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The productivity mystery

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Abstract

An analysis using extensive Finnish micro data reveals new insights into the mysterious productivity growth slow-down that has taken place since the middle of the 2000's. Multifactor productivity growth is divided into technological development and structural reallocation, and the latter item is analyzed within clusters that have homogeneous factor inputs, such as intangibles. Intangible capital-intensive clusters are the only industries where intangible capital has contributed to the multifactor productivity growth, although this contribution has occurred at a decreased rate. The fixed-capital-intensive firms, such as paper and pulp, basic metal industries and large retailers, have economized their fixed costs and adjusted their capital stock downwards; thus, they have generated multifactor productivity through a different type of structural reallocation. Europe faces a challenge of technology improvements, as deepening fixed capital and intangible capital are no longer sources of rapid labor productivity growth.

Keywords: Multifactor productivity; Intangible capital; R&D; Marketing; Linked employer-employee data

1. Introduction

In the OECD countries, the annual growth of labor productivity fell from 2 percent in the period from 2001-2007 to only 0.8 percent in the period from 2007-2012. In Europe, the latter period experienced no growth, and in these countries, productivity growth has been lagging behind the U.S. since 1995 according to the European Competitiveness Report (EC 2013). In addition, whereas European countries have experienced a fall in multifactor productivity growth, in the U.S., multifactor productivity has been the major driver of GDP growth since 1995. Multifactor productivity is defined as the overall efficiency with which labor and other factor inputs are used together (OECD, 2011).

These developments have given rise to intensified research. On the basis of evidence from Japan, Kobayashi and Shirai (2012) suggest that financial constraints such as those constraints that have been generated by the financial crisis since 2007 reduce risk-taking. Another possible explanation is insufficient investments in ICT and related organizational investments in the pre-2007 period (Bresnahan et al., 2002; Bresnahan and Greenstein 1999; Ito and Krueger, 1996). According to the European Competitiveness Report (EC 2013), market services have lagged behind the other sectors since 2000, and more recently, manufacturing has suffered the most from the low demand since 2007. In the United Kingdom, which has experienced an unusually long period of slow growth, explanations have been sought in the reduction of the capital-labor ratio (Pessoa and van Reenen, 2013; Crawford et al., 2013) because fixed capital investments exceeded the corresponding investments in the U.S. before 2007. A second potential explanation is the fall of real wages (Blundell et al., 2013).

Finland is among the countries where the change has been the most pronounced. Although it was once among the better performers in the OECD area, Finland now finds itself among the weakest performers with respect to both labor productivity and multifactor productivity, which actually fell during 2007-2012. This fall took place at a time when real wages were developing rather strongly, and hence, wage developments cannot have any explanatory power in the Finnish case.

Given the protracted period of lackluster performance, it is difficult to believe that the slowdown in productivity is a cyclical phenomenon explained by labor hoarding. It is unclear to what degree the decrease in multifactor productivity can be explained by an inability to adopt and utilize new techniques at the firm level, by insufficient economic growth or by market restructuring.

Finland has a good micro-level database that allows for an in-depth analysis of these questions. Moreover, the data make it possible to widen the scope and to include intangible capital and the related value-added. Indeed, it is a well-known fact that the exclusion of intangible factors in output gives an increasingly biased view of economic performance (see, e.g., Corrado et al., 2005, 2009).

This paper will attempt to deepen the current analysis in the field in several ways. First, this paper will give the effects of intangible investments. In addition to research and development, which will be included in the official EU statistics on value added as of this year, the effects of investments on organizational and ICT capital will be included. Innovativeness is also influenced by other intangibles than R&D, especially in services, and these new forms of intangibles have not grown in the EU since 2000 (EC, 2011; Piekkola, 2011).

Second, multifactor productivity is disentangled to separate the effects emanating from new technological development from those effects that arise from structural reallocations of existing resources to more efficient firms (which is a second component of multifactor productivity growth observed at an aggregate level, such as within each cluster). Ilmakunnas and Piekkola (2014) (I&P) show that workers engaged in organizational activities increase the firm's multifactor productivity. Although R&D activities account for a large share of intangible activities, I&P show that the returns have been low. However, they do not analyze the structural reallocation, and the definition of R&D used here is broadened to cover all engineering work in services.

These questions can be analyzed following Petrin and Levinsohn (2012) (PLE). In their analysis, multifactor productivity is measured by deducting the contributions of all production factors (including the intangible ones) to the growth of value added. Following Basu and Fernald (2002), PLE show that because each firm makes a double contribution to the aggregate multifactor productivity, the aggregation of data at the firm level should be based on the share of firm-level revenue in the aggregate value added (i.e., the Domar weights). The productivity contributions of intermediate inputs arise first directly, and then, they are made indirectly by reducing the costs of other firms that use the products of the firm as input. Each firm's contribution to the changes in productivity (in terms of both technical efficiency and structural reallocation effects) arise from changes in the use of labor with a basic education, labor with a tertiary-level education, fixed capital, intangible capital and intermediate inputs. Structural misallocation would arise if, e.g., labor that has been trained to use new technology is subjected to previous technology. Multifactor productivity analysis also provides information on the reallocation of intermediate inputs, which is an important part of structural reallocation.

In this study, Finnish (linked) employer-employee data for the 1997-2012 period are used, and the study concentrates on manufacturing and market services (including scientific firms and some real estate and administrative firms, but excluding the financial sector). Clusters with similar uses of production factors are formed, as firms differ largely in the way they employ different production factors. Whereas a retail company may invest in intangibles, another company may concentrate on labor-intensive activities, and a third could intensively use fixed capital. To identify the effects on productivity growth of these different behavioral patterns, more homogenous clusters are formed; otherwise, many important intangibles-intensive industries such as pharmaceuticals would be left unanalyzed because there are too few firms in the industry.

Section 2 describes the data and presents the clustering of the Finnish private sector, Section 3 presents the productivity measures, Section 4 shows the main results of the decomposition of multifactor and labor productivity growth, and Section 5 concludes.

2. Linked employee-employer data

The labor data were collected by the Confederation of Finnish Industries, and they cover 10 million man-years and contain some 70,000 observations at the firm level for the years 1997-2012. The data include a rich set of variables covering compensation, education, and professions. The white-collar employees are compensated on the basis of salaries, whereas the blue-color workers, who compose half of all employed workers, receive an hourly wage. The dataset on labor is linked to financial data provided by the private company Suomen Asiakastieto[1]. Non-consolidated firm data on profits, value added, and capital intensity (fixed assets) are used. Only firms with sales exceeding €1.5 million (at 2000 prices) are included in the analysis.

Clusters are formed within the manufacturing, construction and services industries. The final linked employer–employee dataset of 5.28 million man-year annual observations (instead of 6.66 million when the data include all industries and, in particular, other non-manufacturing production and health and public services) covers an average of 2,276 firms with 22,498 firm-year observations for the 1997-2012 period and covers 53% of the turnover of Finnish private companies in 2011. The employee data in the sample have an annual average of 332,500 employees, that is, one-fifth of the total private-sector workforce.

Following Görzig, Piekkola and Riley (2010), Piekkola (2013), intangible capital is included in the production function. The organizational (management and marketing), R&D (research and development) and ICT (information and communication technologies) occupations are

[1] Suomen Asiakastieto is the leading business and credit information company in Finland.

assumed to create intangible capital.[2] It is assumed that a share of these employees' efforts is of a lasting nature, and hence, it is accumulated into a stock of intangible investment goods. Intermediate and capital costs are also incurred in the production of intangible capital goods, and these goods are evaluated from the input-output tables in the following business services in category 7 of the Classification of Economic Activities in the European Community (NACE Rev. 2):

- Other business activities (Nace 71) as a proxy for organizational goods,
- Research and development (Nace 72) as a proxy for R&D goods, and
- Computer and related activities (Nace 62) as a proxy for ICT goods.

The input-output tables in these services are used to derive the factor multiplier, which is the indicator of the cost structure in the production for these types of goods in any firm.[3] The nominal value of intangible capital investment N_{it}^{IC} of type IC, IC=OC, R&D, or ICT for firm *i* in industry/cluster j at time t is given by

$$P_t^N N_{it}^{IC} \equiv M_{jt}^{IC} wL_{it}^{IC} \text{ with } IC = OC,\ R\&D, ICT \ , \qquad (1)$$

where the nominal annual earnings wL_{it}^{IC} are multiplied by the combined multiplier M_{jt}^{IC}, which is the product of the shares of organizational, R&D and ICT effort that produce

[2] The 17.8% share of personnel in organizational, R&D and ICT work in 2003 is comparable to the average share of 18% in the six European countries with LEED data in the EU's 7th framework programme project INNODRIVE 2009-2011.The shares of organizational occupations were generally approximately 8.8%. Management (3.4%) and marketing (5.4%) are the main categories for organizational work. The share of R&D workers is similar at 7.1% (or 4.2% if those workers who have more than a tertiary technical education but are not directly employed in an OC, ICT or R&D occupation are excluded). The total share of ICT workers is approximately 2.1%. An increasing share of intangible-capital-related workers is also explained by the falling share of production workers; this proportion had fallen from approximately 61% in 1997 to 39% by 2012.

[3] The input-output tables are from the EU KLEMS database, which is the product of the 6th framework research project financed by the European Commission to analyze productivity in the European Union at the industry level.

intangible goods and the factor multiplier from the input-output tables. Appendix B describes in greater detail the parameter values of M_{jt}^{IC}. The parameter P_t^N is the investment deflator in business services (Nace 69-75), which is assumed to represent the deflator for intangible assets in all sectors. Employee compensation is evaluated on the basis of annual earnings (which include performance-related pay and social security contributions). Double deflation at the Nace 2008 single-digit level is used in the calculations of the real value added, and it includes intangible investments.

