capital goods. Looking at the current free trade environment this seems at first sight plausible, but as studies with firm-level data show (see BRYNJOLFSSON & HITT 1995, 1996, 2000, 2003), a significant degree of heterogeneity in the use of ICT technology at the firm level prevails even in the US economy. This gives empirical evidence that not all factor inputs needed are tradable as standardized commodities and services. Therefore, firm-specific

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losses is another example. Complex ICT systems need much more serious planning than simply offering access to the PC and Internet, then waiting for a major productivity shock including the introduction of work flow organization, content management, the establishment of well-connected value chains in e-commerce and e-business, as well as having many e-government applications. Without reducing the risk of overall failure, or at least significant cost overruns and delays, ICT cannot deliver what was promised in the early euphoria of the Internet boom or New Economy Bubble. As Abramowitz (1986) summarized, the social capability to absorb and make use of new technologies seems to play an important role in their effectiveness.

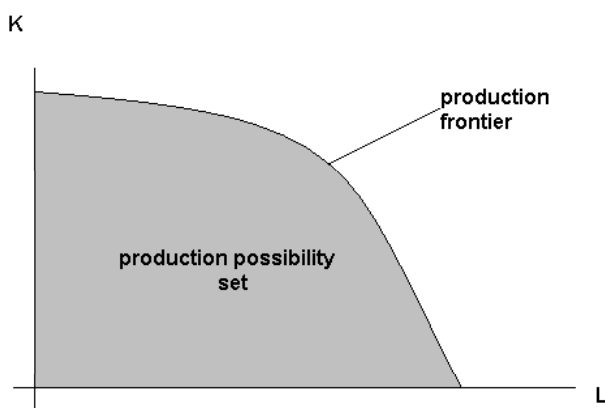
factors like organizational structure, human capital, intangible capital (see, e.g., MALONE *et al.* 2003 or LONI & LARSEN 2001) and the overall institutional legal system and regulation in a state will play an important role in explaining differences in the efficiency of ICT capital use.

## 2 The production possibility frontiers approach

To address of these inefficiencies, alternative methods pay explicit attention to the presence of inefficiencies between different production systems, whether at the level of national economies as whole or at the industry or firm level. Among these are the DEA (data envelopment analysis; see COELLI *et al.* 1997, Chap. 6 & 7) and the frontiers approaches (*ibid.* Chap. 8 & 9).

Neither method assumes that resources always and everywhere are used efficiently such that producers always produce at the production efficiency frontier (in the classical terminology the production function). Instead both operate on a production possibility set.

Figure 1  
Production possibility set and frontier



If, given the input set, the produced output level stays below the potential maximum level, then the respective inefficient use of resources indicates indirectly that the production system or single producer faces inabilities to match the best available practice. Farrell (1957) was the first to distinguish between technical and allocative efficiency. *Technical efficiency* reflects the ability of a firm to obtain maximal output from a given set of inputs. *Allocative efficiency* is used for the ability of a firm to use the inputs in optimal proportions, given their respective prices. The combination of both gives a measure of the total *economic efficiency*.

In the beginning of the literature on production possibility frontiers (see, e.g., AIGNER & CHU 1968, AFRIAT 1972), one assumed that the leader of a sample was always reaching the boundary of the frontier. Therefore one used the term *deterministic production possibility frontier*. The best producer, therefore, could not improve his performance any further.

This view, however, is at least somewhat misrepresentative, as most managers would agree that even being the leader always has ample room for further improvement. World champions in a sport would never believe that either they cannot improve or others cannot top them eventually. Another criticism relates to the sensitivity of such a frontier to the possible influence of measurement errors and other noise at the frontier (see TIMMER 1971). Estimating a deterministic possibility frontier therefore would not give robust results under such circumstances. Furthermore, excluding the best-practice firm from a random sample would lead to highly biased efficiency estimates. Therefore it was sensible to weaken the deterministic frontier approach by changing the deterministic frontier into a stochastic one (see AIGNER *et al.* 1977, MEEUSEN & van der BROECK 1977).

A stochastic possibility frontier introduces a theoretical benchmark which usually cannot be matched by any actual producer. It is a quasi-ideal production frontier which, due to all kinds of impediments in the particular situations of each producer, cannot be matched completely (at least permanently). This gives sufficient incentive for even the best-practice producer to search for further improvements. Assuming for the moment a log-linear production function where  $i$  firms produce their output given the technological parameter  $\beta$ , the stochastic possibility frontier is determined by two types of random errors. These are the always-positive inefficiency random variable  $u_i$  and the new random error term  $v_i$ , which has the usual properties of identical, independent, normally distributed errors with mean  $\mu = 0$ , and constant variance,  $\sigma_v^2$ .

