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PRODUCTIVITY SLOWDOWN AND THE ROLE OF THE ICT IN ITALY: A FIRM-LEVEL ANALYSIS

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ABSTRACT

This paper presents a firm-level analysis of the productivity slowdown that has been recently observed in Italy. DEA techniques are applied to the firm-level data collected within the annual surveys on the economic accounts of enterprises carried out by the Italian National Statistical Institute (ISTAT). TFP changes over the years 1996-1999 have been measured for 33 industries and have been decomposed into technological change (shift in the production frontier) and change in relative technical inefficiency (due to modifications in the distance of the single firms from the frontier). This decomposition has turned out to be helpful in interpreting the nature of the observed productivity slowdown. Econometric regressions of the firms' TFP changes on a number of variables, including a component factor correlated to ICT, reveal that the information and communication technologies may have had a positive and significant impact on TFP in all the examined industries during the period.

JEL Classification Codes: D2, L2, O4

Keywords: ICT, Technical efficiency, Productivity

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SUMMARY

This paper attempts to measure total factor productivity (*TFP*) growth in Italy for a large number of industries using micro-data of firms for the period 1996-1999. Using a non-parametric technique based on index numbers, the average *TFP* growth within the industries is decomposed into changes in the best-practice frontier (technological change) and changes in the firms' distance from that frontier (changes in relative technical efficiency). The influence of the *ICT* on *TFP* growth is, then, studied by means of econometric regressions, controlling for the contribution of a number of other factors.

The *TFP* growth and its components are constructed, for each firm, using Malmquist index numbers constructed by means of *Data Envelopment Analysis*. The results obtained are aggregated at the level of industry by taking their weighted averages. The econometric regressions are carried out to look for correlations between the productivity performance and the relevant explanatory variables, including the intensity of use of *ICT*, tangible capital, human capital, and *R&D*.

In the average, during the period 1996-1999, *TFP* has slightly decreased (-0.39%), due to a negative effect of technological change (-0.95%) and a positive change in technical efficiency (+0.56%). The negative "technological change" can be rationalized as second type of technical efficiency change, whereas the best-practice frontier can be seen to remain, in fact, unchanged.

During the same period, *TFP* has varied substantially among the industries both in sign and magnitude. The industries that have suffered from the greatest decrease in *TFP* are *Real Estate, renting and business services, Health services, Computer services and related activities, Petroleum and coal products, Research and Development, Hotels and restaurants, Transport and storage services, Other community and social work*. The observed decrease in *TFP* in these industries has been due mainly to the negative effects of technological change.

The negative technological change has been noted particularly in *Wholesale and retail trade, Medical and precision instruments, Wood products, Machinery and Equipment, Pharmaceutical products, Textiles, apparel, and leather, Pulp, paper, and paper products, and Aircraft and spacecraft*. By contrast, a positive technological change and a positive technical efficiency change have been found in *Office, accounting, and computing machines, Shipbuilding, Post and telecommunications, Iron and Steel*. A positive technological change but a negative technical efficiency change have been noted in *Chemicals, Non-ferrous metals, Food, beverage, and tobacco, Electricity, gas, and water, Rubber and plastic products*.

The econometric results reveal that the *ICT* is positively correlated to *TFP* in all the industries examined and this correlation appears to be significant in a certain number of cases. Apart from the adjustment and organizational costs that are generally encountered with the installation of new types of capital goods, a substantial portion of the productivity stagnation observed during the recent years in Italy can be explained with the relatively low accumulation of information and communication technologies.

RALLENTAMENTO DELLA PRODUTTIVITA' E RUOLO DELLE ICT IN ITALIA: UN'ANALISI A LIVELLO DI IMPRESA.

SINTESI

Scopo di questo lavoro è quello di effettuare un'analisi a livello di impresa del rallentamento della produttività recentemente osservato in Italia. Alcune procedure basate sulla *Data Envelopment Analysis* sono state applicate ai dati raccolti nell'ambito delle indagini annuali sui conti economici delle imprese effettuate dall'ISTAT. I cambiamenti nella produttività multifattoriale durante il periodo 1996-1999 sono stati misurati per 33 industrie e sono stati quindi scomposti in cambiamento tecnologico (dovuto allo spostamento della frontiera di produzione) e cambiamento nell'efficienza tecnica relativa (dovuto a modificazioni nelle distanze delle singole imprese dalla frontiera). Questa scomposizione risulta utile nell'interpretazione della natura del rallentamento della produttività. Le regressioni econometriche effettuate includono la stima del contributo delle tecnologie dell'informazione e delle comunicazioni e mostrano che queste hanno avuto un impatto positivo sulla produttività in tutte le industrie prese in esame durante il periodo considerato.

Classificazione JEL: D2, L2, O4

Parole chiave: ICT, Efficienza tecnica, Produttività.

1 INTRODUCTION

During the last decade, the Italian economy has been suffering from a stagnant total factor productivity (*TFP*)[1]. This appears to be in contrast with the upsurge of productivity growth experienced in other industrialized countries, notably the United States, Canada, Australia and Scandinavian countries[2]. The United Kindom has registered a non-negligible *TFP* growth, even if it has largely decelerated during the last half of the decade[3]. In continental Europe, France and Germany have had a relatively low productivity growth, but have not shown the deceptive stagnation that has been observed in Italy.

Explaining why Italy has been lagging behind other industrialized countries in productivity growth may help us to define policies oriented to foster economic growth and the international competitiveness of domestic firms. It may be of interest to know in what extent productivity gains or losses are distributed across the sectors of the economy and whether these may affect the operating surplus of the firms.

Moreover, the recent debate on the impact of the new information and communication technologies (*ICT*) on *TFP* is still open as regards the European continental countries. It remains to be confirmed whether the *ICT* is an important factor for enhancing the firms' capacity to improve productivity and net income. A number of recent studies have offered strong hints concerning a positive correlation between the intensity of use of *ICT* and productivity performance, although they have been confined within the growth accounting framework on the assessment of direct contribution of the *ICT* capital as a factor of production to the output growth (see, for example, Daveri, 2000, 2001 and, more recently, Bassanetti, Cruciani, Jona Lasinio and Zollino, 2003, for the case of Italy). The question, perhaps more relevant, concerning the indirect effect of the *ICT* on output growth via the induced technological change (and productivity growth) has remained thus far almost unexplored.

