Human Capital and Information Technology as Factors of Production: Evidence from German service firms[*]

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Abstract:

This paper analyses the role of human capital and information technology (IT) in the service production process. The analysis is based on cross-sectional data for 1230 West German firms in 1994. The data are drawn from the first wave of the Mannheim Service Innovation Panel (MIP-S). Factor demand functions are used to analyse the determinants of the firm-specific skill structure. The empirical evidence indicates that IT investment and highly skilled labour (as measured by university graduates) are complements in the production process while IT investment serves as a substitute for unskilled labour. The substitutability of IT investment and medium skilled labour (workers with completed vocational training) is rather weak. Using a translog production function to assess the productivity of different input factors, we find that human- and information-capital provide the most powerful contributions to output in the service sector.

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1 Introduction

In microeconomic theory it is widely believed that less expensive IT capital substitutes for more expensive management and clerical workers (Solow 1961). While in the 1960s the public opinion feared that computer controlled machines would eventually replace blue collar workers, many people nowadays are afraid that IT could replace the middle management (Drucker 1988). In this line of argumentation, transaction cost theory states that the number of managers could be sharply cut due to the introduction of IT (Malone 1991). All of this suggests that IT alters the skill structure within firms. In the US, 80 percent of IT expenditures are invested in the service sector (Brynolfsson 1993), German figures show similar tendencies. Among all sectors it is therefore the service sector that is the most severely affected and that will experience the most changes.

Within the service sector, wholesale trade, the finance and insurance industries, and business services have shown the highest adoption rates of IT (McFetridge 1992). The link between both information- and communication-capital and the skill structure has been empirically analysed by a number of studies (for example, Bresnahan et al. 1998, for an overview see Chennells and Van Reenen 1998). The majority of studies relies on industry-level data to relate the change in the employment share of skilled labour – rather than the level of the employment share – to the industry's IT to total investment ratio. In contrast to public opinion, a common finding indicates the complementarity of IT capital and skilled labour. For the US at the four digit SIC level, Berman et al. (1994) and Autor, Katz and Krueger (1997) provide evidence that computer-intensive industries witness higher growth rates of the demand for skilled labour. Haskel and Heden (1998) present similar results for the UK at the firm level while Duguet and Greenan (1997) provide evidence that the change in the skill structure is related to the introduction of process and production innovations using French firm level data. Based on a panel of 600 U.S companies, Bresnahan et al. (1998) find that a larger IT capital stock is associated with a greater demand for skilled labour and that human capital intensive firms have a higher expected return on their IT capital stock per worker.

Related literature examines the productivity contribution of information technology to output in a production function framework. Estimates of the output elasticity of IT-capital range from 0.05 (Brynolfsson and Hitt 1995) to 0.10 (Lichtenberg, 1995) for an unbalanced panel of 200-400 U.S. companies. Their primary data source is the IDG/computerworld surveys on IT spending which focuses on large firms of which about one third are from the service sector. At the firm level, Licht and Moch (1997) find a much higher output-elasticity of IT-equipment of approximately 0.5 based on a sample of 790 German firms. Information on IT usage has been provided by International Data Corporation Germany. Using similarly disaggregated data for 60 US business units, Loveman (1994), however, estimates that the contribution of information capital to final output is negligible. Lichtenberg (1995) and Dewan and Min (1997) instead focus on the marginal rate of substitution between different types of skills (including IT labour), IT capital, and other factors of production. Lichtenberg (1995) finds that one IT worker can be substituted for six non-IT workers. In contrast, Dewan and Min's (1997) results indicate an elasticity of substitution of approximately one between IT capital and other factors of production (capital and non-differentiated labour).