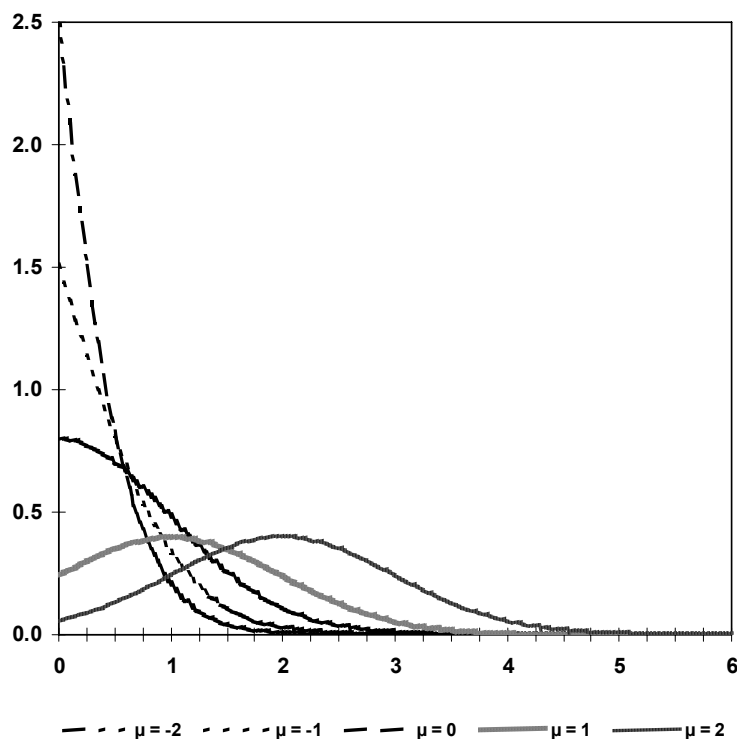
The production frontier is therefore determined by the deterministic part plus a stochastic part consisting of a mixture of two probability distributions: one non-negative one,  $u_i$ , (e.g., a positive truncated normal distribution), plus the usual normal distribution of the error term,  $v_i$ . As a result, the estimation of a stochastic possibility frontier has to estimate the parameters of the two probability distributions simultaneously.

The following graph shows different types of truncated normal distribution density function, which depends on the truncation parameter  $\mu$ , in Figure 2.

The stochastic frontier function is therefore bounded from above by

$$\ln(y_i) = \beta_0 + \sum_{j=1}^m x_{ij} \cdot \beta_j + v_i \quad \text{for } i = 1, \dots, N. \quad (1)$$

Figure 2  
Truncated normal densities



The model equation can be estimated by using the standard maximum likelihood methods. However, one has to make explicit assumptions about the underlying probability distributions of the two random variables. The estimation function cannot be derived explicitly. One has to numerically optimize the ML function. This is estimated with the Frontier 4.1 program (see COELLI 1996). For the exact specification of the ML function, see BATTESE & CORRA (1977). They show that the ML estimators are consistent and asymptotically efficient (AIGNER *et al.* 1977).

The model is not limited to a Cobb-Douglas function estimation, but could be easily adjusted to a more flexible functional form of a translog production function (see CHRISTENSEN *et al.* 1972).

$$\ln(y_i) = \beta_0 + \sum_{j=1}^m x_{ij} \cdot \beta_j + \sum_{j=1}^m \sum_{k=1}^m \beta_{jk} \cdot x_{ik} \cdot x_{jk} + v_i - u_i \quad \text{for } i = 1, \dots, N \quad (2)$$

One-sided generalized likelihood ratio tests for such estimators were derived later (COELLI 1995).

In the current paper, we use this stochastic possibility frontier approach to measure the degree of inefficiency in different countries' use of factor inputs at the telecommunication industry level. The possibility frontier approach, however, gives no explanation of the causes of such inefficiencies, but merely states that a certain factor combination is used inefficiently. Organizational or institutional failures are not revealed because they are not explicitly introduced in the estimation of the stochastic possibility frontier.

In its standard form, the stochastic possibility frontier approach uses the model for a cross-section analysis for example, to evaluate the efficiency or inefficiency of telecommunication service providers (see, e.g., COELLI *et al.* 1998 p. 193 ff.). Later, Pitt and Lee (1981) developed a version for panel data. Schmidt and Sickels (1984) subsequently observed that when panel data are available there is no need to specify a particular distribution for the inefficiency effects, because the parameters of the model can be estimated using the traditional panel data methods of fixed effect estimation (dummy variables) or error-component estimation (see GRIFFITH *et al.* 1993).

In our analysis, we will use a panel data approach because we have a small number of available countries. By pooling industry and country data in a multi-country panel, we have sufficient observations. There is ample room to look for more generalizations of the stochastic possibility frontier model, but these are beyond the scope of this paper.

### 3 Data

Our study uses the data supplied for four EU countries (Germany, France, U.K. and Netherlands) by the Groningen Growth and Development Centre (see O'MAHONEY & van ARK 2003).

The data are organized from the aggregate level into 26 industries. They cover a time range from 1981 until 2002. As input factors in the production function they distinguish labour inputs plus quality change in labour input, non-ICT and ICT capital stocks, and total factor productivity (TFP). Output is measured by real value added at 1995 prices.

The panel is unbalanced because for the year 2002 the observations for the France and the UK are missing. The Frontier 4.1 program takes this unbalanced panel data situation into account.

From this dataset one could form different panel data subsets. One could pool country data by single industries (such as telecommunication industry) over time, but one could also study the efficiency of the overall economy by pooling the data across all industries, thus capturing structural inefficiencies in factor allocation across sectors. In the following estimation, we will use only the data for the telecommunication industry for a five-country panel data set. The countries included are the US, Germany, France, the UK, and the Netherlands, plus an aggregate of the EU4.