In particular, the growth accounting methodology misses by nature the point of measuring the role of *ICT* in increasing productivity through the induced changes in the production technology. In fact, this methodology does not fully consider the role of capital as a vehicle of innovation and technological

1 See, for example, ISAE (2001, pp. 74-79)(2003, pp. 57-64).
2 See Gust and Marquez (2002).
3 Basu, Fernald, Oulton, and Srinivasan (2003) offer a detailed discussion of the UK experience.

change[4]. Moreover, the empirical weight of the *ICT* capital inputs is generally relatively low and can only marginally account for the overall output growth. More relevant can be, instead, their indirect contribution to output growth through the induced changes in the technology and organization of production.

This paper attempts to measure total factor productivity growth for a large number of industries using micro data of firms. The average *TFP* growth within the industries is measured by taking the weighted average of firms' *TFP* growth rates, which can be decomposed into changes in the best-practice frontier (technological change), and changes in the firms' distance from that frontier (changes in relative techinical efficiency). The influence of the *ICT* on *TFP* growth is, then, studied by means of econometric regressions. The elasticity of *TFP* with respect to *ICT* is estimated by taking into account the simultaneous influence of other determinants.

The micro data obtainable from the annual surveys of the Italian National Statistical Institute (*ISTAT*) on the economic accounts of enterprises permit us to analyze the productivity performance over time and across industries at the level of firms. The empirical study presented here has been made by following three steps:

(*i*) Non-parametric techniques derived from *Data Envelopment Analysis* are applied to micro data to construct the *best-practice* or *technological frontiers* of production within the examined industries;

(*ii*) Malmquist index numbers of total factor productivity growth of the single firms within each industry are calculated. They are partitioned into *technological changes* and *changes in technical efficiency*. Technological changes are measured as shifts of the best-practice frontier within the same industry, whereas changes in technical efficiency are measured by estimating changes in the firms' distance to that frontier;

(*iii*) Econometric regressions are used to look for correlations between the productivity performance and relevant explanatory variables, including the intensity of use of information and communication technologies (*ICT*) and other types of capital goods (tangible capital, human capital and stocks of *R&D*).

The paper is organized as follows. The second section presents the methodology of the analysis. The third section describes the data used. The fourth section

[4] The neoclassical models of growth have been criticised on a similar point on the ground of the theoretical literature on endogenous growth that has pointed out beneficial effects that can be derived from capital accumulated in external units and the overall economic system.

presents the empirical results obtained. The fifth section contains conclusive remarks.

2 THE METHODOLOGY

2.1 Measuring TFP, relative technical efficiency, and technological change

The empirical analysis starts with the identification of the best-practice (or technological) frontier of production in each examined industry. This frontier is defined as the set of the most efficient production points in the space of outputs and inputs. One of the methods that can be used to identify this set is *Data Envelopment Analysis*, a linear programming technique by which the production frontier is put in evidence as the piece-wise-linear convex hull formed by referring to the most efficient production points. Using *DEA* results, Färe, Grosskopf, Norris, and Zhang (1994) have constructed the Malmquist index of *TFP* growth, defined by Caves, Christensen and Diewert (1982), and have shown how these indexes can be decomposed into changes in the firms' distance from the efficient frontier (technical efficiency changes) and the shift of the frontier itself (technological change).

The *DEA* technique applies a separate linear programming problem for each of the firms or production units within an examined industry. Consider *N* firms in each industry (with *N* varying across the examined industries). Let the inputs and outputs of the *i*th firm be respectively represented by the *K*-order column vector $\mathbf{x}_i$ and the *M*-order column vector $\mathbf{y}_i$. The input and output data for all *N* firms form the $K \times N$ input matrix $\mathbf{X}$ and the $M \times N$ output matrix $\mathbf{Y}$, respectively.

Assuming the general case, which includes variable returns to scale, the output-oriented measure of the *i*th firm's technical efficiency is derived from the data envelopment form defined by the following optimisation problem:

(1) $$\max_{\phi_i, \lambda} \quad \phi_i$$

$$\text{subject to} \quad \begin{aligned} \mathbf{Y}\lambda - \phi_i \mathbf{y}_i &\geq \mathbf{0}_M \\ \mathbf{x}_i - \mathbf{X} \cdot \lambda &\geq \mathbf{0}_K \\ \mathbf{N1}' \cdot \lambda &= 1 \\ \lambda &\geq \mathbf{0}_N \end{aligned}$$

Where $1 \le \phi_i < \infty$, with ϕ_i being a scalar, λ is an N-order column vector of constants, **N1** is an N-order column vector of ones. The convexity constraint (**N1'**$\cdot\lambda = 1$) ensures that an inefficient production unit is only "benchmarked" against production units of a similar size (in the case of constant returns to scale, this constraint is not imposed, the λ weights sum up to a value different from one and the benchmarking may be made against production units that are substantially larger or smaller than the examined *i*th production unit). The value (ϕ_i - 1) is the proportional increase in output(s) that could be obtained by the *i*th production unit with the input quantities held constant. The output-oriented measure of technical efficiency (TE_i) of the *i*th production unit is given by:

(2) $$TE_i = 1/\phi_i$$

TE_i varies between zero and one ($0 < TE_i \le 1$, where $TE_i = 1$ means that the *i*th production unit is fully efficient and operates on the best-practice frontier).

Technical efficiency measures can be depicted in Figure 1a in the case of constant-returns to scale and in Figure 1b in the case of decreasing returns to scale. The technology is represented, for simplicity, by the one-output one-input piece-wise linear frontier. For the inefficient production unit operating at point P, the Farell input-oriented measure of *TE* corresponds to *AB*/*AP*, while the output-oriented measure of *TE* corresponds to *CP*/*CD*. As it can be seen in Figure 1a, the input-and output-oriented measures are equivalent (*AB*/*AP* = *CP*/*CD*) with the constant returns to scale technology.