The evaluation of the components of multifactor productivity requires an estimation of a production function. Rather than estimating the output elasticities separately on the basis of detailed industry classifications (which are also done as a robustness check), it is more coherent to classify firms and compute the production function estimation according to these firms' utilization of factor inputs using the partition cluster method. The deviation of the use of the factor inputs from the median values are used as criteria for the classification. The average value added shares of the intangible investment (separately organizational, R&D and ICT investments) and fixed capital investment are used as the selection criteria (and thus, the labor income shares are the residuals). As a result, each cluster is as homogeneous as possible with respect to the utilization of factor inputs. The Calinski and Harabasz (1974) pseudo-F values give six as the optimal number of clusters.

Table 1 shows the six clusters constructed, as described above, from industries covering manufacturing, construction and services. This calculation covers these industries' shares in the total value added, the median capital investment intensities as well as the five largest branches and their shares in the valued added of each cluster.

Table 1. The clusters

Clusters (in parenthesis value added shares %)	Obser-vations	Value added shares % 1998	Value added shares % 2012	OC(i)	R&D(i)	ICT(i)	Fixed capital(i)
1Organisazational capital intensive: wholesale, retail (0.44), information (0.17), administrative (0.11), transportation (0.11), accommodation (0.08)	3,983	**15.5**	**18.9**	41.2	3.7	1.9	9.2
2 Fixed capital intensive: paper and pulp (0.59), wholesale, retail (0.11), chemicals (0.05), real estate (0.05), transportation (0.03)	4,545	28.5	21.7	8.7	5.0	0.2	54.5
3 Labor and fixed capital intensive: wholesale, retail (0.24), information (0.13), basic metal (0.1), transportation (0.07), beverage (0.06)	3,994	27.7	23.5	4.5	2.3	0.0	37.8
4 Labor and intangibles intensive with organizational and R&D capital: machinery and equipment (0.13), food (0.11), wholesale, retail (0.08), other transport (0.08), pharmaceutical (0.08)	4,558	18.6	15.0	16.9	23.0	0.8	21.5
5 Labor non-capital intensive: information (0.89), scientific (0.05), wholesale, retail (0.03), transportation (0.03), wearing apparel (0)	4,745	1.0	1.1	5.7	3.3	0.0	12.8
6 R&D capital intensive: machinery and equipment (0.24), electrical equipment (0.21), scientific (0.15), information (0.12), computer electronic (0.08)	2,510	**8.7**	**19.8**	16.5	51.6	0.8	2.7
All	24,335	100	100	12.1	7.2	0.0	22.2

(i) OC=organizational investment, R&D=R&D investment, ICT=Information and communications investments. Columns shows median use of each factor inputs, %.

One way to characterize the clusters is to separate those clusters that can exploit returns to scale, such as fixed-capital-intensive and fixed-capital-and-labor-intensive clusters, which together composed 45.2 percent of the private sector's value added in 2012. The knowledge-capital-intensive clusters using organizational or R&D capital amounted to 38.7 percent of the private sector's value added in 2012 and relied on "internal" returns to scale using inputs that cannot easily be replicated by other firms. Cluster analysis shows the growing importance of the organizational and R&D capital-intensive clusters. Whereas the organizational-capital-intensive cluster increased its share from 15.5 percent to 18.9 percent, the R&D capital-intensive cluster grew from 8.7 percent to 19.8 percent; manufacturing covers half of the latter cluster's growth. The remaining clusters are labor-intensive clusters with a 16.1 percent proportion of the total value added in 2012.[4]

The fixed-capital-intensive cluster is dominated by the paper and pulp industry (59 percent). The scale effects can potentially be large, which would cause constant market restructuring (Van Marrewijk, 2007, p. 211–212). The fixed-capital-and-labor-intensive cluster has the highest share of well educated workers, as 30 percent of its work force has a tertiary education. This cluster is also the most diversified in terms of its industrial structure. The organizational capital cluster consists mainly of market services, with the information industry having a prominent share (17%); this industry is followed by administrative services (administrative and support service activities Nace class N) and transportation.[5] The R&D capital-intensive cluster has wide coverage of industries, whereas 80% of the R&D investments in OECD countries are in electronics and optical equipment, transport-related manufacturing, and chemical and pharmaceutical industries. In the labor-and-intangible-

[4] The tiny labor and non-capital-intensive cluster, value added share of which is merely one percent, is included to complete the picture. This cluster is dominated by the information industry (89%).
[5] Transport is the most heterogeneous branch with respect to the use of factor inputs, and transport firms are found in many of the clusters.

capital-intensive cluster, the combination of intangible capital with labor-intensive activities might enable an expansion of the service and production range (Greenaway et al., 1995, 1505–1506.). Under perfect information, a higher price goes with higher quality, and the high-quality products satisfy the consumption of high-income level segments.[6]

[6] These arguments follow from the thesis presented by Crespo and Fontoura (2004, p. 54) on intra-industry trade.

3. Modeling multifactor and labor productivity growth

The production function for firm *i* is in the Cobb-Douglas form and is given by

$$Q_{it} = MP_{it} \prod\nolimits_k X_{kit}^{\varepsilon_k} M_{it}^{\varepsilon_M} - F_{it}, \tag{2}$$

where Q_i is turnover net of fixed costs F_i and X_i denotes the primary inputs of type *k*, $k = B, H, K, R$; B = the hours worked by laborers with a basic education; H = the hours worked by laborers with a tertiary education; K = the input of fixed capital; and R = the input of intangible capital. Lastly, M_i = the input of intermediate products. The multifactor productivity MP_{it} is Hicks-neutral (with constant returns to scale).

The real stock R_{it}^{IC} of intangible capital of type IC, IC=OC, R&D, or ICT for a firm *i* is on the basis of (1):

$$R_{it}^{IC} = R_{it-1}^{IC}(1-\delta_{IC}) + N_{it}^{IC},\ R_i^{IC}(0) = N_i^{IC}(0)/(\delta_{IC} + g_{IC}), \tag{3}$$

where $N^{IC}(0)$ denotes the initial investment, $R^{IC}(0)$ is the initial intangible capital stock, δ_{IC} is the depreciation rate, and g_{IC} denotes the growth rate of the intangible capital stock of type IC, which is computed using the geometric sum formula. The initial intangible investment $N_i^{IC}(0)$ is defined as the average investment over the five-year period following the first year the firm is observed in the data. The average is used to assess the average investment rate instead of the initial stock. In (3), the growth rate g_{IC} is set at 2% for all intangibles, which follows the sample average growth rate (2 percent) of real wage costs for intangible-capital-related activities.

The cluster division used OC, R&D and ICT capital investment value added shares are included in the selection criteria. Organizational, R&D and ICT capital are highly correlated, and many clusters are dominated by one of these types of capital. Within each cluster, the total intangible assets are considered as a whole in the estimation of the production function. The total final demand output *Y* that goes to the final demand (which is equivalent to the value added in a closed economy) in firm *i* is

$$Y_{it} = Q_{it} - M_{it}. \tag{4}$$

The differential in levels in the multifactor productivity MP_i is

$$\begin{aligned} MP_t - MP_{t-1} \equiv \sum\nolimits_{i\in C} P_i(Y_t^C - Y_{t-1}^C) - \sum\nolimits_{i\in C}\sum\nolimits_k W_{ik}(X_{ikt}^C - X_{ikt-1}^C) + \\ \sum\nolimits_{i\in E} P_i Y_t^E - \sum\nolimits_{i\in E}\sum\nolimits_k W_{ik} X_{ikt}^E - \left(\sum\nolimits_{i\in Dt-1} P_i Y_t^D - \sum\nolimits_{i\in Dt-1}\sum\nolimits_k W_{ik} X_{ikt}^D\right), \end{aligned} \tag{5}$$

where P_i is the price of plant *i*'s output, $\sum_i P_i(Y_{it}^C - Y_{it-1}^C)$ is equal to the change in final demand, $\sum_{i\in C}\sum_k W_{ik}(X_{ikt}^C - X_{ikt-1}^C)$ is the change in the primary inputs, W_{ik} equals the unit cost of the *k*th primary input, and $X_{ikt}^C - X_{ikt-1}^C$ is the change in the use of primary input *k* in firm i (with superscript C for continuing firms). In addition, $\sum_{i\in E} P_i Y_t^E$, $W_{ik} X_{ikt}^E$, $\sum_{i\in D} P_i Y_t^D$, and $W_{ik} X_{ikt}^D$ are, respectively, the final demand and the primary inputs in entering firms E and exiting firms D.

The growth rates are adjusted by the Domar (1961) weights $D_{it} = P_{it}Q_{it} / \sum_i P_{it}Y_{it}$ (which are needed because the intra-industry flows of the intermediate inputs are factored out):

$$\begin{aligned}\Delta \ln MP_t = & \sum_{i \in C} \bar{D}_{it} \Delta \ln Y_{it} - \sum_{i \in C} \sum_k \bar{c}_{ikt} \Delta \ln X_{ikt} + \sum_{i \in E} S_{it}^{E} \ln VA_{it} \\ & - \sum_{i \in E} \sum_k c_{ikt} \ln X_{ikt} - \left(\sum_{i \in Dt-1} S_{it-1}^{D} ln VA_{it-1} - \sum_{i \in Dt-1} \sum_k c_{ikt-1} \ln X_{ikt-1} \right) \end{aligned}, \quad (6)$$

with Δ denoting the difference operator. Furthermore, $\Delta \ln Y_{it} = (\ln Y_{it} - \ln Y_{it-1}) / Q_{it}$ is the growth rate of firm *i*'s output that contributes to the final demand, where the denominator is given by Q_i and $c_{ik} = W_{ik} X_{ik} / \sum_i P_i Y_i$ is the share of primary input in the output. A bar over a variable indicates a Tornquist-Divisia approximation $\bar{Z}_i = 0.5(Z_i + Z_{i-1})$ for $Z_i = D_i$ or c_{ik}, and $S_t^Z = \sum_{i \in Z} P_{it} Y_{it} / \sum_i P_{it} Y_i$ is the final output share of group *Z*=*E* or *D* of the total value added. The growth in aggregate final demand is not directly observed, and the growth-accounting identity at the aggregate level $\sum_i P_i Y_i = \sum_i VA_i$ can be used to generate the aggregate value added, where $VA_i = P_i Q_i - P_i M_i$. This usage gives the decomposition by Basu and Fernald (2002), which was recently developed by PLE and Petrin et al. (2011) in an unbalanced panel

$$\Delta \ln MP_t = \Delta \ln MP_t^C + \sum_{i \in E} S_{it}^{vE} \ln VA_{it} - \sum_{i \in E} \sum_k c_{ikt} \ln X_{ikt}$$
$$-\left(\sum_{i \in D-1} S_{it-1}^{vD} ln VA_{it-1} - \sum_{i \in D-1} \sum_k c_{ikt-1} \ln X_{ikt-1} \right) , \qquad (7)$$

where $\Delta \ln MP_t^C = \sum_{i \in C} \left(\bar{D}_{it}^v \Delta \ln VA_{ti} - \sum_k \bar{c}_{ikt} \Delta \ln X_{ikt} \right)$, $D_i^v = VA_i / \sum_i VA_i$,