## 4 Estimation results

The telecommunication industry is an interesting case to study because the differences in ICT capital usage have had a particularly important impact on this industry over the past two decades. Therefore one would expect an even larger impact of ICT capital usage than for the economy as a whole.

### 4.1 Error component model<sup>3</sup>

Estimating the stochastic possibility frontiers for the telecommunication industries using the approach above we obtain the following technical efficiency rankings.

Somewhat surprising, France and the UK lead in their average technical efficiencies relative to Germany, the Netherlands and the US. The variation in efficiency performance by country is greater in telecommunications than in the aggregate production possibility sets for the whole economies.<sup>4</sup>

The weakness of the US telecommunication industry with regard to technical efficiency, however, seems in line with common sense given their relative competitiveness position. A delay in mobile communication services relative to Europe with regard to a common standard GSM might be due to heterogeneity in US mobile communication technologies have impediments in implementation during the 1990's.

We tested two different model specifications: the Cobb-Douglas function and the translog function. The Cobb-Douglas-function is simply a special case of the translog production possibility function, where the second order terms are omitted. The translog production function is a second order approximation of an unknown production possibility set, meaning it has a high degree of generality to various production possibility sets.

The parameters related to ICT capital stocks are significant at the 5% and 1% levels for the estimates of the frontier in the Cobb-Douglas function estimates. However, labour quality does not contribute positively to the technological efficiency. Harrod-neutral techno-

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<sup>3</sup> Separating the inefficiency error from the random error of the joint random variable has inspired Coelli to name this type of models error component model.

<sup>4</sup> The results obtained for the economy as a whole will be published in a separate paper including the 15 oldest EU member countries and the US.



logical progress has contributed positively and is significant, while non-ICT capital has no significant effect on output growth in the telecommunication industry during our sample period. The latter might result because the fixed wireline networks did not expand significantly in most countries, and the investments in the wireless networks did not need as much investment in non-ICT capital as the earlier fixed wireline networks. Output growth is predominantly ICT capital-led, but even then much less investment is needed than before.

Interestingly, the elasticities for ICT capital investment indicate positive effects for output growth and are larger than for non-ICT capital investments. Labour contributes positively to output growth. A reduction in the labour force in the telecommunication industry occurred immediately after deregulation. However, the elasticity of labour inputs is well below unity, so that overall all factor inputs are diminishing with regard to output growth in telecommunications. Autonomous technological progress is the key driver for output, and is composed largely of ICT capital.

Table 1  
Telecommunications industry

	Translog <sup>1</sup>		Cobb-Douglas	
	$\beta$	t-value	$\beta$	t-value
Constant: $\beta_0$	0.035	3.2	0.101	0.5
Non-ICT Capital: $\beta_1$	-0.654	2.1	-0.177	0.4
ICT Capital: $\beta_2$	0.020	0.2	0.135	6.1
Labour Quality: $\beta_3$	-0.342	0.6	-0.648	0.7
Labour: $\beta_4$	0.027	3.3	0.781	2.5
Time: $\beta_5$	0.426	0.7	0.469	4.2
Error term: $\sigma_v^2$	0.023	3.9	0.029	1.6
Inefficiency term: $\gamma^2$	0.901	9.1	0.780	0.7
Truncation parameter: $\mu$	0.087	2.0	0.113	0.4

<sup>1</sup> Only estimates of the first order terms of the translog function.

$$^2 \gamma = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2}$$

Even if the parameters of the first order terms in the Translog-function specification differ in magnitude from those of the Cobb-Douglas-function this may be attributed that the second order terms of the Tranlog-function account for some non-linearities in the explanatory variables since the parameter values on the main diagonal elements in table 2 are with exception of labour quality staisitical significant.

There is empirical evidence that the distribution of the inefficiency random variable as a positive truncated normal distribution is slightly larger than a half-normal distribution for the translog function but half-normal for the Cobb-Douglas function. So we might assume without a great loss of generality that a half-normal distribution is a reasonably good approximation of the true truncated normal distribution.

Table 2

**Second order parameter estimates of the translog function in telecommunication**

		Non-ICT capital	ICT capital	Labor Quality	Labor
Non-ICT capital	coeff.	- 2.54	1.54	5.25	2.41
	t-ratio	- 2.60	3.08	1.11	0.85
ICT capital	coeff.		- 0.17	- 1.88	- 2.38
	t-ratio		- 2.13	- 1.18	- 3.45
Labor Quality	coeff.			1.88	33.85
	t-ratio			0.35	5.27
Labor	coeff.				10.62
	t-ratio				7.46

Estimates with Frontiers 4.1, Nonlinear Maximum Likelihood, 1981-2002

Looking at the parameters estimated for the second order terms of the translog function in Table 2 one notices that the elements on the main diagonal, except that for labour quality, are statistical significant at the 5% level. The cross effect between non-ICT and ICT capital is significant, as well as that of labour quality and labour. The latter has an especially large parameter estimate, which could be interpreted as efficiency growth in telecommunication having a significantly large skill bias in favour of high-skilled labour.