In this paper, we focus explicitly on the service sector to provide some more indicative evidence of the contributions of IT to both productivity and the firm's input mix. The motivation for the choice of sector is twofold. The sectoral distribution of IT suggests vastly differing degrees of importance of IT by sector and motivates a more detailed study of those sectors in which IT capital is highly concentrated. In addition, a detailed study of the service sector can enhance our understanding of the empirical regularities of the tertiary sector, an area where research has been limited despite the sector's growing importance in most industrialised countries' economies. We will focus both on factor demand functions for different types of skills and on production functions to estimate substitution possibilities between IT capital and different types of skills. In the first part of the paper the determinants of the skill structure will be examined. Following Bresnahan et al. (1998), we investigate the link between IT and skill intensity rather the change in skill intensity. The data is drawn from the 1995 Mannheim Service Innovation Panel (MIP-S) which has been previously analysed by Licht and Moch (1997) and Kaiser (1998). Since the data set includes quite detailed firm-specific characteristics such as firm organisation and innovative activity, this paper provides new insight into the determinants of the skill-structure. In the second part of the paper we estimate the return on human capital and IT investment as well as elasticities of substitution. For the production function a flexible form is applied. In contrast to Brynolfsson and Hitt (1995), we divide the labour used in the production process into three separate skill classes where highly and medium skilled labour is measured by, respectively, the number of university graduates and vocational school graduates employed by the firm.

The layout of the paper is as follows. Section 2 presents the econometric model. Section 3 describes and summarises the data. In sections 4 and 5 we present the results for the factor demand equations and the production function. Section 6 concludes.

2 Econometric Model

2.1 The Production function

This study uses the production function framework to examine the contributions of IT capital and human capital to output as well as the elasticities of substitution between the different types of inputs. The functional form used in this paper is the translog production function with five input variables. In its logarithmic transformation, the relation between inputs and output can be written as (omitting the firm subscript for convenience):

$$(1)\ \ln Y = \ln \alpha_0 + \sum_i \alpha_i \ln X_i + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \ln X_i \ln X_j$$

where X_i and X_j are stock measures of inputs, Y denotes output. One advantage of the translog functional form over the Cobb-Douglas production function is that the output elasticities are not restricted to be the same across all types of firm. Starting from the translog production function, several restrictive functional forms are nested and can be statistically tested, for example the Cobb-Douglas production function imposes the restrictions of $\gamma_{ij} = 0 \ \forall$ i, j in equation (1). The output elasticity with respect to input i which measures the percentage increase in output in response to a unit increase in the input variable is computed as the derivative of the production function with respect to the logarithm of i. For the translog functional form, the output elasticity is thus a function of input i, as well as the remaining inputs into production, j.

$$\eta_i = \frac{\partial \ln Y}{\partial \ln X_i} = \alpha_i + \sum_j \gamma_{ij} \ln X_j > 0$$

The Wald test is used to test the null hypothesis that the output elasticity is not significantly different form zero. The translog production function is defined on five inputs: labour divided into three skill classes (university graduates – H, vocational school graduates – M, and workers without degree including apprentices – U) and two types of capital (IT-capital – IT and Non-IT capital – K). To derive a stock measure of capital inputs into production, most commonly a weighted average of past levels of investment is computed. In this study, data limitations dictate the use of current period investment as a proxy for the overall capital stock which is appropriate under a constant investment to capital ratio. Investment is disaggregated into Non-IT investment and IT investment.

The direct approach to estimating the production function has been criticised because it ignores the simultaneity created by the input and output decisions (Griliches and Mairesse 1997). To the extent that the firm knows the differences in unobserved factors, such as productivity, when it chooses inputs, OLS estimates of the production function will be inconsistent since the error term is not independent of the inputs. This problem of simultaneity can be solved by instrumental variable (IV) estimation. Appropriate instruments for firm level data include the predetermined input levels from previous periods (Griliches and Hausman 1986, Mairesse and Hall 1995).

Following Zellner et al. (1966) we assume that the firm's objective is profit maximisation. This assumption can be justified in terms of a two-stage process where input choice is made prior to the output decision. Estimation of the production function is only consistent with profit maximisation. In this case OLS can be used to directly estimate the production function. In order to reduce the multicollinearity problem, linear homogeneity of degree can be imposed on the translog function. The multicollinearity problem is much more severe in small samples. If labour costs by individual skill groups are available, a better way to deal with the multicollinearity problem is to use the dual approach of estimating a cost function. Unfortunately, our data set does not include factor price information for all of the inputs into production. Other potential problems with the data that could affect the results include erroneous responses to the survey questions. This will be addressed by the use of median regression models. Here estimates are obtained by minimising the sum of the absolute rather than the sum of the squared residuals.