$c_{ik} = W_{ik} X_{ik} / \sum_i VA_i$ and $S_t^{vZ} = \sum_{i \in v} VA_i / \sum_i VA_i$, Z=*E*, *D*. This formula can be written using

$\Delta \ln MP_t^C = \left(\sum_i -(\sum_{i \in E} - \sum_{i \in D-1}) \right) \left(\bar{D}_{it}^v \Delta \ln VA_{it} - \sum_k \bar{c}_{ikt} \Delta \ln X_{ikt} \right)$ as

$$\Delta \ln MP_t = \sum_i \left(\bar{D}_{it}^v \Delta \ln VA_{ikt} - \sum_k \bar{c}_{ikt} \Delta \ln X_{ikt} \right)$$
$$+ \sum_{i \in E} S_{it}^E \left(\ln VA_{it} - \sum_k c_{ikt} \ln X_{ikt} - \Delta \ln MP_t^C \right) \qquad (8)$$
$$- \sum_{i \in D-1} S_{it-1}^D \left(\ln VA_{it-1} - \sum_k c_{ikt-1} \ln X_{ikt-1} - \Delta \ln MP_{t-1}^C \right)$$

The first term in the growth formula shows the total change in the productivity that was observed in the aggregate data, i.e., when all firms are aggregated before taking the difference (including entrants and exiting firms). The second term in the decomposition shows that new entrants contribute to the multifactor productivity growth if their multifactor productivity is higher than the average for continuing firms. Equivalently, the exiting firms contribute to the multifactor productivity growth if their multifactor productivity is lower than for continuing firms.[7]

[7] The productivity growth would be biased upwards by around 1 percent per year if half of the firms entering and exiting in our panel in the whole period of 16 years were ignored.

PLE shows that in terms of growth rates, (5) can be decomposed as

$$\begin{aligned}
\Delta\ln MP_t = {} & \sum_i \bar{D}^v_{it}\,\Delta\omega_{it} + \sum_i \bar{D}^v_{it}\sum_k (\varepsilon_{ik} - \bar{s}_{ikt})\Delta\ln X_{ikt} \\
& + \sum_i \bar{D}^v_{it}(\varepsilon_{im} - \bar{s}_{imt})\Delta\ln M_{it} - \sum_i \bar{D}^v_{it}\,\Delta\ln F_{it} \\
& + \sum_k \Big(\Big(\sum_i S^E_{kt}\sum_k (\varepsilon_{ik} - \bar{s}_{ikt})\ln X^E_{ikt} - \sum_k (\varepsilon_{ik} - \bar{s}_{ik})\Delta\ln X^C_{ikt}\Big) \\
& \quad + \Big(\sum_i S^E_{mt}(\varepsilon_{im} - \bar{s}_{imt})\ln M^E_{it} - (\varepsilon_{im} - \bar{s}_{im})\Delta\ln M^C_i\Big)\Big) \\
& - \sum_{k-1}\Big(\Big(\sum_i S^D_{kt-1}\sum_k (\varepsilon_{ik} - \bar{s}_{ikt-1})X^D_{ikt-1} - \sum_k (\varepsilon_{ik} - \bar{s}_{ikt-1})\Delta\ln X^D_{ikt-1}\Big) \\
& \quad + \Big(\sum_i S^D_{mt-1}(\varepsilon_{im} - \bar{s}_{imt-1})M^D_{it-1} - (\varepsilon_{im} - \bar{s}_{imt-1})\Delta\ln M^D_{it-1}\Big)\Big)
\end{aligned} \tag{9}$$

where ε_{ik} and ε_{im} are the elasticities of output with respect to the primary and intermediate inputs, $s_{ikt} = W_{ikt}\,X_{ikt}/VA_{it}$, $s_{imt} = P_{it}M_{ikt}/VA_{it}$ are the value added shares, $\Delta\ln M_{it}$ is the growth in intermediate inputs, and $\Delta\ln F_{it}$ is the growth in fixed and sunk costs (the residual of the decomposition). Lastly, $\Delta\omega_{it}$ is the growth in the remaining output after the contributions of both the primary and intermediate inputs at the plant level have been deducted, and this variable is given by

$$\Delta\omega_{it} = \Delta\ln Q_{it} - \sum_k \varepsilon_k \Delta\ln X_{ikt} - \varepsilon_M \Delta\ln M_{it} \tag{10}$$

Equation (9) can be divided into the technical change and the structural effects as follows:

$$\Delta\ln MP_t^{technical} = \bar{D}^v_{it}\,\Delta\ln\omega_{it} \tag{11a}$$

$$\Delta\ln MP_t^{structural} = \Delta\ln MP_t - \bar{D}^v_{it}\,\Delta\ln\omega_{it} \tag{11b}$$

The labor productivity at the aggregate level LP is defined as the output per hours worked $LP_t = Y_t / L_t$, where $Y_t = \sum_i Y_{it}$ and $L_t = \sum_i L_{it}$. The labor productivity growth within firms depends on the multifactor productivity growth and on the accumulation of intangible and fixed capital towards their steady-state values. Furthermore, the change in the average labor productivity is first decomposed into the efficiency and market reallocation effects in accordance with Diewert and Fox (2010) and Böckerman and Maliranta (2012):

$$\begin{gathered} LP_{it} - LP_{it-1} = \sum_{i \in C} \overline{s}_{hit} (lp_{it} - lp_{it-1}) + \sum_{i \in C} \overline{lp}_{it} (s_{hit} - s_{hit-1}) \\ + S_t^E (LP_t^E - LP_t^C) - S_{t-1}^D (LP_t^D - LP_{t-1}^C) \end{gathered}, \tag{12}$$

where $s_{hit} = L_{it} / \sum_i L_{it}$ is the share of firm *i* of the total hours worked, $\overline{s}_{hit} = 0,5(s_{hit} + s_{hit-1})$ is a Tornquist approximation, $S_t^Z = \sum_{i \in Z} L_{it} / \sum_i L_{it}$ is the share of group *Z*=*E* or *D* of all hours worked (*E* is the entrants and *D* is the exiting firms), and LP^C is the labor productivity in the continuing firms. ΔLP_t is derived by dividing both sides by $\overline{LP}_t = 0,5(LP_t + LP_{t-1})$.

Then, the growth of the average labor productivity $\Delta LP_t \equiv (LP_t - LP_{t-1}) / \overline{LP_t} \approx \ln LP_t - \ln LP_{t-1}$ is divided into internal (within) $\Delta LP^{\text{internal}}$ and market reallocation (between) effects $\Delta LP^{\text{reallocation}}$:

$$\begin{aligned} &\Delta LP_t = \Delta LP_t^{\text{internal}} + \Delta LP_t^{\text{reallocation}}; \\ &\Delta LP_t^{\text{internal}} = \sum_i \overline{s}_{hit} \Delta lp_{it} \\ &\Delta LP_t^{\text{reallocation}} = \Delta LP_t - \Delta LP_t^{\text{internal}} = \sum_i \overline{s}_{hit} \Delta lp_{it} \left(\frac{lp_{it}}{\overline{\overline{LP}}_t} - 1 \right) \\ &\quad + \sum_i \frac{\overline{lp}_{it}}{\overline{\overline{LP}}_t} (s_{hit} - s_{hit-1}) + S_t^E \frac{LP_t^{ENTR} - LP_t^C}{\overline{LP}_t} \\ &\quad - S_{t-1}^D \frac{LP_{t-1}^{EXIT} - LP_{t-1}^C}{\overline{\overline{LP}}_t} \end{aligned} \tag{13}$$

The first term $\Delta LP_t^{\text{internal}}$ denotes the internal labor productivity growth, i.e., the productivity growth within each firm weighted by its share of the total hours worked. The second term $\Delta LP_t^{\text{reallocation}}$ denotes the effects arising from market reallocation. Here, the first term $\sum_i \bar{s}_{it} \Delta lp_{it} (lp_{it} / \overline{LP}_t - 1)$ describes the effect of divergence. The divergence and hence the labor productivity increases when the labor productivity in firm *i* improves, that is, when Δlp_{it}>0, and the firm has higher than average productivity, that is, when $lp_{it} > \overline{LP}_t$. The second term is further divided based on whether among the firms that are on average above or below the median labor productivity, the most productive firms within that group are gaining market share. The third term measures the effect that arises if the productivity of new firms deviates from the net productivity of the continuing firms. The fourth term denotes the same effect for exiting firms, where $S_t^X = \sum_{i \in X} l_{it} / \sum_i l_{it}$ denotes the share of working hours of groups *X=ENTR* and *X=EXIT* and the term LP_t^C denotes the productivity in continuing firms. Note that the structural reallocation term in multifactor productivity (11b) and the market reallocation term in labor productivity growth (13) are not directly linked. Structural factors can relate to positive markups so that the relative costs of factor inputs may differ from one firm to another. In the absence of markup pricing (under perfect competition), structural factors can still be part of the transition of the capital accumulation process to a steady state. This structural reallocation may lead to improved market reallocation if the consequent improvement in multifactor productivity is greater in high-value added firms.