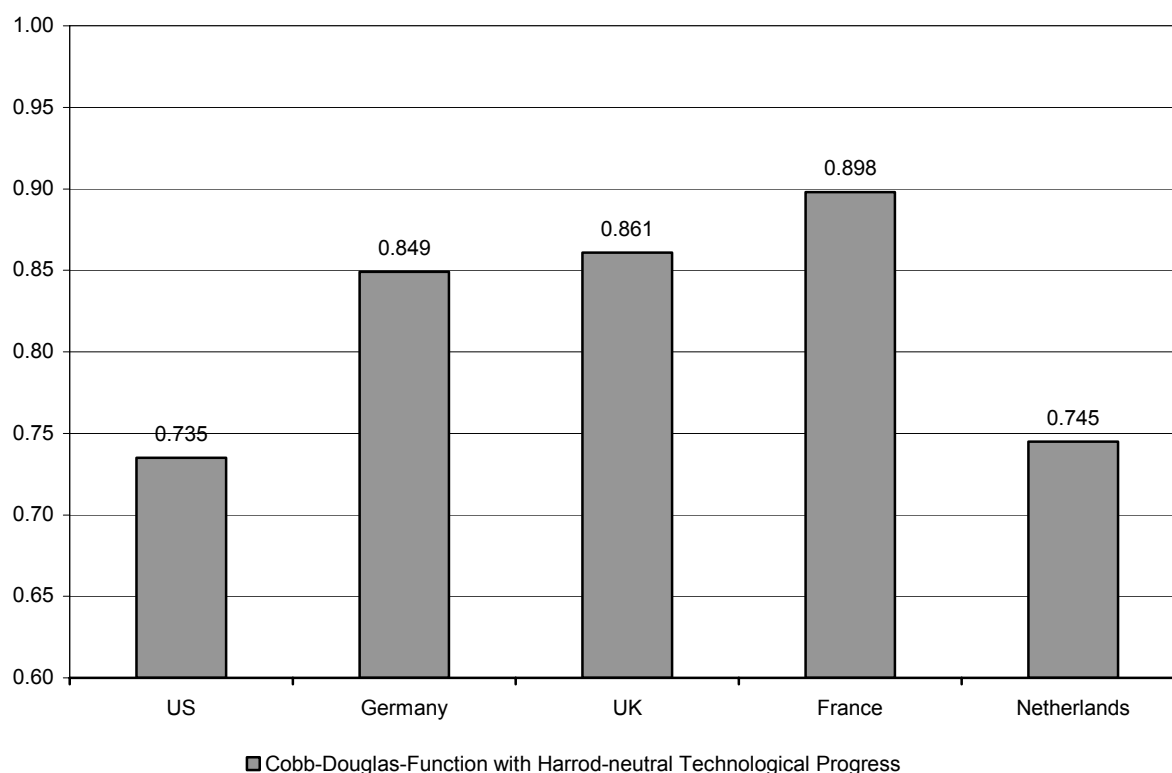
Looking at the results of the estimates of the average inefficiencies by country over the time period from 1981 until 2002 one obtains the following ranking. France leads with 0.898,

followed by the UK with 0.861, Germany with 0.849, the Netherlands with 0.745 and finally the US with 0.735. However, these averages hide important dynamic developments studied by the following model.

Figure 3

**Average inefficiency\* in telecommunication industries in the US and selected EU-countries, technical efficiency effects\*\***

1981 - 2002



\* If the value is equal to unity total efficiency is accomplished by a country. Values below unity determine the distance of the country from the stochastic possibility frontier, SPF.

\*\* Cf. Battese, Coelli (1995), Erber (2005).

Source: GGDC, Calculations of the DIW Berlin.

## 4.2 Technology efficiency effects frontiers

We also tested a model where the inefficiency term is not fixed over time, so that we get time-varying inefficiency estimates (see BATTESE & COELLI 1995). The inefficiency error variables are auto-correlated for each country over time by the following relation  $u_{it} = u_o \cdot \exp(-\eta \cdot (t - T))$ . Due to the increase in the number of parameters to be estimated in