Malmquist productivity index numbers can be defined by using the concept of distance functions. The output distance function is defined as:

(3) $$d^{\mathrm{T}}(\mathbf{x},\mathbf{y}) = min\{d: (\mathbf{y}/d) \in \tilde{A}^{T}(\mathbf{x})\}$$

where $\tilde{A}^{T}(\mathbf{x})$ is the set of all possible levels of the output **y** for a given technology T and the input level **x**. The optimal value of the scalar d^* (= $d_0(\mathbf{x},\mathbf{y})$) permits us to calculate the maximal proportional expansion of the output for a given input level. It is equal to unity if **y** is on the frontier, otherwise it is less (greater) than one if the output, **y**, is positioned below (above) the frontier the production possibility set (the location of the output level above the frontier is technically unfeasible, but it is possible to virtually construct such an outcome in comparisons of actual levels of **y** in one period and the frontier existing in another period). We note that $d^{T}(\mathbf{x},\mathbf{y})$ has the meaning of technical efficiency, that is

(4) $$d^T(\mathbf{x},\mathbf{y}) = TE$$

Following Caves, Christensen and Diewert (1982), the Malmquist (output-oriented) index of *TFP* change between period 0 and period 1 is defined as follows:

(5) $$TFP_M(\mathbf{y}_0, \mathbf{x}_0, \mathbf{y}_1, \mathbf{x}_1) \equiv \left[\frac{d^0(\mathbf{y}_1, \mathbf{x}_1)}{d^0(\mathbf{y}_0, \mathbf{x}_0)} \cdot \frac{d^1(\mathbf{y}_1, \mathbf{x}_1)}{d^1(\mathbf{y}_0, \mathbf{x}_0)} \right]^{\frac{1}{2}}$$

The measure of change in *TFP* can be depicted in Figure 2a in the case of constant-returns to scale and in Figure 2b in the case of decreasing returns to scale. The technology is represented, for simplicity, by the one-output one-input piece-wise linear frontier. The *TFP* variation observed between the inefficient production unit operating at point P^0 and that operating at point P^1 is given by $(OA^1/OC^1):(OA^0/OC^0)$. Dividing the two ratios at the numerator and denominator by the average productivity on the respective frontiers of efficient production, given by $B^1D^0/OB^1 \cong B^0C^0/OB^0$ at time 0 and $B^1D^1/OB^1 \cong B^0C^1/OB^0$ at time 1, yields

$$\frac{\frac{OA^1}{OB^1}}{\frac{OA^0}{OB^0}} \cong \frac{\frac{OA^1}{OB^1}}{\frac{B^1D^0}{OB^1}} : \frac{\frac{OA^0}{OB^0}}{\frac{B^0C^0}{OB^0}} = \frac{OA^1}{B^1D^0} : \frac{OA^0}{B^0C^0} = \frac{d^0(\mathbf{x}_1,\mathbf{y}_1)}{d^0(\mathbf{x}_0,\mathbf{y}_0)}$$

$$\frac{\frac{OA^1}{OB^1}}{\frac{OA^0}{OB^0}} \cong \frac{\frac{OA^1}{OB^1}}{\frac{B^1D^1}{OB^1}} : \frac{\frac{OA^0}{OB^0}}{\frac{B^0C^1}{OB^0}} = \frac{OA^1}{B^1D^1} : \frac{OA^0}{B^0C^1} = \frac{d^1(\mathbf{x}_1,\mathbf{y}_1)}{d^1(\mathbf{x}_0,\mathbf{y}_0)}$$

with strict equalities in the case of constant returns to scale (since, in this case, $B^1D^0/OB^1 = B^0C^0/OB^0$ and $B^1D^1/OB^1 = B^0C^1/OB^0$).

The distance functions cannot be computed without knowing the frontier production set. A number of different methods have been devised to estimate this frontier[5]. The *DEA* approach outlined above is one of the convenient

[5] See, for example, Milana and Zeli (2002) for references to the different methods proposed in the literature.

alternatives. Generalising to the case of variable returns to scale the *DEA*-like approach proposed by Färe, Grosskopf, Norris, and Zhang (1994) for the estimation of the distance functions that are necessary to construct the Malmquist index defined by (5) yields:

$$[d^1(\mathbf{y}_1, \mathbf{x}_1)]^{-1} = max_{\phi_i, \lambda} \quad \phi_i \tag{6}$$

$$\text{subject to} \quad \begin{aligned} \mathbf{Y}_1 \cdot \lambda - \phi_i \mathbf{y}_{i1} &\geq \mathbf{0}_M \\ \mathbf{x}_{i1} - \mathbf{X}_1 \cdot \lambda &\geq \mathbf{0}_K \\ \mathbf{N1'} \cdot \lambda &= 1 \\ \lambda &\geq \mathbf{0}_N \end{aligned}$$

$$[d^0(\mathbf{y}_0, \mathbf{x}_0)]^{-1} = max_{\phi_i, \lambda} \quad \phi_i \tag{7}$$

$$\text{subject to} \quad \begin{aligned} \mathbf{Y}_0 \cdot \lambda - \phi_i \mathbf{y}_{i0} &\geq \mathbf{0}_M \\ \mathbf{x}_{i0} - \mathbf{X}_0 \cdot \lambda &\geq \mathbf{0}_K \\ \mathbf{N1'} \cdot \lambda &= 1 \\ \lambda &\geq \mathbf{0}_N \end{aligned}$$

$$[d^1(\mathbf{y}_0, \mathbf{x}_0)]^{-1} = max_{\phi_i, \lambda} \quad \phi_i \tag{8}$$

$$\text{subject to} \quad \begin{aligned} \mathbf{Y}_1 \cdot \lambda - \phi_i \mathbf{y}_{i0} &\geq \mathbf{0}_M \\ \mathbf{x}_{i0} - \mathbf{X}_1 \cdot \lambda &\geq \mathbf{0}_K \\ \mathbf{N1'} \cdot \lambda &= 1 \\ \lambda &\geq \mathbf{0}_N \end{aligned}$$

$$[d^0(\mathbf{y}_1, \mathbf{x}_1)]^{-1} = max_{\phi_i, \lambda} \quad \phi_i \tag{9}$$

$$\text{subject to} \quad \begin{aligned} \mathbf{Y}_0 \cdot \lambda - \phi_i \mathbf{y}_{i1} &\geq \mathbf{0}_M \\ \mathbf{x}_{i1} - \mathbf{X}_0 \cdot \lambda &\geq \mathbf{0}_K \\ \mathbf{N1'} \cdot \lambda &= 1 \\ \lambda &\geq \mathbf{0}_N \end{aligned}$$

These four linear programming problems must be solved for each i^{th} firm in the sample. Note that in problem (9) the data points are likely to lie above the frontier of an earlier period considered for comparison. In the case of technical progress, it would possible to obtain a value of ϕ_i<1. This value could also be obtained with problem (8) in the case of a technical regress.