PLE obtained in their analysis a very large variance in the reallocation effects of labor productivity. One explanation is the aggregation of multifactor productivity across firms using the value added share as the weight of each firm, whereas the aggregation of labor productivity we employ is based on the shares of working hours. Using the shares in value added gives a large weight to capital-intensive, large firms, which have more volatile incomes than the firms in the labor-intensive service sector.

Finally, it would be tempting to concentrate on longer trends in multifactor productivity. Planas, Roeger and Rossi (2013) show that capacity utilization and multifactor productivity were positively correlated in almost all of the pre-enlargement EU countries during the period from 1985-2011 so that the rapid drop in multifactor productivity in 2009 is likely to be explained by lower capacity utilization rates. However, e.g., in manufacturing, the capacity utilization rates have remained permanently lower with the share of firms with extra capacity increasing from approximately 20 percent until the beginning of 1998 to approximately 60 percent in 2010-2012 (the peak of 70 percent was reached at the end of 2008 according to the Confidence Indicators by the Confederation of Finnish Industries). Because the contribution of lower capacity utilization is not unknown, multifactor and labor productivity growth are not de-trended.

4. Empirical estimates of multifactor and labor productivity growth

The empirical estimation is done by the use of instrument estimation in the gmm method with the Woolridge (2009) modification preferred by PLE. In addition, stochastic frontier estimates are presented for comparison. Intermediate inputs have been used as the sole instrument in the literature, but in many small companies, the intermediate input can vary greatly from year to year; furthermore, values can be missing. The hiring of new workers is the preferred instrument for productivity shocks, and it is also used in I&P in an Olley-Pakes instrument estimation. In I&P, the results were close to the results obtained using both intermediate input and hiring as instruments. The hiring rate is defined as the number of new workers in relation to the number of employees in the two periods. Hiring and materials are non-zero in approximately 98 percent of the firms in the data set; that is, virtually all firms hire at least one employee per year and have non-zero material purchases. The exogenous variables are fixed capital, lagged hiring and these variables' interactions. Intermediate input is used as an endogenous variable in addition to the proportions of skilled and unskilled workers (see the footnote of Table A.1 in Appendix A).

Stochastic frontier analysis (SFA) has contributed to an increasing research effort in this area (Kumbhakar and Lovell 2000, Coelli et al 2005). Because the production frontier is formed by "best practice" firms, it indicates the maximum potential output for a given set of inputs. The estimation procedures are stochastic with white noise, but an additional one-sided error represents any other reason firms would be outside of (or within) the boundary. Observations within the frontier are "inefficient", so given an estimated production frontier, it is possible to measure the relative efficiency of certain groups or a set of practices from the relationship between the observed production and some ideal or potential production (Greene, 1993). The production function (2) is written in a general stochastic production frontier model as follows (without the time subscripts and sunk costs):

$$ln Q_i = f(lnX_i, lnM_i) - u_i - v_i \qquad (14)$$

where $f(\ln X_i, \ln M_i) = \ln MP_i + \left(\sum_k \varepsilon_k \ln X_{ki} + \varepsilon_M \ln M_i\right)$, v_j is the stochastic (white noise) error term and u_j is a one-sided error representing the technical inefficiency of firm j. Both v_j and u_j are assumed to be independently and identically distributed (iid) with variances o_v^2 and o_u^2, respectively. The production of each firm i can be estimated as

$$ln\hat{Q}_i = f(lnX_i, lnM_i) - u_j. \quad (15)$$

The efficient level of production (i.e., no inefficiency) is defined as

$$lnQ_i^* = f(lnX_i, lnM_i). \quad (16)$$

The technical efficiency (TE) is given by

$$lnTE_i = ln\hat{Q}_i - lnQ_i^* \quad (17)$$

and $TE_i \equiv e^{-u_j}$ is constrained to be between zero and one. If u_j equals zero, then TE equals one, and the production is said to be technically efficient. Thus, the technical efficiency of the *i*th firm is a relative measure of its output as a proportion of the corresponding frontier output. A firm is technically efficient if its output level is on the frontier, which implies that Q / Q_i^* equals one.

The instrument estimation uses one-period lagged values for fixed capital that is considered exogenous and one-period and mostly two-period lagged values of the other primary inputs and intermediate inputs as instruments. For comparability, SFA estimation also includes one-period and two-period lagged values. As a result, the explanatory variables are assumed to adjust within three periods to productivity shocks, which are proxied by the hiring of new employees lagged up to two periods.

Table 2 shows the output elasticities for clusters using either instrument estimation (INS) or stochastic frontier analysis (SFA), and in the latter case, the elasticities are summed over the three periods.[8] The full estimation results are shown in Appendix A in Tables A.1 and A.2. On average, the returns to scale are 90-100 percent using the preferred instrument estimation, except in the following cases: the returns are 80 percent in the labor-and-intangible-capital-intensive cluster and 73 percent in the fixed-capital-intensive cluster. The fixed capital data are of poor quality, which most likely explains the low output elasticity and thereby explains the low returns to scale in the fixed-capital-intensive cluster.

Nevertheless, the results show that the output is more responsive to intangible capital than to fixed capital input. The intangibles have notably high output elasticity in the intangible-capital-intensive clusters of 18 percent in the instrument estimation. Given the relative sizes of the clusters, the elasticities in the instrument estimations are close to the 10 percent share at which the intangibles are presumed to be of GDP in many aggregate-level studies, such as Jalava (2007) for Finland; see also Jona-Lasinio and Iommi (2011), who cover the EU27 countries, and Marrocu et al. (2012), who obtain somewhat lower average output elasticities of 6 percent when using the fairly imprecise recording of intangible assets in firms' balance-sheets.

[8] The SFA specification includes country-fixed and industry-fixed effects as well a set of time dummies to control for unknown or unobserved factors and zero intangibles. The time-invariant model is applied whenever the inefficiency term is assumed to have a truncated-normal distribution.

Table 2. Output elasticities for the clusters

Cluster		Basically educated	Highly educated	Fixed capital	Intangible capital	Inter-mediates	Returns to scale
Organizational capital intensive	INS	0.28	0.17	0.05	0.18	0.30	0.98
	SFA	0.31	0.16	0.09	0.10	0.10	0.75
Fixed capital intensive	INS	0.06	0.07	0.14	0.01	0.44	0.73
	SFA	0.11	0.04	0.26	0.01	0.39	0.81
Fixed capital and labor intensive	INS	0.25	0.16	0.12	0.04	0.34	0.91
	SFA	0.19	0.10	0.16	0.01	0.32	0.78
Labor and intangibles intensive	INS	0.25	0.20	0.00	0.06	0.28	0.80
	SFA	0.17	0.16	0.14	0.03	0.25	0.74
Labor non-capital intensive	INS	0.18	0.16	0.11	0.33	0.10	0.88
	SFA	0.12	0.47	-0.01	-0.04	0.01	0.55
R&D capital intensive	INS	0.31	0.20	0.03	0.18	0.22	0.94
	SFA	0.27	0.23	0.10	0.17	0.13	0.89

The output elasticity of workers with basic educations is plausible at 25-31percent in instrument estimation in other than the fixed capital cluster or the labor and non-capital intensive clusters. The estimation results are not very different in the instrument and SFA estimations. The following table shows the trends in technical efficiency in the latter estimation.