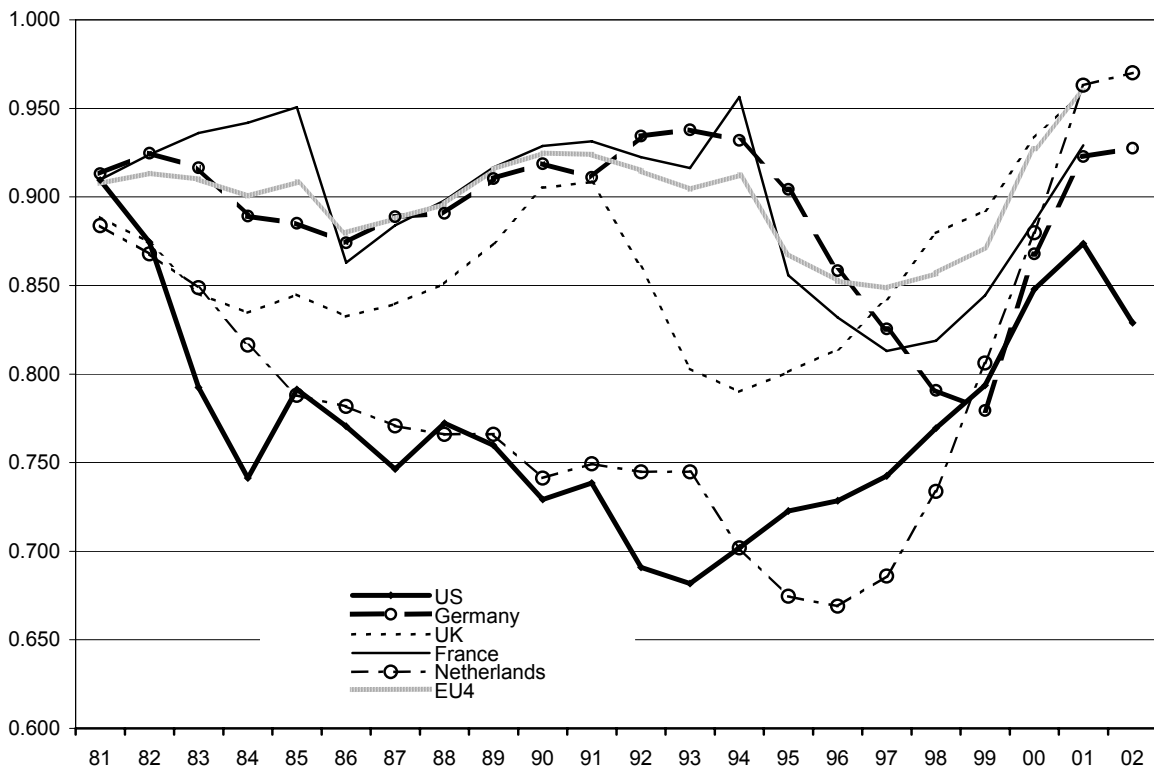
the model, it was simplified by assuming that the inefficiency distribution is half-normal and that a Cobb-Douglas function is a sufficiently good approximation of the true model.

Looking at the results from this estimation (see Figure 4 and Table 3), we notice that the estimation of average inefficiencies of the previous section does not reveal important dynamics in the catching up or falling behind in inefficiencies for the sample countries. For all countries included in the panel estimation, we find that there is a high time-varying volatility in the inefficiency estimation. In France, the inefficiency increased dramatically in the mid-1980's, then increases afterwards to a new peak in 2001.

Figure 4  
**Development of inefficiency\* in the telecommunication industries in the US and selected EU-countries, technological efficiency effects\*\***

Cobb-Douglas-function with Harrod-neutral technological progress

1981 - 2002



\* If the value is equal to unity means a country achieved total efficiency. Values below unity determine the distance of the country from the stochastic possibility frontier.

\*\* Cf. Battese, Coelli (1995), Erber (2005).

Source: GGDC, Calculations of the DIW Berlin.

Table 3  
**Development of inefficiency\* in the telecommunications industries in the US and selected EU-countries, technological efficiency effects\*\*, 1981-2002**

	US	Germany	UK	France	Netherlands	EU4
1981	0.910	0.913	0.889	0.910	0.884	0.907
1982	0.875	0.925	0.874	0.924	0.868	0.913
1983	0.792	0.917	0.845	0.936	0.849	0.910
1984	0.741	0.889	0.835	0.942	0.816	0.900
1985	0.791	0.885	0.845	0.951	0.788	0.908
1986	0.770	0.874	0.832	0.863	0.782	0.880
1987	0.746	0.889	0.839	0.884	0.771	0.888
1988	0.772	0.891	0.851	0.898	0.766	0.896
1989	0.760	0.910	0.874	0.917	0.766	0.916
1990	0.729	0.919	0.905	0.929	0.741	0.925
1991	0.738	0.911	0.908	0.931	0.749	0.924
1992	0.691	0.934	0.861	0.922	0.745	0.915
1993	0.682	0.938	0.803	0.916	0.745	0.904
1994	0.702	0.932	0.790	0.956	0.702	0.912
1995	0.723	0.904	0.801	0.856	0.675	0.868
1996	0.728	0.858	0.814	0.832	0.669	0.852
1997	0.743	0.825	0.843	0.813	0.686	0.849
1998	0.769	0.791	0.880	0.819	0.734	0.857
1999	0.794	0.779	0.892	0.844	0.806	0.871
2000	0.848	0.868	0.933	0.886	0.880	0.927
2001	0.874	0.923	0.960	0.929	0.963	0.960
2002	0.829	0.927			0.970	
∅ Rank 81-02	5	3	2	1	4	
Rank 2001	5	4	2	3	1	
Minima	1984, 1993	1986, 1999	1986, 1994	1986, 1997	1996	1997
Maxima	1985, 2001	1983, 1993, 2002	1991, 2001	1985, 1994, 2001	1981, 2002	1985, 1991, 2001

\* Estimated by using a Cobb-Douglas-production function with Harrod-neutral technological progress.

\*\* Cf. Battese, Coelli (1995), Erber (2005).

Source: GGDC, Calculations of the DIW Berlin.