2.2 Elasticities of substitution

The translog production function can be used to calculate the elasticities of substitution between different inputs. In the two-factor model, the elasticity of substitution is simply:

$$\sigma = \frac{\partial \log(X_2 / X_1)}{\partial \log(f_2 / f_1)}$$

Here X_1 and X_2 measure the level of the two inputs into production, while f_1 and f_2 are the marginal products of the two inputs. The elasticity of substitution thus expresses the percentage change in the factor ratio X_2/X_1 resulting from a percentage change in the technical rate of substitution. Two inputs are substitutes if the elasticity of substitution is significantly positive. Assuming perfect competition and the availability of firm-specific prices, a simpler interpretation of σ is the percentage change in the factor ratio divided by the percentage change in the ratio of marginal products or percentage change in relative prices. The elasticity of substitution thus measures how a factor will be replaced by other inputs as it gets relatively more expensive. For instance, IT capital will be clearly favoured when the price of IT declines and one would expect that IT capital is substituted for expensive labour. The technical rate of substitution, on the other hand, measures how factors are traded off to attain the same level of output. For the more general case of an n-factor production function, the Allen partial elasticities of substitution (AES) can be used. Allen (1938, p. 504) defined the partial elasticity of substitution between inputs i and j as:

$$\sigma_{ij}^{A} = \left(\sum_{g=1}^{n} f_g X_g / X_i X_j \right) \left(\left| F_{ij} \right| / \left| F \right| \right)$$

where $\left| F_{ij} \right|$ denotes the (i,j)th cofactor and $\left| F \right|$ the determinant of the bordered Hessian matrix F (6×6):

$$F = \begin{bmatrix} 0 & f_H & f_{IT} & f_K & f_M & f_U \\ f_H & f_{HH} & f_{HIT} & f_{HK} & f_{HM} & f_{HU} \\ f_{IT} & f_{ITH} & f_{ITIT} & f_{ITK} & f_{ITM} & f_{ITU} \\ f_K & f_{KH} & f_{KIT} & f_{KK} & f_{KM} & f_{KU} \\ f_M & f_{MH} & f_{MIT} & f_{MK} & f_{MM} & f_{MU} \\ f_U & f_{UH} & f_{UIT} & f_{UK} & f_{UM} & f_{UU} \end{bmatrix}$$

The matrix F contains the first- and second-order derivatives of the production function $Y = f(IT,K,H,M,U)$. For example, the marginal product of IT capital is $f_{IT} = \partial f / \partial IT$ and the cross derivative with respect to graduates is $f_{ITH} = \partial^2 f / \partial IT \, \partial H$. Assuming linear homogeneity of degree one, $Y = \sum_i f_i X_i$, it follows that:

$$\sigma_{ij}^{A} = \left| G_{ij} \right| / \left| G \right|$$

where $\left| G_{ij} \right|$ is the (i,j)th cofactor and $\left| G \right|$ is the determinant of the bordered Hessian matrix (6×6):

$$G = \begin{bmatrix} 0 & \eta_H & \eta_{IT} & \eta_K & \eta_M & \eta_U \\ \eta_H & \gamma_{HH} + \eta_H^2 - \eta_H & \gamma_{HIT} + \eta_H \eta_{IT} & . & . & . \\ \eta_{IT} & \gamma_{HIT} + \eta_H \eta_{IT} & \gamma_{IT} + \eta_{IT}^2 - \eta_{IT} & . & . & . \\ \eta_K & \gamma_{HK} + \eta_H \eta_K & . & \gamma_{KK} + \eta_K^2 - \eta_K & . & . \\ \eta_M & \gamma_{HM} + \eta_H \eta_M & . & . & . & . \\ \eta_U & \gamma_{HU} + \eta_H \eta_U & . & . & . & . \end{bmatrix}.$$

In the case of linear homogeneity, the AES is a function only of the output elasticities and the parameters of the translog function. Furthermore, as is well known, a sufficient condition for stability is that the bordered principal minors of F must be negative.