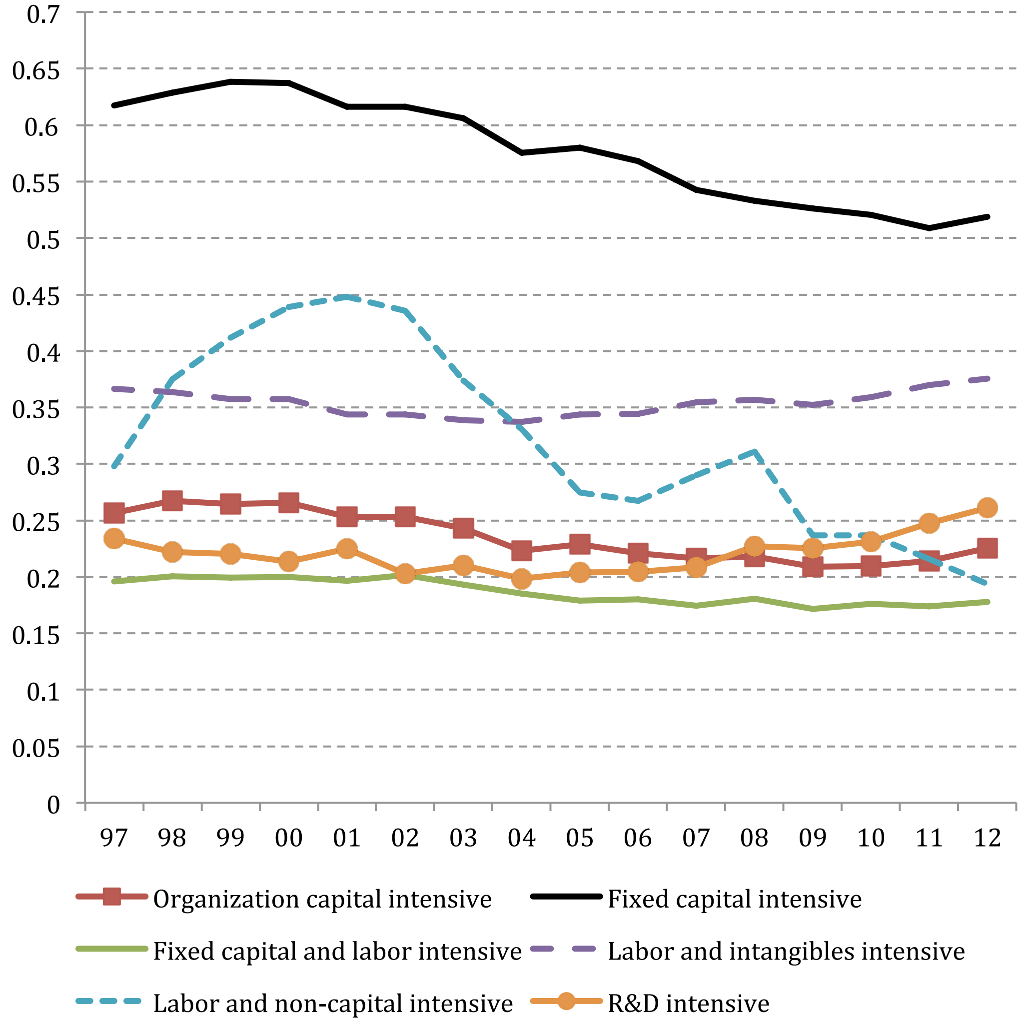

Figure 1. The trends in technical efficiency by cluster

It is observed that the technical efficiency is on average low. Table A.2 in Appendix A shows the ratio of the variance of the inefficiency component to the variance of the composite error term (gamma), which ranges from 0.58 in R&D capital-intensive cluster to 0.85 in fixed-capital-intensive cluster. Because the distribution of technical efficiency scores in many clusters is skewed to the right, the distance between the most efficient firms and other firms is large; see Figure A.1 in Appendix A, which was obtained at the aggregate level. The technical efficiency is shown in Figure 1 to have decreased over time in the fixed-capital-intensive cluster and to a lesser extent in the organizational cluster and the fixed-capital-and-labor-intensive cluster. Instead, the efficiency improved in the R&D intensive and labor-and-intangibles-intensive clusters.

In the following, output elasticities derived from instrument estimations are used. However, a technological shift is also considered by estimating the production function separately for the periods 1997-2006 and 2007-2012. Table A.1 shows the estimation statistics and Table A.2 shows the output elasticities using grouping by single-digit Nace Rev. 2 industries (the Classification of Economic Activities in the European Community). In the industry-specific estimations, 3,565 out of a total of 22,498 firm-year observations are lost because of the lack of a sufficient number of firms in the single-digit industries.[9] The industry-specific estimations yield very low output elasticities with respect to intangible capital in information and whole and retail sales, although firms that intensively use organizational capital are typically from these industries. The output elasticity is also low in the scientific industry, which is an important part of the R&D intensive cluster. Finally, the output elasticity of fixed capital is very low in the paper and pulp industry.

These results indicate that industries are heterogeneous in the use of factor inputs, and hence, a common production function is hard to derive. Because the intangibles are typically complementary to the use of other factor inputs, the output elasticities appear to be strongly biased downwards. An additional problem is the 35 percent decrease in value added of the manufacturing sector in the period 2008-2012, and the single-digit output elasticities may reflect this downsizing. Major causes for the decline are the paper and pulp industry and the electronics industry (even when excluding Nokia), and thus, the electronics industry would not be a good indication of the potential of R&D activity in the future.

[9] The industries dropped in the industry-level analysis but included in some of the clusters are beverages, furniture, leather, mining, pharmaceutical, textiles, and apparel.

Table 3 shows the value added and multifactor productivity (MP) growth, and the MP growth explained by intangible investment alone. These figures do not require a production function estimation. The MP explained by intangibles is the difference in MP including intangible investment as a factor input and as a part of the value added, and traditional MP growth ignoring intangibles. The MP growth has been heterogeneous among the clusters. Since 2007, the total factor productivity growth has slumped, and only the intangible and fixed-capital-intensive clusters have been able to maintain positive growth. For the R&D intensive sector, growth is partly explained by the supply of R&D personnel from the downsizing of Nokia's staff in Finland (Nokia itself is excluded from the study).[10]

The last row shows the aggregated growth rates of all of the clusters. The MP growth has decreased from 5.1 percent in the period 1998-2006 to 0.6 percent in the period 2007-2012. Since 2007, the contribution of intangible investments to growth has been negative, on average. There is no clear explanation for this phenomenon, but one reason could be uncertain prospects for the global economy.

[10] Nokia's employment in Finland had decreased from a peak of around 25000 to around 12000 by 2012.

Table 3. The value added and productivity growth in clusters

Cluster	Value-added growth 1998-2006, %	Value-added growth 2007-2012, %	MP growth 1998-2006, %	MP growth 2007-2012, %	MP growth from intangibles 1998-2006, %	MP growth from intangibles 2007-2012, %
Organizational capital intensive	13.2	2.6	10.7	1.5	0.6	0.3
Fixed capital intensive	5.9	-0.9	0.5	1.2	4.9	-2.4
Fixed capital and labor intensive	7.3	-1.7	4.9	0.3	1.9	-2.3
Labor and intangibles intensive	7.7	-1.9	6.5	0.0	0.0	1.9
Labor non-capital intensive	8.6	-7.4	3.6	-9.1	3.9	0.8
R&D capital intensive	12.7	5.9	8.8	4.0	2.2	1.2
All industries	6.9	-1.0	5.1	0.6	2.4	-0.7

The growth from intangibles is the difference in the multifactor productivity MP growth if these intangibles are included or excluded (as traditionally) in the value added and as one factor input.

4.1 *Output elasticities using cluster analysis*

Figure 2 below shows the multifactor productivity growth. The components are structural reallocations without sunk costs, lower fixed/sunk costs (more positive figure indicates that the sunk costs have decreased) and three-year moving averages of technical development. The structural productivity growth is given by (9), whereas the sunk costs are the remaining residual when deducting (9) from (11b).

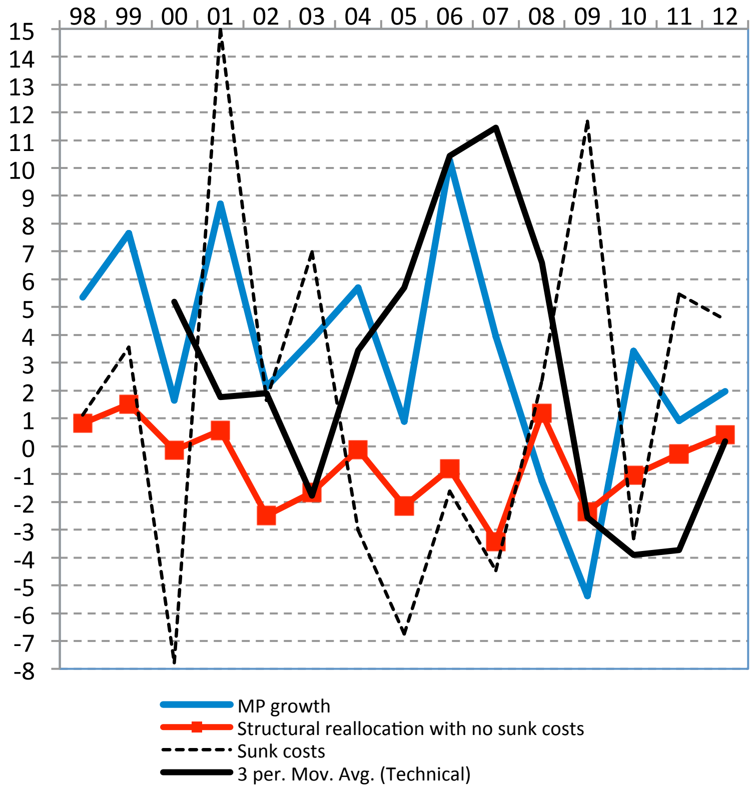

Figure 2. The multifactor productivity growth

Figure 2 shows that the MP growth has decreased over time, which is mainly because of the decrease in technical development. Figure 2 also shows the rapid technological change in the period 2006-2007 before a significant drop in technical development in 2009 that was associated with savings in fixed/sunk costs. Lower sunk costs have on average improved the multifactor productivity growth, but there were exceptions in the years 2000, 2005-2007 and 2010.

Table 4 shows the labor growth and the multifactor productivity growth by their components; it also shows the contributions of the technical and structural factors in the period 2007-2012, when the production function is estimated separately for the years 2007-2012 (marked with 'new'), for the earlier period not shown here). The year 2007 is included in the second period to have a full business cycle in this period.

The annual labor productivity growth has slowed from approximately 5 percent in1998-2007 to 0.3 percent in the period 2011-2012, and the decrease in multifactor productivity growth has been of the same magnitude from approximately 5 percent in the period 1998-2007 to 1.4 percent in the period 2011-2012. Table 4 shows that the growth in technical change has been on average at 2.3 percent. Hence, the growth in technical change is similar to the 2.2 percent growth observed for U.S. manufacturing in the years 1976-1996 by Petrin et al. (2011). However, in contrast to U.S. manufacturing, the multifactor productivity has decreased since 2007 primarily because of the drop in technical development.

Structural improvements continued to support productivity growth except in the years 2005-2007. Petrin et al. (2011) find that structural changes are persistent and less dependent on business cycles than technical development. Following earlier analysis by Piekkola and Åkerholm (2013), Table 4 shows that over time, the market reallocation effects have increased more than the structural reallocation effects. Table A.4 in Appendix A shows the sources of market reallocation from (13), and this table indicates that among the firms with above median productivity, the high productivity firms have been gaining market shares, and furthermore, the change in the composition of firms though entries and exits has been favorable.

Table 4. Multifactor and labor productivity growth

Year	Multifactor productivity			Labor productivity		
	MP growth	Tech-nical	Structu-ral	LP growth	Internal	Reallo-cation
98-01	5.8	2.2	3.7	3.6	6.0	-2.4
02-04	3.9	3.4	0.5	4.3	4.6	-0.3
05-06	5.6	11.2	-5.7	2.9	5.5	-2.6
07-10	0.2	0.0	0.2	0.2	1.5	-1.3
07-10 new	0.2	-0.5	0.7			
11-12	1.4	-3.6	5.1	2.5	0.3	2.1
11-12 new	1.4	-3.6	5.0			
Average	3.3	2.3	1.0	2.6	3.7	-1.1

Finally, the contribution of technical development has decreased since 2007 irrespective of whether the production function estimation is applied to the entire period or separately to the years 2007-2012 (the 2007-2010 new and the years 2011-2012 new figures in Table 4).