In comparison with France, the two Anglo-Saxon countries, the US and the Netherlands, experienced a fairly steady increase in inefficiency from the early 1980's until the mid-1990's. In about 1993 a turnaround occurred, resulting in a rebound to significantly higher efficiency levels. The Netherlands, however, lags behind the US with regard to the dynamics of inefficiency changes at all points in time. The Netherlands decline is steeper and the recovery weaker. In 2001, the UK efficiency level peaked together with the Netherlands.

France and Germany show a similar pattern of initial decreasing efficiency followed by a turn around. But the increase of efficiency occurred later in both countries than in the US, the UK and the Netherlands. Germany lags furthest behind in its catching up. This indicates that

the efficient use of new ICT technologies in the telecommunication industry varies significantly across countries. In particular, the early development leaders could gain a temporary comparative relative efficiency gain over the others which erodes while countries that implemented new technology later, like Germany, catch up.

The rankings obtained in the previous section, therefore, only give averages of this dynamic process of adoption of new ICT. This hides important differences because it conceals individual country's adjustment processes, each one which differs in the timing and speed of adopting best-practice technologies.

### 4.3 J-curve of adoption of innovations and phase delays

Adoption of innovations is expected to take place gradually, particularly if one considers the macro perspective of a national industry. This gradual change, however, only needs time, but comes at a cost in transitory inefficiency increases. Paul David (1991, 2000) has pointed out in a number of studies of the historical diffusion of general-purpose technologies, such as the steam engine or the dynamo. The microelectronic revolution, which led, *inter alia*, to the invention of the Internet as a general communication platform, started to take a similar shape in the mid-1990's. The transition from an old technological paradigm – the analog line switching telephone network, to modern packet switching digital IP networks supports – presents the possibility of a transitory inefficiency effect in telecommunication technology. Not all customers (and therefore the whole infrastructure) switch technologies at once. Maintaining a parallel network infrastructure is costly and will decrease efficiency. Until a certain threshold is reached in the size of the traditional phone networks enabled as IP-based digital broadband networks, the benefits of the new technology might be outweighed by high initial infrastructure investment costs. This is true until positive network externalities<sup>5</sup> outstrip initial costs. This supports the hypothesis that efficiency might decrease before it can increase and move to a higher level. The J-curve has become a common term for this shape of development.<sup>6</sup>

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<sup>5</sup> Network externalities are size effects of networks where the utility of the individual network members depends on the size of the network due to the larger number of accessible members. Therefore positive network externalities are beneficial effects, negative are harmful effects, e.g. if congestion in a network occurs with the increasing number of network members.

<sup>6</sup> In foreign trade theory, the adjustment path of the devaluation of a currency to stimulate the adjustment of the trade balance has been observed to show similar shapes with regard to the trade balance. Instead of the long-run effect expected by of economic theory that devaluation will lower the net trade deficit, the short-run effect is just

In the unilateral case this is the whole story. But if one starts to compare different units with regard to their paths of adoption, there is the possibility of delays. One country might start the process early to achieve a first-mover advantage. Other more risk-adverse countries might delay adoption because they are sceptical that the new innovation will merit its expectations. The risk of investing in an innovation could later lead to stranded costs when the innovation fails to fulfil the expected gains in efficiency. This leads to a phase delay of adoption from one country to others. Figure 5 gives a graphical representation of this J-curve adoption process with a phase delay between the two representative countries.

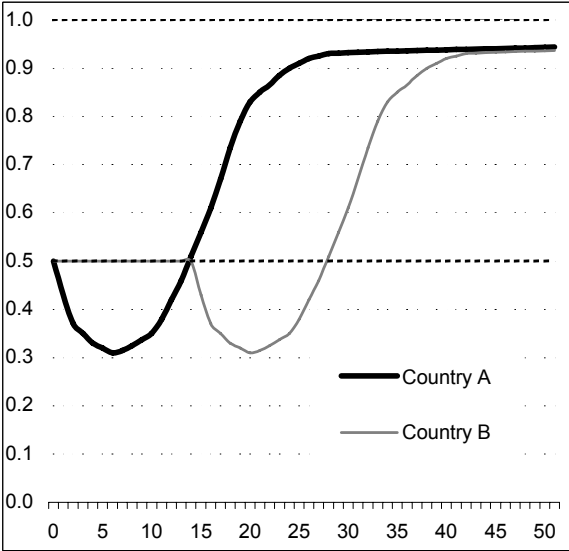
If, however, one compares the relative level of the two countries over time, one obtains the second graph of the Figure 5. What makes a striking difference is that the magnitude of relative inefficiency-differences changes much more dramatically across time during the process than the one depicted in Figure 5. This is due to the asynchronous adoption of the innovations in the two countries. The country that started first experiences, relative to the other country (which just passes through the valley of transitory inefficiency of the J-curve), when reaching the upward section of the J-curve, a seemingly much larger transitory relative acceleration in its bilateral comparative advantage in efficiency, but this momentary state does not give an accurate long-term perspective of how the efficiency gap will develop. A temporary efficiency miracle in one country relative to the other is just an intermediate state in the long-term adjustment process. Extrapolating these short-term movements as long-term trends will therefore be grossly misleading.