The Malmquist index of *TFP* change defined by (5) can be decomposed as follows

$$(10) \qquad TFP_M(\mathbf{y}_0,\mathbf{x}_0,\mathbf{y}_1,\mathbf{y}_1) = EC \cdot TC = \frac{d^1(\mathbf{y}_1,\mathbf{x}_1)}{d^0(\mathbf{y}_0,\mathbf{x}_0)}\left[\frac{d^0(\mathbf{y}_1,\mathbf{x}_1)}{d^1(\mathbf{y}_1,\mathbf{x}_1)}\cdot\frac{d^0(\mathbf{y}_0,\mathbf{x}_0)}{d^1(\mathbf{y}_0,\mathbf{x}_0)}\right]^{\frac{1}{2}}$$

where

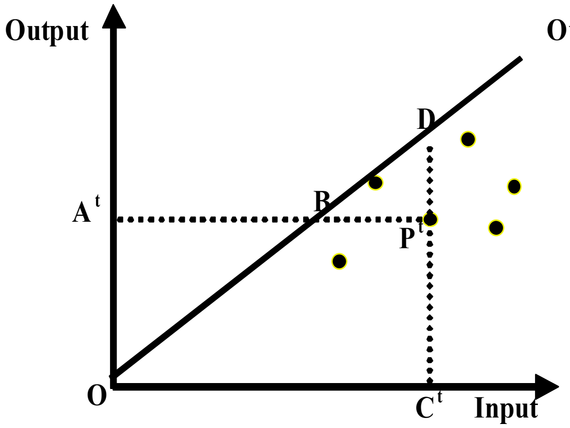
$$(11) \qquad EC \equiv \frac{d^1(\mathbf{y}_1,\mathbf{x}_1)}{d^0(\mathbf{y}_0,\mathbf{x}_0)}$$

is an index efficiency change between periods 0 and 1 (which corresponds to the ratio $(OA^1/B^1D^1)/(OA^0/B^0C^0)$ in Figures 2a and 2b) and

$$(12) \qquad TC \equiv \left[\frac{d^0(\mathbf{y}_1,\mathbf{x}_1)}{d^1(\mathbf{y}_1,\mathbf{x}_1)}\cdot\frac{d^0(\mathbf{y}_0,\mathbf{x}_0)}{d^1(\mathbf{y}_0,\mathbf{x}_0)}\right]^{\frac{1}{2}}$$

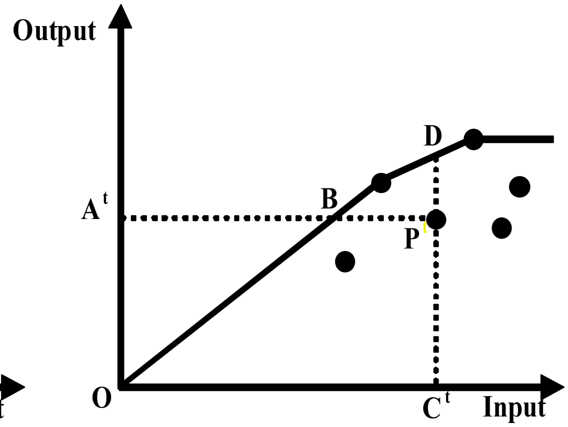
is an index of technological change (which is represented by $[(B^1D^1/B^1D^0)/(B^0C^1/B^0C^0)]^{1/2}$ in Figures 2a and 2b).

Figure 1a



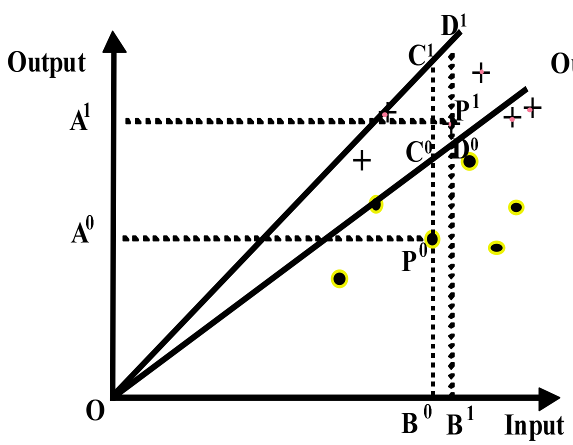
(a) Constant returns to scale

Figure 1b



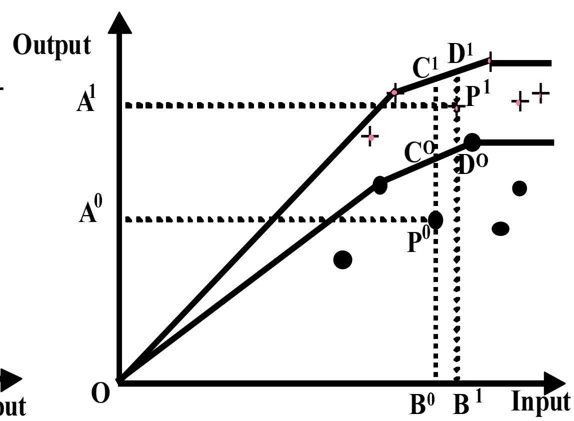
(b) Decreasing returns to scale

Figure 2a



(a) Constant returns to scale

Figure 2b



(b) Decreasing returns to scale

2.2 Looking for explanations of *TFP* change

The two components of *TFP* change seem to not to be independent. In particular, technological change, especially when it is induced by introduction of new technologies, tend to reduce inefficiencies. The *X*-efficiency theory may help to explain how *TE* may depend on technological change and investments in new technologies. As Leibenstein (1978, pp. 114-115) noted, there are several reasons why *TE* should change when there is a change the production technology. He mentioned the following: (*i*) Tastes may lead individuals further from the maximizing mix of activities under one technology than under another; (*ii*) Work coordination and discipline may be greater using the new technologies than the old ones; (*iii*) The old technologies may be valid as well as the new ones, but are more rigid and may detrimental to the synchronization of new activities; (*iv*) Personnel selection under the old techniques may be inappropriate under the new techniques; (*v*) The morale aspects of the work situation may change under the new techniques; (*vi*) There may be a different trade-off between effort and increase in labour productivity between the new techniques and the old (with reactions in one of opposite possible directions consisting in less effort to maintain labour productivity constant or higher effort to meet potential rewards in rising productivity).