Table A.5 in Appendix A shows the means and standard deviations of the productivity growth and their components over the years. Compared to Petrin et al. (2011), the standard deviations of multifactor productivity and its components are much higher than the corresponding statistics for labor productivity. The standard deviation of multifactor productivity growth is 4.0 percent overall compared with 2.6-3.0 percent in Petrin et al. (2011). The volatility is naturally even higher within the clusters. High volatility is explained by the exceptional years 2000 and 2009, as in the former year, the ICT bubble burst and in the latter year the GDP fell by 8 percent. The volatility of labor productivity is somewhat lower and is approximately 3.7 percent. In addition, the aggregate labor productivity is derived using the hours worked rather than the more turbulent value added as weights (turbulence is especially problematic in export-oriented industries).

It is a possibility that the rapid technological change in the period 2005-2007 was followed by a permanent change in the production conditions. Competition has erased various price margins, and the focus has been more on more efficient allocations of resources. Thus, it is of considerable interest to examine the determinants of structural change from (9) and (11b) where the latter includes sunk costs. This is done separately for the years 1997-2006 and 2007-2012 using the production function estimation for the whole period in Table 5 and using a different production function for the periods in Table 6. The last two rows in Table 5 show the average structural change, which is aggregated from the structural change in the clusters.

Table 5. Structural change and its components

Cluster	Year	1 Reallo-cation all	2 Basic educated	3 Highly edu-cated	4 Intangible capital	5 Fixed capital	6 Inter-mediate	7 Reallo-cation 2-6	8 Sunk costs
Organizational capital intensive	98-06	9.8	2.6	6.5	2.1	-0.6	6.5	17.1	-7.4
	07-12	-1.6	-0.2	2.2	0.8	-0.5	1.9	4.2	-5.8
Fixed capital intensive	98-06	-4.3	-0.5	1.5	0.0	0.1	1.4	2.4	-6.7
	07-12	3.3	-1.9	2.8	0.0	2.0	2.2	5.1	-1.7
Fixed capital and labor intensive	98-06	4.5	-1.0	3.7	1.5	0.6	-2.1	2.6	2.0
	07-12	4.2	-0.1	8.1	3.4	0.4	-1.4	10.4	-6.2
Labor and intangibles intensive	98-06	1.2	-0.9	0.8	1.0	-0.4	0.9	1.4	-0.2
	07-12	-1.0	0.3	1.6	0.6	-0.6	1.2	3.0	-4.0
Labour non-capital intensive	98-06	-1.0	-1.4	2.9	1.0	0.0	1.2	3.6	-4.7
	07-12	2.6	1.4	1.3	1.0	0.7	-0.2	4.0	-1.4
R&D intensive	98-06	-0.6	1.6	-1.6	1.4	0.6	-0.5	1.6	-2.2
	07-12	3.2	3.9	0.5	2.0	0.7	-0.6	6.6	-3.3
All	98-06	0.5	-0.5	2.8	0.7	-0.3	0.9	3.5	-3.0
	07-12	1.8	-0.9	2.3	0.6	0.6	1.4	3.9	-2.1

In the whole period 1998-2012, the mobility of the highly educated workforce has been the most important factor promoting structural change; the corresponding contribution was, on average, approximately 2.5 percentage points per year. In particular, the organizational and labor-intensive clusters benefitted considerably from a highly educated workforce moving to firms with greater value added relative to the cost structure. Almost symmetrically, the situation has been the opposite for workers with low degrees of education, who have moved to firms where the labor costs exceed the productivity; this phenomenon only strengthened in the second period. The structural change was less positive in the years 2007-2012 due to the misallocation of the workforce with a basic education to the labor-intensive clusters, where the multifactor productivity growth has deteriorated.

It is evident that because the fixed or sunk costs have been considerable, substantial structural improvements have been caused by savings in fixed costs. More efficient use of intermediate inputs has been another important structural factor, and in the first period under study, it was already critical in these clusters: the organizational-capital-intensive cluster and the R&D capital-intensive cluster. Intangible capital (in the whole period) and downsizing of fixed capital (in the second period) have also contributed approximately 0.6 percentage points to the structural growth in productivity.

Table 6 shows the structural allocations in the years 2007-2012 as a result of applying the new technology adopted in this period. Old technology refers to what would have happened to the structural allocations if the technology in the earlier period 1998-2006 had also been applied in the 2007-2012 period.

Table 6. Structural change and its components in the period 2007-2012 with old and new technology form 2007-2012

	1	2	3	4	5	6	7	8
Cluster	Reallo-cation all	Basic educated	Highly edu-cated	Intangible capital	Fixed capital	Inter-mediate	Reallo-cation 2-6	Sunk costs
Organizational capital intensive	1.8	-1.1	7.1	3.1	0.1	3.4	12.5	-10.7
Old technology	-1.6	-0.2	2.2	0.8	-0.5	1.9	4.2	-5.8
Fixed capital intensive	4.2	-0.6	1.0	0.1	2.6	-4.6	-1.4	5.6
Old technology	3.3	-1.9	2.8	0.0	2.0	2.2	5.1	-1.7
Fixed capital and labor intensive	-4.2	-2.3	2.0	0.9	-0.7	-4.3	-4.4	0.2
Old technology	4.2	-0.1	8.1	3.4	0.4	-1.4	10.4	-6.2
Labor and intangibles intensive	-4.1	-3.8	1.4	0.1	1.2	-5.8	-6.9	2.8
Old technology	-1.0	0.3	1.6	0.6	-0.6	1.2	3.0	-4.0
Labour non-capital intensive	-0.4	-3.2	0.1	3.7	0.0	0.0	0.6	-1.0
Old technology	2.6	1.4	1.3	1.0	0.7	-0.2	4.0	-1.4
R&D intensive	-1.3	-0.5	1.2	1.1	-0.7	1.1	2.2	-3.5
Old technology	3.2	3.9	0.5	2.0	0.7	-0.6	6.6	-3.3
All	-1.3	-1.5	2.5	1.1	0.6	-1.2	1.4	-2.8
Old technology	1.8	1.5	1.4	1.6	0.0	-1.3	3.2	-1.4

With the new technology applied in the years 2007-2012, the productivity growth has become even more strikingly driven by the mobility of highly educated labor. In contrast, the workforce with only a basic education is more clearly stuck in poorly performing firms. However, the most important difference is that the reallocation of intermediate inputs is beneficial only in intangible-capital-intensive sectors, whereas the fixed-capital and labor-intensive clusters have suffered from the inefficient use of intermediate inputs. In these intangibles-intensive industries, the relative prices of intermediate inputs have also decreased in relative terms compared to producers' prices, while in many fixed-capital-intensive manufacturing industries the opposite phenomenon has occurred.[11]

From Table 7 below, it is seen that the output elasticities for intermediate inputs have increased in both the organizational capital cluster and the fixed-capital-intensive cluster in the years 2007-2012 compared to the 1998-2006 period, but intermediate inputs also became more costly in the fixed-capital-intensive cluster. Hence, fixed-capital-intensive firms face the challenge of economizing their intermediate input use, which requires more technology-oriented and flexible subcontractors. The following table shows the estimated output elasticities in the two periods under study.

[11] A gap between the producer price and the intermediate good price has been created since 2000 (we set the producer and intermediate input price as 100 in 2000) in the following services: wholesale trade (13 units), computers, information and consulting (9 units), legal and head office services (30 units), scientific research and development (19 units) and food and beverage service activities (23 units). In contrast, in manufacturing as a whole the intermediate input price development has increased more than the producer prices (15 units on average), which has occurred most strikingly in the paper and pulp and medical industries (20-25 units). The manufacture of electronic components and the financial sector have experienced rapid technological development, and producer prices have decreased more in these areas than in other industries. However, in the manufacturing of metal products and construction, the producer and intermediate price indices have moved in a parallel way.

Table 7. The output elasticities from 1998-2006 and 2007-2012

Cluster		Basic educated	Highly educated	Fixed capital	Intangible capital	Inter-mediates	Returns to scale
Organizational capital intensive	1998-2006	0.27	0.18	0.06	0.17	0.27	1.0
	2007-2012	0.23	0.24	0.06	0.15	0.35	1.0
Fixed capital intensive	1998-2006	0.11	0.04	0.19	-0.01	0.39	0.7
	2007-2012	0.05	0.03	0.12	0.03	0.47	0.7
Labor and fixed capitla intensive	1998-2006	0.21	0.16	0.16	0.01	0.34	0.9
	2007-2012	0.25	0.22	0.09	0.06	0.32	0.9
Labor and intangibles intensive	1998-2006	0.22	0.20	0.03	0.07	0.32	0.8
	2007-2012	0.29	0.23	0.00	0.05	0.29	0.9
Labor non-capital intensive	1998-2006	0.00	0.33	0.07	0.37	0.06	0.8
	2007-2012	0.29	0.00	0.07	0.50	0.01	0.9
R&D capital intensive	1998-2006	0.29	0.21	0.01	0.18	0.25	0.9
	2007-2012	0.29	0.18	0.06	0.22	0.21	1.0

The output elasticity of fixed capital (which admittedly has a downward bias due to measurement errors) decreases in the second period in the fixed capital and the fixed-capital-and-labor-intensive clusters. Thus, the productivity growth is maintained by downsizing the fixed capital stock. Indeed, the output elasticity of intangible capital has remained unchanged or increased from the first period to the second period. It is also observed that the output elasticity of the workforce with only a basic education has remained roughly the same, whereas the corresponding elasticity of highly educated workers has increased.