2.3 Factor Share equations

An alternative approach to investigate input substitution is the estimation of factor demand equations. Many econometric studies of the complementarity of IT and skilled labour have used a variable cost function framework to examine whether skill intensity and technology are positively correlated in a given cross-section (Doms et al. 1997). Using a similar set-up, we assume that IT and non-IT investment are quasi-fixed factors whereas the three types of labour are variable inputs into production. Under homogeneity of degree one in prices and homotheticity, Shepard's lemma implies the following cost shares for the three types of labour (see Chennells and Van Reenen 1998):

$$\frac{d\ln C}{d\ln P_i} = \frac{P_i X_i}{C} = S_i = \alpha_i + \sum_{j=H,M}^{n} ß_{ij} \ln(P_j / P_U) + ß_{iK} \ln(K/Q) + ß_{iIT} \ln(IT/Q) + ß_t z + u$$

where S_i (i = H, M, U) are the cost shares for the three types of labour and Q total sales in nominal prices as a proxy for output. Assuming a constant investment to capital ratio, the investment to output ratio is taken as a proxy for the capital to output ratio in the two investment sectors, IT and non-IT.[1] The parameters $ß_{iK}$ and $ß_{iIT}$ measure the effects of the non-IT investment to sales ratio (K/Q) and the IT investment to sales ratio (IT/Q) on the labour cost shares. A positive coefficient on the investment to output ratio in the university graduates share equation ($ß_{HK} > 0$) indicates, for example, that capital is a complement to skilled labour. Similarly, a positive coefficient on the IT-investment to output ratio indicates skill-technology complementarity. If both $ß_{HIT} > 0$ and $ß_{UIT} < 0$, then technology is skill-biased. Since factor prices (i.e. wages by skill classes) are generally not available at the firm level, one can take the skill-specific employment shares to proxy the unknown cost shares. Furthermore, assuming that relative wages (P_H / P_U) or (P_M / P_U) are constant within industries, the effects of relative wages can be captured by sector dummies.

The general specification relates the employment shares of each skill class, **E_i**, to the log IT-expenditure to total sales ratio, the log non-IT expenditure to total sales ratio, as well as a set of appropriate control variables z:

(2) $E_i = \alpha_i + ß_{iK} \ln(K/Q) + ß_{iIT} \ln(IT/Q) + ß_t z + u$ $\qquad$ *i = H, M, U*

Appropriate control variables which may affect the skill composition of a firm's labour force include indicators of firm level performance. The MIP-S data set contains detailed firm level information on the firm's export orientation, process and product innovations, ownership form (part of industrial conglomerate), or recent organisational changes. In particular, export orientation represents a good control variable because the exporting activity of German firms is concentrated in skill-intensive goods and services.

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[1] Even though the net capital stock is not available at a disaggregated level for IT and non-IT, the overall net capital stock and investment flows are strongly positively correlated. Based on 14 service industries, the Pearson correlation coefficient and regression estimates between the investment to sales ratio and the net capital stock to sales ratio indicate a strong positive relationship. The Pearson correlation coefficient is 0.97 and significant at the 1 percent level. The regression estimated by OLS yields $I/Q = \underset{4.8}{0.052} + \underset{14.8}{0.056} C/Q$, adjusted R^2=0.94, where I is Investment in nominal prices, Q gross output and C net capital stock at constant prices. Thus given a constant share of IT expenditures out of total investment, this evidence provides some justification for the use of IT and non-IT investment to proxy the relevant capital stocks.