Looking at the empirical results obtained from our estimations in Figure 4 we observe that this J-curve adoption pattern occurs for all five countries during our observation period. This lends empirical support to the idea that the J-curve adoption process was an essential element in the diffusion of the Internet technology and the deregulation of telecommunication markets in these countries. Both led to a short-term increase in inefficiency followed by a subsequent long-term increase in efficiency.

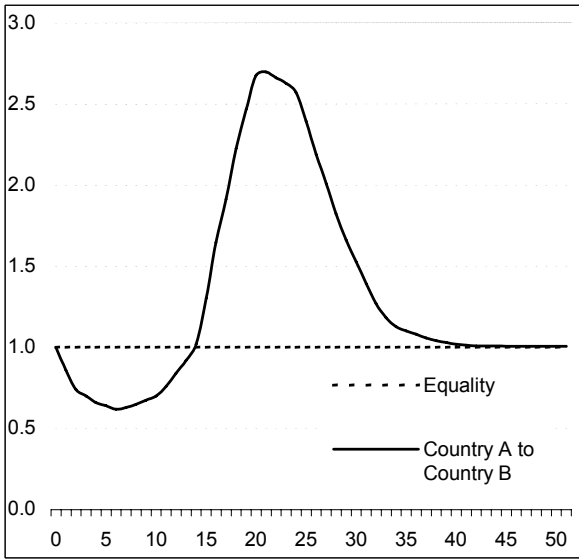
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the opposite. The net trade deficit first increases due to imperfect markets and adjustment costs before it starts to decrease when the adjustment process has reached a certain level of maturity.

Figure 5  
J-curve trajectories of efficiency development by an adoption of an efficiency enhancing innovation including a phase delay



Relative bilateral efficiency development of country A to country B



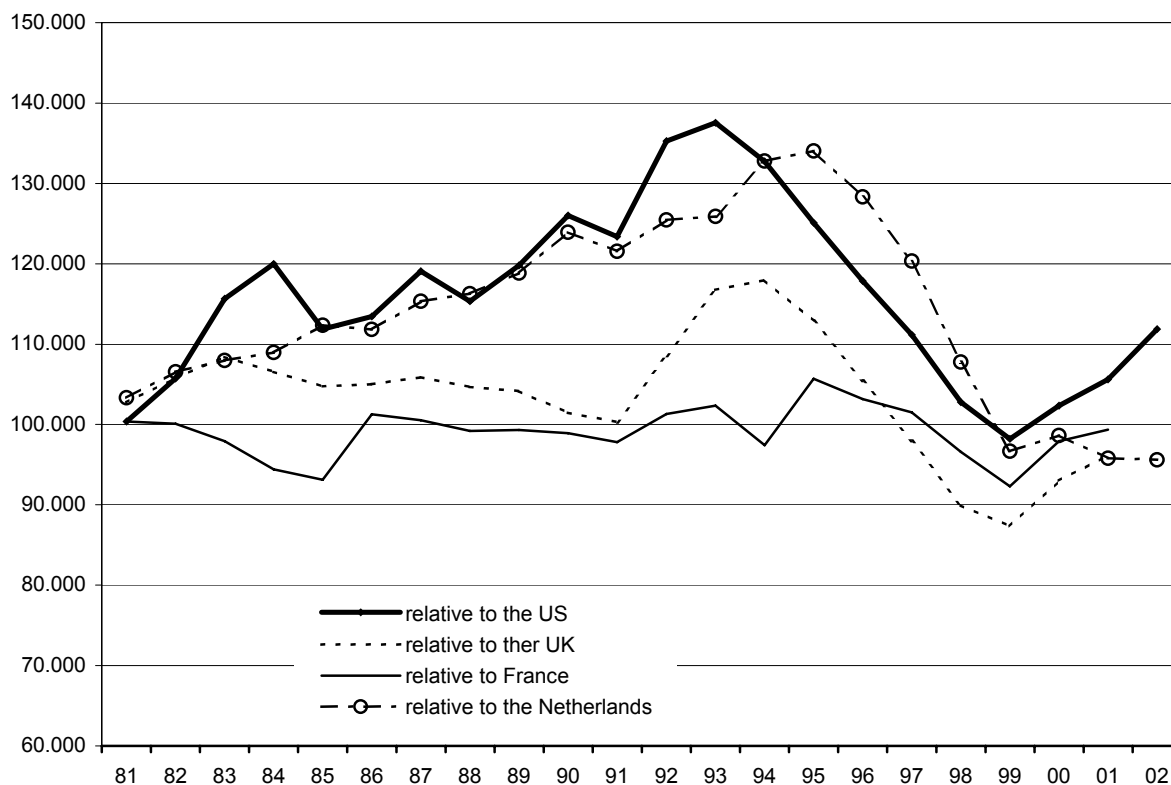
Source: Own Calculations.



Figure 6  
**Development of inefficiency-gaps\* in the telecommunication industries in Germany relative to the US and selected EU-countries, technological efficiency effects\*\***

Cobb-Douglas-function with Harrod-neutral technological progress

1981 - 2002



\* If values are equal to 100 total efficiency/inefficiency equality between Germany and the other countries prevail. Values below 100 denote an inefficiency-gap of Germany relative to the other country. Value above 100 denote an efficiency-advantage relative to the other country.