One possibile way to start explaining why *TFP* has changed is to find correlations between this variable and its possible determinants. Since the variables derived from the balance sheets of the firms are affected by quite a number of conditions, in order to simplify their The following regression has been made on the panel data of the Italian enterprises considered in the ISTAT surveys for the years 1996 and 1999:

$$(13)\quad \ln \mathbf{TFP} = \alpha + \beta_1\mathbf{F1} + \beta_2\mathbf{F2} + \beta_3\mathbf{F3} + \beta_4\mathbf{REGION} + \beta_5\mathbf{SIZE} + \beta_6\ln \mathbf{ROE} + \beta_7 \ln (\mathbf{LC/VA}) + \mathbf{e}$$

where:

TFP: Malmquist index of total factor productivity change;

F1: First principal component correlated, with a positive sign, with the logarithm of the index of ratio *ICT*/*K* (*ICT*/total capital) and, with a negative sign, with the logaritm of the index of ratio *K*/*L* (capital/labour);

F2: Second principal component correlated, with a positive sign, with the logaritm of the index of ratio *W*/*C* (cost of skilled labour/total labour costs);

F3: Third principal component correlated, with a positive sign, with the logaritm of the index of ratio *R&D*/*K* (stock in *R&D*/total capital stock);

REGION: Dummy for Central-Northern Italy and Southern Italy;

SIZE: Dummy variable of employment size (100 - 250; >250 employees);

ROE: Index of Return on Equity;

LC/VA: Index of ratio of labour cost on value added;

e: Normally distributed stochastic error.

2.3 Principal Component Analysis

The principal components analysis (*PCA*) is used in this framework because of complexity of original variables. The original variables are derived from the balance sheets of the examined enterprises. Many factors or components influence the behaviour of the variables of interest and a clear relation among these variables is difficult to be estimated directly through regression techniques. Therefore, a transformation of these original variables can be made to isolate the "undisturbed" effects of the variables and to use only the principal components in the regression model.

The estimated eigenvalues are presented in Table 1. The first three components represent quite well the total variance. In fact, around 80% of total variance can be explained by the first three components. Note that these factors represents a comparable proportion of the variance.

Table 1. Eigenvalues of the Correlation Matrix

PC	Eigenvalue	Proportion of variance	Cumulative
F1	1.14634681	0.2866	0.2866
F2	1.00556950	0.2514	0.5380
F3	0.98475685	0.2462	0.7842
F4	0.86332684	0.2158	1.0000

In order to obtain a better interpretation of the first three factors a Varimax rotation method has been applied. Table 2 shows that the first factor is very closely correlated to both *ICT*-capital ratio (*ICT/K*) and capital-labour ratio (*K/L*). In particular, the first factor is correlated positively to *ICT/K* (77%) and negatively to *K/L* (-73%). The incidence of cost of skilled labour on total labour costs (*W/C*) is well represented in the second factor (99%), meanwhile *R&D*/*K* is well correlated to the third factor (99%).

Table 2. Rotated Factor Pattern

Original variables	Factor 1	Factor 2	Factor 3
ln ICT/K	0.77	0.11	-0.08
ln K/L	-0.73	0.12	-0.11
ln W/C	0.00	0.99	0.01
ln R&D/K	0.02	0.01	0.99

The interpretation of the second and the third factor is straitforward. The second factor represents "Skill", whereas the third factor represents "*R&D* Expenses". The interpretation of the first factor is more complex, but it can be considered a quite 'pure' *ICT* component in its positive direction and a quite 'pure' Capital-Labour ratio in its negative direction. A complete set of scores for each individual (enterprise) is generated by the *PCA*. The matrix of scores for the three first components is used to estimate the econometric model.

3. DESCRIPTION OF THE DATA

A detailed survey on economic and financial accounts of enterprises is carried out annually in Italy by ISTAT. This survey is intended to cover all enterprises operating in Italy with at least 20 employees until 1997 and at least 100 employees from 1998 to the present date. The survey is conducted by following the normative guidelines of the 4th *EEC* Directive scheme under the Italian national Law No. 69 of 26 March 1990 and the national Legislative Decree No. 127 of 9 April 1991 (see, for example, ISTAT, 1998)[6].

The survey collects data concerning profit-and-loss accounts and balance sheets. Moreover, information regarding employment, investment, personnel costs and certain regional items is also collected. Although the data collection is aimed at covering the universe of enterprises falling within the established range, there is a non-response problem. Several procedures are used in order to prevent or integrate missing data.

The total population of Italian enterprises with at least 20 employees and counted around 68,000 firms in 1997. In that year and previous year, the data collected were related also to *R&D* and *ICT* expenses and capital stocks. The

[6] The dataset constructed from the ISTAT annual surveys on economic accounts of enterprises is part of a larger Statistical Information System on Enterprises (SISSIEI) being developed by ISTAT itself that intends to integrate all available statistical information on specific statistical units (technically, all the survey data in this system can be linked at firm level via firm codes).

respondent enterprises were about 27,000. As for small enterprises with less than 20 employees, a sample survey had been carried out annually with some information about *ICT* obtained at aggregate level of items. After the year 1997, the statistical burden on enterprises was reduced in order to decrease their administrative costs. In fact, also the questionnaire for large enterprises is still very heavy to be filled accurately.

Since 1998, the survey has collected data about all enterprises with at least 100 employees and the number of respondent enterprises was consequently reduced to nearly 3,700. Because of this limitation, many series were interrupted, especially those regarding small - and medium - sized enterprises. The survey based only on sampling that previously had been carried out for enterprises with less 20 employees was extended also to larger enterprises by increasing the threshold from a maximum of 20 employees to a maximum of 99 employees.

A major continuity in the time series was maintained for large enterprises, especially for the information relevant for *R&D* and *ICT* investments. The questionnaire of sample surveys that collect data about enterprises with less than 100 employees does not ask the interviewees to provide the necessary information to measure and estimate *R&D* expenses and acquisition of *ICT*.