One estimation problem is that the employment shares are bounded between 0 and 1. In this case the truncated regression model would be appropriate. Furthermore, in some cases the observed data contain a cluster of zeros,[2] in particular for the highly skilled and unskilled employment shares. These variables might be censored either in the upper tail ('on the right') or in the lower tail of the distribution ('on the left'). For this kind of data the censored regression model rather than truncated regression model would be appropriate. As well known, OLS estimates are inconsistent and usually biased toward zero (Greene 1997). The employment share equation can be estimated by a variant of the tobit model or the multiplicative heteroscedasticity tobit model.[3] In the basic censored regression model, the true underlying dependent variable, y*, is a function of a set of independent variables, x:

(3) $\boldsymbol{y^* = \beta x + \varepsilon, \varepsilon \sim N[0, \sigma^2]}$

while the actually observed value of the dependent variable, y, is given by:

$$\mathbf{y} = \begin{cases} \mathbf{L, y^* <= L} \\ \mathbf{y^* = \beta x + \varepsilon, L < y^* < U} \\ \mathbf{U, y^* >= U} \end{cases}$$

(In a truncated regression model, the values for y if y* <= L or y* >= U are unobserved)

The assumptions of the standard Tobit model include the homoscedasticity of the disturbance terms. Homoscedasticity will be violated though, if for example the variance is proportional to one of the regressors or its square. We will correct for potential heteroscedasticity by using a multiplicative heteroscedastic tobit model. Under multiplicative heteroscedasticity, the variance of the error terms is given by $Var[\varepsilon_i] = \sigma_i^2 = \sigma^2 \exp(\gamma' z_i)$ where **z** is a set of independent variables that possibly coincides with **x.** In the current application, good choices for **z** may be the non-IT and IT investment to sales ratios rather than the control variables.

3 Data description

Our empirical analysis is based on the first wave of the Mannheim Service Innovation panel (MIP-S). This survey has been conducted to examine the innovation behaviour of service firms (for details see Licht and Moch, 1997). Approximately 2550 firms participated in the first wave of the service panel which contains information for 1994 (1629 firms in the West and 924 in the East). The key variables covered by the study are sales, investment, the skill structure of the workforce and a large number of quantitative and qualitative dummy variables (product and process innovations, effects of innovation, R&D activities, importance of external sources of knowledge). Incomplete information on gross investment, IT investment, the different types of labour and the dummy variables led to a reduction to 1231 West german firms (for details see Table 6–1 in

[2] Note that the highly skilled and unskilled shares are censored from below.

[3] Note that the standard tobit model deals with censoring on one side of the distribution only.

Appendix). After excluding one outlier (investment to sales ratio exceeds 500 percent), 1230 firms were included in the analysis.

Table 3–1: Summary statistics

Variable	Mean	Median	Std. Dev.	Min.	Max.	zero values (%)
West German firms (OBS=1230)						
university graduates, H, (# of employees)	30	3	141	0	2550	0.281
workers with vocational degree, M, (# of employees)	274	20	3152	0	107000	0.022
workers without degree/apprentices, U, (# of employees)	167	6	1628	0	52000	0.246
gross investment, incl. IT (in Mill DM)	12	0.25	163	0	5563	0.147
investment in communication and information technology (in Mill DM).	2.17	0.05	32	0	1063	0.155
high skilled labour share	0.148	0.054	0.22	0	1	0.281
medium skilled labour share	0.597	0.651	0.28	0	1	0.022
unskilled labour share	0.255	0.151	0.28	0	1	0.246
non-IT investment as percent of total sales	0.052	0.010	0.12	0	1.32	0.147
IT-investment as percent of total sales	0.013	0.003	0.03	0	0.42	0.155
East German firms (OBS=721)						
university graduates, H, (# of employees)	28	4	194.22	0	4000	0.169
workers with vocational degree, M, (# of employees)	80	16	246.28	0	4000	0.029
workers without degree/apprentices, U, (# of employees)	48	3	207.16	0	3330	0.341
gross investment, incl. IT (in Mill DM)	5.15	0.24	20.75	0	266	0.132
investment in communication and information technology (in Mill DM).	0.34	0.04	1.41	0	20	0.149
highly skilled labour share	0.225	0.100	0.26	0	1	0.169
medium skilled labour share	0.579	0.646	0.29	0	1	0.029
unskilled labour share	0.196	0.090	0.27	0	1	0.341
non-IT investment as percent of total sales	0.160	0.021	0.41	0	5.04	0.132
IT-investment as percent of total sales	0.019	0.005	0.06	0	0.94	0.149

[a] The means given in the table are arithmetic means.