Petrin et al. (2011) found that in U.S. manufacturing, structural change was the main driver of multifactor productivity growth in the period 1976-1996. However, this result can also be explained by the fact that manufacturing was a declining industry with the GDP share of manufacturing falling from 21 percent to 15 percent in the years 1976-1996. Here, technical development is found to be equally important, and it shows the largest decline since 2007. Table 8 compares the MP growth in the periods 1998-2006 and 2007-2012 in each cluster with the different production functions for the periods 1998-2006 and 2007-2012. The last rows show the between-cluster effects that are the difference between the figures for “All” (aggregation without clustering but letting the output elasticities vary from one cluster to another) and the aggregated effects over those patterns that were observed in the clusters.

Table 8. The productivity growth from 1998-2006 and 2007-2012 with different technologies

Cluster	Year	Multifactor productivity			
		Total	Technical	Structural	Structural with no sunk costs
Organizational capital intensive	98-06	10.1	2.5	7.6	16.9
	07-12	0.8	0.5	0.3	0.2
Fixed capital intensive	98-06	1.7	-1.2	2.9	3.7
	07-12	0.7	-7.8	8.5	-0.5
Fixed capital and labor intensive	98-06	1.0	2.7	-1.6	2.6
	07-12	-0.8	1.0	-1.9	-1.1
Labor and intangibles intensive	98-06	-0.5	4.7	-5.3	-4.3
	07-12	-3.0	1.2	-4.2	-2.9
Labor non-capital intensive	98-06	-7.5	-5.4	-2.1	3.8
	07-12	-10.4	-7.7	-2.6	-1.2
R&D intensive	98-06	4.0	4.6	-0.6	3.7
	07-12	2.9	-0.3	3.2	-0.3
All	98-06	2.3	2.7	-0.4	4.0
	07-12	0.6	-1.2	1.8	-0.9
Between clusters	98-06	0.1	-0.6	0.7	-0.3
	07-12	-0.7	-0.4	-0.3	0.0

The intangible-capital-intensive sectors have experienced rapid improvement in their multifactor productivity growth in the first period 1997-2006, and the R&D capital-intensive cluster maintained high growth in the second period as a result of structural factors. In all of the intangible-capital-intensive sectors, the growth in the later period was still supported by structural change, although the multifactor productivity growth was modest (as shown above in Table 4). Recall from Table 5 that the structural reforms relate to more efficient use of a highly educated workforce, intangible investments and cost savings in intermediate inputs. The outcome is also explained by the higher output elasticities that existed in the second period, which are given in Table 7. Fixed-capital-intensive firms have undergone the largest structural change and have suffered the most from technological inefficiency; in this cluster, all of the structural gains have been achieved through lower fixed costs.

The last row in the table shows that in the years 2007-2012, the aggregate MP growth was 0.7 percent lower than what would be implied by the weighted average of the clusters. This result indicated that the clusters that are more productive have not sufficiently increased their market shares.

5. Conclusion

Finland is among the countries where the turnaround in productivity growth has been the most pronounced since mid-2000. An analysis on the basis of extensive Finnish micro data reveals new insights into the productivity mystery. It is apparent, that firms behave differently within the same branch, and therefore, they were regrouped into clusters where the firms use the same types of inputs in production. Then, it is shown that while productivity growth has generally relied on a more efficient use of production factors, over the last few years, this growth has almost entirely relied on a reallocation of resources from lower productivity activities to firms with higher productivity. This positive structural change has occurred through the mobility of skilled workers and reallocation of intangible capital and intermediate inputs between firms.

In all of the examined industries, technical development has slowed down, but this is particularly pronounced in the fixed-capital-intensive cluster. On the other hand, technological development has been more favorable in the clusters which invest in relative terms most in intangible capital, even if a slowdown can be discerned also in these firms. It is also apparent that intangibles-intensive firms have been able to use intermediate inputs more efficiently and benefit from the reduction in the relative prices of these inputs.

The R&D-intensive cluster has continued to experience relatively good productivity performance primarily through structural reallocation. Also, the improvement in multifactor productivity has in recent years been emanating from structural reallocation rather than from technological development.

The fixed-capital-intensive firms, such as paper and pulp, basic metal industries and large retailers, have economized on their fixed costs and adjusted their capital stock downwards. Thus, they have improved their multifactor productivity through a different type of structural reallocation. The economic inefficiency has actually increased over time.

A structural reallocation might not yield a permanent comparative advantage or an increase in internal returns to scale. Moreover, the need to be at the frontier of technology development to maintain technological efficiency is even more pressing. The productivity mystery also might indicate an inability to generate new growth through fixed capital accumulation in the fixed-capital-intensive cluster and a challenge to improve the quality of intangible investment in all clusters. It is evident that intangible-capital-intensive clusters will be the most important sources of future growth,

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Appendix A.

Table A.1 The instrument estimation of the output elasticities for clusters

	Organi-zation capital intensive	Fixed capital intensive	Fixed capital and labor intensive	Labor and intangibles intensive	Labor and non-capital intensive	R&D intensive
Basically educated	0.280***	0.0606	0.247***	0.253***	0.179*	0.311***
	(7.01)	(1.66)	(7.03)	(7.7)	(2.18)	(7.49)
Highly educated	0.167***	0.0706**	0.164***	0.197***	0.164	0.201***
	(4.9)	(2.6)	(7.56)	(5.05)	(1.26)	(4.23)
Intangible capital	0.176***	0.00688	0.0399**	0.0638*	0.330***	0.177***
	(4.78)	(0.67)	(2.97)	(2.07)	(3.4)	(3.65)
Intermediate input	0.300***	0.445***	0.340***	0.285***	0.0961*	0.223***
	(13.64)	(14.49)	(12.95)	(10.4)	(1.99)	(12.08)
Fixed capital	0.0541**	0.144***	0.121***	0.00344	0.108	0.0304
	(2.73)	(3.86)	(4.11)	(0.13)	(1.54)	(1.2)
Observations	2874	1557	3534	2886	227	1853
R Squared	0.743	0.944	0.880	0.835	0.749	0.847
Weak identification test (Cragg-Donald Wald F statistic)	520.9	278.3	378.0	352.4	27.4	215.3
Kleibergen-Paap Wald F statistic)	0.0	0.0	0.0	0.0	0.0	0.0
Hansen J statistic	15.4	9.4	13.1	15.4	10.2	11.6
Chi-sq(7)	0.031	0.226	0.069	0.031	0.175	0.115

All figures, except for the hiring numbers, are in logs. The exogenous variables are fixed capital with one-period lag, the second and third potencies of lagged fixed capital and hiring, lagged interactions of fixed capital and its second potency to hirings and lagged interactions of hiring and its second potency to fixed capital. The endogenous variables are basically educated, highly educated, intangible capital and intermediate input. The instruments include one-period and two-period lags of intermediates, unskilled workers, skilled workers, intangible capital, hiring, and the second and third potencies of hiring. The P values: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.2 The stochastic frontier estimation of the output elasticities for clusters

	Organization capital intensive	Fixed capital intensive	Fixed capital and labor intensive	Labor and intangibles intensive	Labor and non-capital intensive	R&D intensive
Basically educated	0.186***	0.0988***	0.131***	0.118***	0.0415	0.233***
	(8.61)	(5.55)	(10.58)	(7.42)	(0.43)	(9.46)
t-1	0.0912***	0.0325	0.0714***	0.0252	0.0775	0.00766
	(3.54)	(1.75)	(5.1)	(1.4)	(0.74)	(0.28)
t-2	0.0282	-0.0249	-0.0143	0.0285	0.00349	0.0297
	(1.3)	(1.59)	(1.09)	(1.8)	(0.04)	(1.29)
Highly educated	0.0495**	-0.00713	0.0534***	0.0795***	0.373***	0.186***
	(2.84)	(0.62)	(4.78)	(4.75)	(4.32)	(9.12)
t-1	0.0353	0.0219	0.00516	0.0498**	0.0917	0.0536**
	(1.84)	(1.78)	(0.43)	(2.6)	(0.96)	(2.6)
t-2	0.0730***	0.0289**	0.0443***	0.0337*	0.0044	-0.0139
	(4.84)	(2.63)	(4.12)	(2.06)	(0.06)	(0.73)
Intangible capital	0.0313*	0.00591	0.00528	-0.00214	-0.0407	0.0838**
	(2.57)	(1.37)	(1.05)	(0.18)	(0.49)	(3.14)
t-1	0.0562***	-0.000129	0.00497	0.0057	-0.00894	0.0616*
	(3.61)	(0.03)	(0.93)	(0.46)	(0.19)	(2.46)
t-2	0.00946	0.00661	0.00385	0.0228*	0.00598	0.0211
	(0.78)	(1.58)	(0.79)	(2.03)	(0.16)	(1.21)
Fixed capital	0.0744***	0.124***	0.150***	0.0572***	-0.0271	0.0651***
	(8.71)	(6.12)	(15.03)	(4.28)	(1.08)	(4.65)
t-1	0.0162	0.134***	0.00748	0.0785***	0.017	0.0316*

	(1.82)	(6.56)	(0.7)	(5.79)	(0.61)	(2.2)
Intermediate input	0.0802***	0.290***	0.275***	0.222***	0.00315	0.0904***
	(14.6)	(26.17)	(33.41)	(27.83)	(0.28)	(12.74)
t-1	0.0230***	0.0992***	0.0468***	0.0261**	0.00873	0.0371***
	(3.89)	(9.21)	(5.3)	(3.05)	(0.67)	(5.06)
t-2	0.0104	0.0616***	0.0350***	0.0373***	0.0212	0.0393***
	(1.83)	(5.89)	(4.65)	(4.83)	(1.68)	(5.66)
Hiring	0.0000371	0.00000275	0.00000686	0.00000484	0.0000442	-0.0000473*
	(1.73)	(0.39)	(0.55)	(0.33)	(0.53)	(2.08)
t-1	0.0000243	0.0000132	-0.0000035	-0.0000109	-0.0000413	-0.0000511**
	(1.13)	(1.91)	(0.3)	(0.76)	(0.44)	(2.64)
t-2	0.00000761	0.00000642	0.00000139	-0.00000345	-0.00016	-0.0000450*
	(0.36)	(0.93)	(0.12)	(0.23)	(1.6)	(2.2)
Observations	2874	1557	3534	2886	227	1853
Gamma	0.85	0.85	0.73	0.70	0.95	0.61
ratio test	2515	3971	7355	4120	348	4208
P-value	0.00	0.00	0.00	0.00	0.00	0.00