A complete set of homogeneous information about *ICT* hardware and software in capital stocks at book value and investments in larger enterprises is available for the period 1996-2000. It is, however, to be noted that the number of respondent enterprises decrease dramatically from over 27,000 in the surveys carried out in 1996 and 1997 to less than 3,700 in the survey that took place in 2000. Very limited information or no information at all about the *ICT* is available for enterprises with less than 100 employees in the ISTAT survey after 1997.

The analysis of productivity growth is carried out using quantities of outputs and inputs. All the relevant variables that are originally collected by the ISTAT surveys are espressed in monetary values at current prices must be, therefore, deflated by means of appropriate deflators. As for the outputs (that are approximated by the firms' turnovers), the values have been deflated by means of the sectoral indexes of producer prices. Tangible capital (at book value) has been deflated by means of the price index for investment goods, whereas the aggregate monetary value of intermediate inputs has been deflated by means of a price index obtained by aggregation of market price indexes for each input category.

The book value of *ICT* capital has been deflated using a specific price index constructed (but not published) by the national accounts office of ISTAT[7]. This deflator has been obtained by aggregation of price indexes for "Office machinery and computers", "Communication equipment", and "Software".

The book value of *R&D* has been deflated by means of the aggregate price index for the intermediate inputs used in the production of investment goods.

Cost of labour has been deflated by means of an index of wages and salaries.

4 EMPIRICAL RESULTS

4.1 Software used for measurement and estimations

The computer program used for *DEA* estimation is DEAP Version 2.1, which is a program developed in FORTRAN (Lahey F77LEM/32) by Tim Coelli to be run under MS-DOS 5.0 or higher versions for IBM-compatible PCs (it can be run also under MS Windows 3.1 or higher versions using FILE MANAGER). It is accompanied by a clear and extensive documentation (see Coelli, 1996 for the user's guide)[8].

The regression estimations have been made using SAS package. This software yields rich diagnostic indicators and is particularly useful to process a large number of data.

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[7] We are indebted to Susanna Mantegazza from the national accounts office of ISTAT for providing us with these price indexes.

[8] A copy of DEAP Ver. 2.1 can be downloaded from the Internet Web site of the Centre for Efficiency and Productivity Analysis, University of New England, Department of Econometrics, NSW, Australia, at the URL *http://www.une.edu.au/econometrics/cepa2.htm#software* (see Hollinngsworth, 1999 for a comparison of alternative computer programs performing DEA).

4.2 TFP change and its components

The results obtained by applying the *DEA*-like Malmquist indexes of *TFP* change are shown in Table 3. The main conclusions are the following:

1. In the average, during the period 1996-1999, *TFP* has slightly decreased (-0.39%), due to a negative effect of technological change (-0.96%) and a positive change in technical efficiency (0.56%). (Since a negative technological change is often difficult to rationalize, it could be interpreted as another type of technical efficiency when the best-practice frontier is assumed to have in fact remained unchanged).

2. During the same period, *TFP* change has varied substantially among the industries both in sign and magnitude. The industries with the greatest increase in *TFP* have been *Office, accounting, and computing machines* (+9.9%), *Shipbuilding* (+9,7%), *Post and Telecommunications* (+6,6), *Iron and steel* (+5,0%). All these industries have registered positive values in both the technical efficiency and technological change components. More contained but still positive TFP changes has been observed in *Chemicals* (+2.3%), *Non-ferrous metals* (+2.15%), *Food, beverage, and tobacco* (+1.2%), *Electricity, gas, and water* (+1.1%), *Rubber and plastic products* (+0.6%). Almost all these changes are the net results of negative changes in technical efficiency and positive effects from changes in technology.

3. Negative changes in *TFP* has been noted in many other industries, among which slight decreases have been registered by *Aircrafts and spacecraft* (-0.1%), *Pulp, paper, and paper products* (-0.2%), *Textiles, apparel, and leather* (-0.4%), *Pharmaceuticals* (-0.5%), *Machinery and equipment* (-1.3%), *Wood products* (-1.3%), *Medical and precision instruments* (-1.8%), *Wholesale and retail trade* (-2.7%). In these industries, the decrease in *TFP* is the outcome of a negative technological change.

4. The industries that have suffered from the greatest decrease in *TFP* are *Real Estate, renting and business services* (-6,6%), *Health and social work* (-6,0%), *Computer services and related activities* (-4,5%), *Petroleum, coal products* (-4,31%), *Research and Development* (-4.3%), *Hotels and restaurants* (-4.5%), *Transport and storage* (-3.8%), *Other community and social work* (-3.4%). Except for *R&D* activities, decreases in *TFP* were mainly due to negative effects of technological changes.

4.3 Econometric results on correlation between TFP changes, ICT and other variables

The econometric estimates of parameters of equation (13) applied on the panel data described above are presented, for each industry, in Tables 4 along with the respective statistical tests. The regressions present, generally, a relatively low level of R^2, as it is common with a large number of degrees of freedom, where all the variables are normalized and "trend" effects are eliminated. We concentrate our comments only on parameter estimation concerning correlation effects between changes in *TFP* changes and those in the stock in *ICT* relative to total capital stock (a represented by Factor 1 in the Principal Component Analysis). The following indications can be drawn from the results:

1. The *ICT* is positively correlated to *TFP* in all the industries examined and this correlation appears to be significant in a certain number of cases.

2. Significant coefficients of the *ICT* (Factor 1) have been obtained in industries that have registered a decline in *TFP* during the period 1996-1999, as for example *Textiles and apparels, Pulp and paper products*, *Fabricated metal products, Precision instruments, Wholesale and retail trade, Hotels and restaurants, Computer services, Research and development,* and *Health and social work*. Significant coefficients of the *ICT* have also been found in industries with positive *TFP* changes, as for example, in *Chemicals, Iron and steel, Shipbuilding, Railroad and transport equipment,* and *Construction*.

3. Since the variables are expressed in terms of rates of changes (logarithmic values of ratios), the respective estimated coefficients can be interpreted as elasticities. The highest elasticities of *TFP* with respect to Factor 1 (which is strongly correlated to the proportion of *ICT* on total capital inputs) have been found in *Aircraft and spacecraft* (0.40), *Construction* (0.30**), *Chemicals* (0.12**), *Radio, TV, and communication equipment* (0.10*), *Precision instruments* (0.10**), *Railroad and transport equipment* (0.10**), *Computer services and related activities* (0.10**), *Research and development* (0.10**), *Other communities, social and personal services* (0.10*) (with the two- and one-star marks indicating that the parameter estimates are, respectively, statistically significant at the 0.05 and 0.1 levels of confidence). We found that the impact of the *ICT* on *TFP* is relatively strong, not only in high-technology industries, but also in certain sectors as *Construction*, *Other community and social services* that are not particularly *ICT*-intensive users.