\*\* Cf. Battese, Coelli (1995), Erber (2005).

Source: GGDC, Calculations of the DIW Berlin.

Figure 6 above gives the graph of the relative inefficiency ratios of our empirical data. As one would expect from the theory of J-curve adoption of an innovation, the relative comparative advantages show a much higher variability, in accord with this theory that the overall efficiency level of the possibility frontier should be taken as a reference system.

Table 4

**Development of inefficiency-gaps\* in the telecommunication industries in Germany relative to the US and selected EU-countries, technological efficiency effects\*\*, 1981-2002**

	relative to the US	relative to the UK	relative to France	relative to the Netherlands	relative to the EU4 average
1981	100.389	102.749	100.381	103.317	103.317
1982	105.732	105.771	100.094	106.556	104.626
1983	115.663	108.404	97.916	107.976	103.708
1984	119.973	106.558	94.414	108.941	100.623
1985	111.860	104.759	93.115	112.339	100.157
1986	113.448	105.001	101.285	111.823	98.906
1987	119.087	105.881	100.539	115.328	100.564
1988	115.343	104.657	99.197	116.291	100.786
1989	119.805	104.155	99.310	118.849	103.007
1990	125.995	101.494	98.914	123.925	103.952
1991	123.376	100.287	97.806	121.576	103.081
1992	135.268	108.581	101.300	125.480	105.733
1993	137.562	116.775	102.349	125.903	106.112
1994	132.767	117.976	97.434	132.780	105.448
1995	125.124	112.885	105.672	134.045	102.325
1996	117.842	105.446	103.169	128.327	97.126
1997	111.177	97.981	101.522	120.350	93.406
1998	102.790	89.918	96.586	107.787	89.489
1999	98.205	87.338	92.300	96.669	88.184
2000	102.349	92.992	97.943	98.646	98.202
2001	105.628	96.150	99.328	95.813	104.415
2002	111.878			95.599	104.942

\* If values are equal to 100 total efficiency/inefficiency equality between Germany and the other countries prevail. Values below 100 denote an inefficiency-gap of Germany relative to the other country. Value above 100 denote an efficiency-advantage relative to the other country.

\*\* Cf. Battese, Coelli (1995), Erber (2005).

Source: GGDC, Calculations of the DIW Berlin.

This lends strong support for the hypothesis that bilateral comparisons taken at an arbitrary time during the transition process will give a misleading perspective of long-term differences. The phase-delayed J-curve adoption as a non-linear adjustment process must be taken into account if one wishes to assess the long-term impacts and relative comparative advantages.

## 5 Conclusions

These estimates of aggregate stochastic possibility frontiers for the telecommunication industries give some indications that this approach could be used to accomplish a benchmarking of different national industries. Using the standard Cobb-Douglas model and more flexible functional forms such as the translog-function approach, understanding of the stability of the output elasticities of the different input factors is achieved. Furthermore, by using the error component model we could test which type of truncated distribution function is suitable for the estimation. By extending the model to include time-varying inefficiencies with the technological efficiency effect frontier, we could get a better understanding on the dynamic development of variations of inefficiencies over time.

Even though it is not possible to estimate a simultaneous model with all these desirable generalizations on production technology (because of limitations in the data set and as well difficulties related to the non-linear estimation of models with a large number of parameters), the results obtained give fairly interesting insights into the different patterns observable in different countries with respect to overall inefficiency and time paths of the development of inefficiency.

The latter results give important information indicating that some of the differences depend heavily on the lead-lag relation when new ICTs emerge and are adopted at different time by leading and lagging countries. The Netherlands and the US have experienced with significant recoveries after deep slumps in efficiency performance. Germany, together with France, performed well for long time, experienced a steep decline in the mid 1990's, and only recently began a slow recovery.

The industrial restructuring process, therefore, does not respond uniformly to new technological opportunities. Much depends on the social capability and the institutional environment to adjust flexibly to these new opportunities. Germany seems to have had more difficulty to adjusting early, while others forged ahead. However, the dynamic process of diffusion and adjustment observed in the past indicates that countries that lag behind initially have plenty of time to catch up later. This gives hope that those who missed the initial phase may eventually receive the benefits.

With regard to the questions raised at the beginning we conclude that ICT investment and its short- to medium-term impacts on productivity and efficiency are very different and expect-

ing immediate benefits will be misleading since the efficiency gains will occur only after some time. The different timing and shapes obtained from our estimates of the J-curve of adoption lends strong support that ICT capital is just an enabler, i.e. a necessary but not sufficient condition to obtain the benefits later on. Therefore a search for explicit factors explaining these differences could be a next step for a better understanding the national differences in the telecommunication industries.

Currently, the convergence between voice communication and the Internet via VoIP, together with the integrated platform of fixed wireless access technologies (like WiFi and WiMax) with mobile phone access via GSM and UMTS, respectively will lead to new significant structural adjustments. Therefore, there is no time to be lost in the technology adoption race for those countries that have failed to move quickly in the past.

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