All of the variables except the variable for hiring are in logs. Year and one-digit industry dummies are included. The gamma parameter is the ratio of the variance of the inefficiency component to the variance of the composite error term and ranges between 0 (non-inefficiency) and 1 (inefficiency). The likelihood ratio shows that the inefficiencies are statistically significant.

component to the variance of the composite error term. The P values: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.3 The output elasticities for the single-digit industries using instrument estimation

Cluster	Basically educated	Highly educated	Intangible capital	Fixed capital	Inter-mediates	Returns to scale	Obser-vations
Accommodation	25.2	8.0	4.9	1.0	55.9	95.0	1432
Administrative	23.8	34.9	14.9	2.7	3.2	79.5	234
Basic metal	15.2	27.4	5.7	16.9	17.8	83.0	275
Chemicals	4.2	-29.2	12.6	34.0	31.2	52.8	470
Computer Electronic	4.5	-18.5	3.4	61.4	38.7	89.5	347
Electrical equipment	4.7	3.7	-0.5	36.1	24.8	68.7	311
Fabricated metal	17.0	27.2	4.5	-7.4	34.4	75.6	1031
Food	7.0	30.3	6.3	7.8	37.2	88.6	963
Information	30.1	38.2	2.8	12.1	9.1	92.2	1907
Machinery and equipment	17.3	4.9	15.8	24.2	29.7	91.9	1289
Non-metallic mineral	44.1	9.2	-4.4	10.8	13.0	72.7	836
Paper and Pulp	14.9	22.8	1.7	3.2	54.3	96.9	488
Plastic	23.9	7.7	1.3	36.1	19.3	88.3	662
Printing	28.9	23.8	0.7	1.6	34.3	89.3	606
Scientific	29.9	5.7	6.1	42.3	7.8	91.7	855
Transportation	2.4	35.8	8.1	21.0	19.6	87.0	924
Vehicles production	18.7	35.5	-0.6	-7.9	46.2	92.0	300
Wholesale, retail	26.0	9.1	3.8	4.6	54.9	98.3	5552
Wood	5.0	14.0	-1.1	-0.4	82.4	99.8	451

Table A.4 The components of labor productivity reallocation

		Components of between effects				
Year	Reallo-cation	Diver-gence	High produc-tivity	Low produc-tivity	Enter	Exit
98-01	-2.4	-1.7	0.2	-0.1	-0.8	0.1
02-04	-0.3	2.4	-1.2	-0.1	-1.4	0.0
05-07	-2.8	1.6	-4.6	0.6	-0.8	0.4
08-10	-0.7	-1.7	0.7	0.0	-0.3	0.7
11-12	2.1	-0.9	1.5	-0.3	0.6	1.2
Average	-1.1	-0.1	-0.8	0.0	-0.6	0.4

Table A.5 The means and standard deviation of the components of the productivity estimates

	Multifactor productivity						Labor productivity					
	MP growth		Technical		Structural		LP growth		Internal		Reallocation	
Cluster	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
Organizational capital intensive	7.0	10.0	1.5	13.8	5.5	13.1	4.0	6.4	3.8	5.6	0.1	5.2
Fixed capital intensive	0.8	8.6	0.0	16.2	0.8	11.5	2.1	7.2	2.5	5.0	-0.4	3.5
Fixed capital and labor intensive	3.0	4.8	2.4	10.3	0.6	9.7	3.8	5.8	3.4	5.8	0.4	3.0
Labor and intangibles intensive	3.1	8.4	4.0	17.3	-0.9	18.4	4.0	5.2	3.5	3.8	0.6	3.9
Labor non-capital intensive	-1.5	14.8	-6.1	13.0	4.6	16.5	1.4	15.2	2.3	4.1	-0.9	14.5
R&D intensive	6.9	6.8	5.7	11.0	1.2	8.0	1.4	4.7	5.6	5.7	-4.2	5.6
Average of clusters	3.2	8.9	1.2	13.6	2.0	12.9	2.8	7.4	3.5	5.0	-0.7	6.0
All	3.3	4.0	2.3	8.0	1.0	6.9	2.6	3.7	3.7	3.3	-1.1	2.8

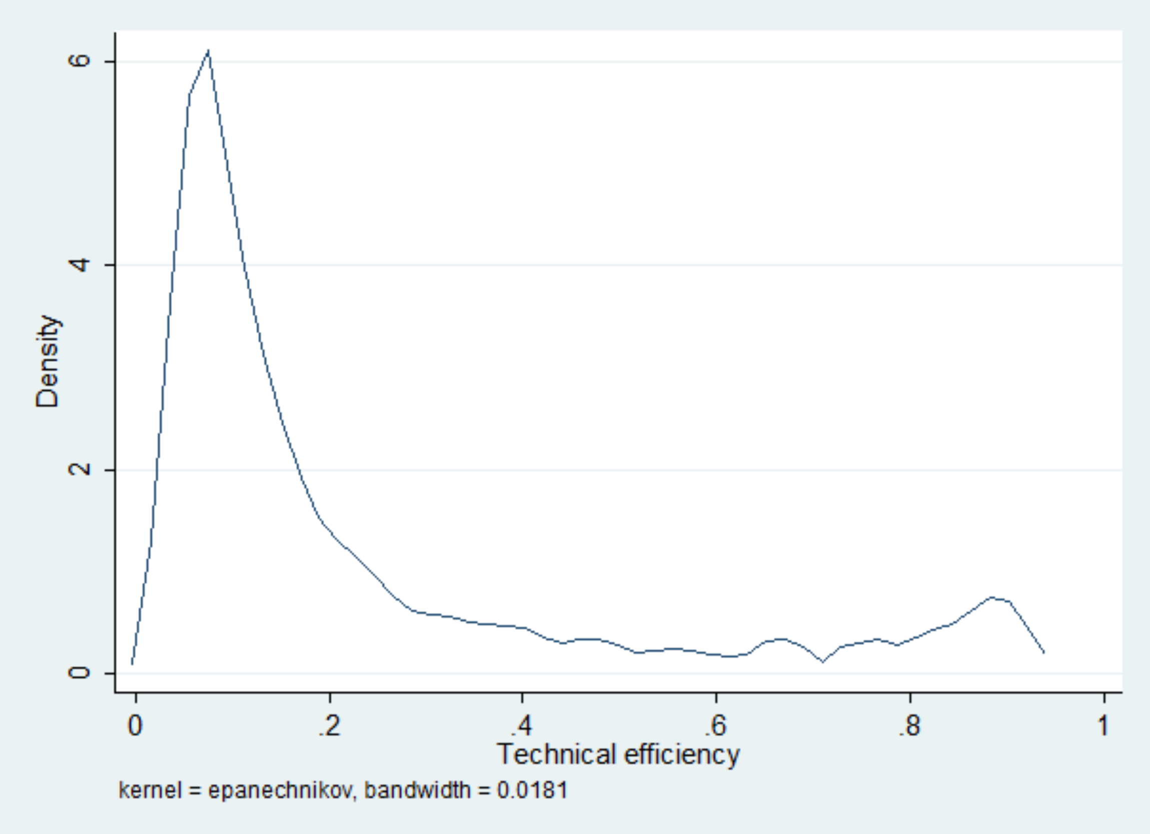

Figure A.1 Kernel density estimates of the technical efficiency for all clusters

Appendix B. Intangible capital

We use annual earnings instead of hourly wages because the earnings include performance-related pay and because workers in managerial positions are not paid for overtime hours. As a result, managers' recorded hours are consistently lower than their actual number of hours.

Görzig et al. (2010) provide the value of a combined multiplier M_{jt}^{IC}, which is time invariant in the expenditure-based approach. The share of workers producing intangible goods is set at 40% for organizational occupations (twice the share used in GPR), 70% for R&D occupations and 50% for ICT occupations. The factor multiplier from the intermediate and capital costs is set to be representative of the entire EU27 area and is a weighted average of the factor multipliers for Germany (40% weight), the UK (30% weight), Finland (15% weight), the Czech Republic and Slovenia (both countries have weights of 7.5%).[12] The factor multipliers employed to account for the use of capital and intermediate inputs are 1.76 for organizational wage expenses, 1.55 for R&D wage expenses and 1.48 for ICT wage expenses. Table B.1 summarizes the combined multiplier M^{IC} (the product of the share of effort devoted IC production and the factor multiplier) and the depreciation rates we employed.

Table B.1 OC, R&D and ICT combined multipliers in the expenditure-based approach and their depreciation

	OC	R&D	ICT
Employment shares	40%	70%	50%
Combined multiplier M^{IC}	70%	110%	70%
Depreciation rate δ_{IC}	20% production 25% services	15%	33%

Organizational and ICT investments represent 70% of the wage costs in the occupations we considered (in ICT, the figure is an approximation of the combined multiplier of 0.74). In R&D activities, the total wage costs are close approximations of the total investment and have a combined multiplier of 110%. The depreciation rate for the organizational investments is set at 20% in production, but the higher Corrado et al. (CHS) (2005) depreciation rate of 25% is retained in services; this higher rate is used because of the longer life cycle of an organizational investment in production. Recent estimates of depreciation from the surveys

[12] These were the countries with LEED data in INNODRIVE.

by Whittard et al. (2009) and Awano et al. (2010) indicate that the R&D depreciation rate is closer to 15% than the 20% figure used in CHS. ICT investments are assigned a 33% depreciation rate.

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