Table 3. DEA-like Malmquist indexes of TFP change and its components in the Italian industries, 1996-1999 (average values)

Industry(*)	Number of firms examined	Efficiency change (1)	Technological change (2)	TFP change (3) =(1)+(2)
		(Rate of change in percentage)		
Food, beverage and tobacco	124	-1.01	2.24	1.23
Textiles, apparel and leathe	179	0.90	-1.28	-0.38
Wood, wood products and cork	59	-1.28	-0.04	-1.32
Pulp, paper paperproducts an	74	-0.88	0.69	-0.19
Petroleum, coal products and	14	0.17	-4.48	-4.31
Chemicals, exluding pharmace	70	-0.74	3.06	2.32
Pharmaceuticals	45	-1.28	0.82	-0.46
Rubber and plastic products	73	-2.78	3.34	0.56
Other non metallic mineral p	89	-1.01	-0.83	-1.84
Iron and steel	64	2.82	2.20	5.02
Non ferrous metals	27	-1.59	3.74	2.15
Fabricated metal products, e	90	-0.44	-0.66	-1.09
Machinery and equipment n.e.	202	1.83	-3.15	-1.32
Office accounting and comput	7	2.61	7.30	9.91
Electrical machinery and app	95	1.41	-1.41	0.00
Radio, TV and communication	30	0.43	-2.69	-2.26
Medical, precision instruments	35	2,82	-4,58	-1,76
Motor vehicles and trailers	63	1.87	-1.59	0.26

Table 3. *(continued)*

Industry(*)	Number of firms examined	Efficiency change (1)	Technological change (2)	TFP change (3) =(1)+(2)
		(Rate of change in percentage)		
Shipbuilding and repair	7	2.37	7.37	9.74
Aircraft and spacecraft	8	1.66	-1.77	-0.11
Railroad equipment and trans	14	0.43	0.09	0.52
Other manufacturing, recycli	24	1.83	-4.72	-2.89
Electricity, gas and water s	35	1.54	-0.44	1.10
Construction	80	7.85	-7.06	0.79
Wholesale and retail trade,	187	-5.16	2.45	-2.71
Hotels and restaurants	39	2.04	-6.15	-4.11
Transport and storage	193	-1.23	-2.55	-3.78
Post and telecommunications	6	4.22	2.41	6.63
Real estate, renting, and ot	134	-0.48	-6.15	-6.63
Computer services and relate	43	0.69	-5.16	-4.47
Research and development	7	-7.11	2.86	-4.24
Health and social work	98	3.50	-9.47	-5.97
Other community, social serv.	35	2.57	-5.95	-3.38

Table 4. Econometric estimations of equation (13) on firm-level panel data of the Italian industries, 1996-1999.

Industry	No. of firms	Constant	F1 (ICT/K)	F2 (SW/CL)	F3 (R&S/K)	REGION (DUMMY)	SIZE (DUMMY)	ln ROE	ln LC/VA	Adjusted R^2
Food, beverages and tobacco	124	0.07	0.04	-0.01	0.00	-0.04	0.01	0.03	-0.15	5.8
		(1.11)	(1.78*)	(-0.45)	(0.04)	(-0.64)	(-0.17)	(0.21)	(-3.10**)	
Textiles, apparel and leather	179	-0.02	0.05	-0.01	0.00	0.01	0.01	-0.00	-0.23	28.2
		(-0.49)	(4.09**)	(-1.89*)	(-0.12)	(0.25)	(0.65)	(-0.19)	(-6.85**)	
Wood, wood products and cork	59	-0.13	0.03	-0.01	0.00	0.11	0.00	0.01	-0.20	8.6
		(-1.21)	(1.16)	(-0.35)	(0.05)	(0.95)	(0.10)	(1.10)	(-2.94**)	
Pulp, paper, paper products and print	74	0.00	0.06	0.03	-0.01	-0.00	-0.01	0.00	-0.36	27.0
		(0.08)	(3.77**)	(1.10)	(-0.69)	(-0.00)	(-0.43)	(0.56)	(-4.19**)	
Petroleum, coal products and nuclear	14	0.15	0.09	-0.24	0.11	-0.10	0.00	-0.07	0.72	94.1
		(0.98)	(1.06)	(-1.86)	(1.06)	(-0.50)	(0.00)	(-1.17)	(-4.81**)	
Chemicals, excluding pharmaceuticals	70	0.04	0.04	0.02	0.02	0.02	-0.02	-0.01	-0.02	9.8
		(0.33)	(2.65**)	(0.56)	(1.15)	(0.11)	(-0.59)	(-1.09)	(-0.62)	
Pharmaceuticals	45	0.13	0.12	-0.05	0.02	-0.16	-0.02	0.00	-0.14	17.5
		(0.54)	(3.20**)	(-1.40)	(0.45)	(-0.73)	(-0.42)	(0.11)	(-1.44)	
Rubber and plastics products	73	-0.03	0.04	0.00	-0.00	0.06	-0.01	0.01	-0.27	52.2
		(-0.57)	(2.86**)	(0.21)	(-0.17)	(1.25)	(-0.73)	(0.82)	(-6.67**)	
Other non-metallic mineral products	89	-0.16	0.06	-0.00	0.01	0.11	0.03	0.01	0.21	14.1
		(-2.68**)	(2.33**)	(-0.12)	(0.31)	(1.74)	(0.80)	(0.74)	(-2.29**)	
Iron and steel	64	0.07	0.05	0.00	0.00	0.03	0.01	-0.00	-0.09	20.3
		(1.08)	(4.08**)	(0.08)	(0.32)	(0.44)	(0.18)	(-0.23)	(-2.67**)	
Non-ferrous metals	27	0.24	0.06	-0.04	0.04	-0.18	-0.06	0.00	-0.29	53.2
		(3.55**)	(2.87**)	(-1.34)	(1.46)	(-2.66**)	(-1.68)	(0.14)	(4.26**)	
Fabricated metal products, ex. machin	90	-0.14	0.05	0.00	-0.00	0.12	0.02	-0.01	-0.29	26.7
		(-2.97**)	(3.05**)	(0.15)	(-0.03)	(2.13)	(0.52)	(-1.12)	(-3.42**)	

Table 4. *(continued)*

Industry	No. of firms	Constant	F1 (ICT/K)	F2 (SW/CL)	F3 (R&S/K)	REGION (DUMMY)	SIZE (DUMMY)	ln ROE	ln LC/VA	Adjusted R^2
Machinery and equipment n.e.c.	202	-0.02	0.02	0.03	0.02		-0.03	0.01	-0.22	12.1
		(-1.39)	(1.4)	(2.28**)	(1.32)		(-1.03)	(0.51)	(-4.61**)	
Office, and computing mach + Electr. machinery and apparatus n.	102	0.15	0.03	0.00	-0.00	-0.13	0.01	-0.02	-0.24	21.7
		(1.99**)	(1.97*)	(0.14)	(-0.43)	(-1.75)	(0.33)	(-1.65)	(-5.32**)	
Radio, TV and communication equipment	30	-0.10	0.10	-0.02	-0.03	0.05	0.05	-0.01	-0.21	20.9
		(-0.79)	(2.40**)	(-0.45)	(-0.63)	(0.35)	(0.76)	(-0.15)	(-2.12**)	
Medical, precision and optical instru	35	0.05	0.10	0.05	-0.03	-0.06	-0.01	-0.01	-0.33	53.0
		(0.36)	(3.23**)	(0.66)	(-0.95)	(-0.46)	(-0.18)	(-0.26)	(-4.57**)	
Motor vehicles & trailers	63	-0.01	0.08	0.04	0.01	0.00	0.03	0.02	-0.02	19.0
		(-0.16)	(3.97**)	(1.26)	(0.63)	(0.06)	(0.85)	(1.60)	(-0.26)	
Shipbuilding and repairing	7	0.18	0.04	0.53	0.19					41.0
		(1.22)	(0.35)	(2.35*)	(1.34)					
Aircraft and spacecraft	8	0.34	0.40	-0.13	0.22	-0.51	0.38			48.0
		(1.19)	(0.67)	(-1.29)	(1.50)	(-1.46)	(1.02)			
Railroad equipment and transport equi	14	-0.11	0.05	-0.09	0.09		0.06	-0.03	-0.38	78.7
		(-2.92**)	(1.47)	(-1.36)	(0.83)		(0.57)	(-1.73)	(-5.29**)	
Other manufacturing, recycling	24	-0.04	0.02	0.00	-0.01		-0.04	0.00	-0.41	43.4
		(-1.65)	(0.89)	(0.18)	(-0.64)		(-0.91)	(-0.42)	(-4.21**)	
Electricity, gas and water supply	35	0.05	0.03	0.03	-0.01	0.03	-0.05	-0.02	0.02	16.0
		(0.64)	(1.09)	(1.45)	(-0.23)	(0.41)	(-0.88)	(-1.12)	(0.34)	
Construction	80	-0.07	0.30	-0.10	-0.01	0.03	0.08	-0.06	-0.11	32.4
		(-0.37)	(5.42**)	(-1.29*)	(-0.17)	(0.15)	(0.57)	(-1.46)	(-0.78)	
Wholesale and retail trade, repairs	187	-0.07	0.06	-0.01	0.01		0.00	0.01	-0.03	12.8
		(-4.19**)	(5.19**)	(-0.23)	(0.90)		(0.03)	(0.55)	(-2.03**)	

Table 4. *(continued)*

Industry	No. of firms	Constant	F1 (ICT/K)	F2 (SW/CL)	F3 (R&S/K)	REGION (DUMMY)	SIZE (DUMMY)	ln ROE	ln LC/VA	Adjusted R^2
Hotels and restaurants	39	-0.8	0.07	-0.20	0.02	0.02	-0.02	0.02	-0.28	34.7
		(-1.04)	(2.94**)	(-0.63)	(1.20)	(0.22)	(-0.43)	(1.19)	(-2.41**)	
Transport and storage	193	-0.16	0.04	-0.01	0.03	0.13	-0.04	0.01	-0.04	6.0
		(-2.95**)	(2.26**)	(-0.50)	(1.24)	(2.65**)	(-0.92)	(0.48)	(-1.32)	
Real estate, renting and other busine	134	-0.31	0.07	0.05	0.03	0.15	0.07	0.03	0.27	15.9
		(-3.71**)	(2.49**)	(1.91*)	(1.08)	(1.67)	(1.11)	(1.63)	(-3.54**)	
Computer services and related activit + Post and telecommunications + R&D	54	-0.04	0.01	0.12	0.07	0.01	-0.08	0.00	-0.31	53.6
		(-0.32)	(4.18**)	(2.37**)	(0.96)	(0.18)	(-0.67)	(0.14)	(-6.85**)	
Health and social work	98	-0.10	0.09	0.06	0.02	-0.02	-0.01	0.00	-0.41	35.5
		(-2.29**)	(5.75**)	(2.53**)	(0.55)	(-0.33)	(-0.22)	(0.01)	(-5.30**)	
Other community, social and personal	35	0.11	0.10	0.08	-0.06	-0.13	-0.06	0.03	-0.03	22.1
		(0.79)	(2.02*)	(1.17)	(-1.21)	(-.92)	(-0.51)	(0.56)	(-0.38)	

t values in parenthesis. * significant at 10% level of confidence. ** significant at 5% level of confidence.

CONCLUSION

The analysis of firm-level data suggests that productivity slowdown observed at the aggregate level of the Italian economy during the recent years has been mainly due to negative technological changes (declining performance of the best-practice production units), which have not been completely offset by improvements in technical efficiency. This result indicates that the negative *TFP* changes may have a structural nature. This trend could have been contrasted by more robust investments in new information and communication technologies. In fact, the panel regressions indicate that, in all the industries examined, *TFP* changes are positively affected by increases in the *ICT* intensity. Apart from the adjustment and organizational costs that are generally encountered with the installation of new investment goods, a substantial portion of the productivity stagnation observed during the recent years in Italy can be explained by the relatively low accumulation of information and communication technologies.

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