Source: Mannheim Service Innovation Panel 1995.

Skill is measured by the employee's level of educational qualification. The original data base distinguishes between five skill classes: (1) university or polytechnical degree in engineering or natural science, (2) university or polytechnical degree in economics or social science, (3) technical college degree ("Berufsfachschule"), (4) workers with a vocational certificate, and (5) workers without any advanced degree or apprentices. To obtain meaningfully sized skill classes, we combined (1) and (2) into the highly skilled class (university graduates, H) and (3) and (4) into medium skilled labour (workers with vocational degree, M). The labour force is taken to be the average number of workers in 1994. Output is measured by total sales in nominal prices. Expenditures on materials are not available. IT is defined by 1994 investment in information and communication technology. It includes expenditures on computers, peripheral equipment, and software. Total gross investment is also provided. In order to avoid double counting, we subtract IT investment from total investment to obtain non-IT investment. For 90 firms of the total of 1230

West German firms, IT investment exceeds total investment. In these cases, the resulting negative non-IT investment has been replaced DM 1. About 180 firms report investment or IT investment expenditures of zero. In the logarithmic specification of the production function, zero expenditure values have been replaced by an expenditure value of DM 1. This leaves us with 1230 firms in the West and 721 firms in the East (see Table 3–1).

Table 3–2: Summary Statistics (Dummy variables)

	West (OBS=1230)	East (OBS=721)
Sectoral distribution:		
Wholesale trade (NACE 51)	0.176	0.115
retail trade and repairs (NACE 50, 52)	0.128	0.107
transport (NACE 61, 62, 63)	0.131	0.146
banking/insurance (NACE 65, 67)	0.169	0.108
computer/software (NACE 72)	0.067	0.043
R&D labs, consultancy (NACE 731, 732, 742, 743)	0.050	0.165
Other services (NACE 633, 70, 71, 741, 744-48, 90, 92)	0.280	0.314
Size distribution:		
Size 1: $L < 25$	0.406	0.420
Size 2: $25 \leq L \leq 49$	0.141	0.178
Size 3: $50 \leq L \leq 249$	0.246	0.283
Size 4: $250 \leq L \leq 499$	0.072	0.057
Size 5: $L \geq 500$	0.134	0.062
Performance indicators		
exporter, 1994	0.243	0.082
change in corporate structure, 1993-95	0.533	0.510
part of industrial conglomerate, 1994	0.363	0.230
product innovator, 1993-95	0.614	0.580
process innovator, 1993-95	0.515	0.472
R&D	0.176	0.122
IT investment = 0, 1994	0.154	0.150
Non-IT investment = 0, 1994	0.147	0.132

[a] The means given in the table are arithmetic means. Performance indicator dummies: exporter = 1 if firm has entered positive revenues from exports for 1994. Change in corporate structure = 1 if firm or conglomerate has experienced a major change in its organisational structure (consolidation of subsidiaries, sale or acquisition of subsidiaries etc.). Part of industrial conglomerate = 1 if firm is parent to or subsidiary of another firm. Product innovator = 1 if firm has introduced product innovations during 1993-95. Process innovator = 1 if firm has introduced process innovations during 1993-95. R&D = 1 if firm is occasionally or continuously engaged in R&D activities.

Source: Mannheim Service Innovation Panel 1995.

Table 3–1 gives averages and standard deviations of the key variables for the East and West German samples. As is typical for service firms, we observe low levels of investment relative to total sales. Despite the rapid IT-accumulation, the unweighted average of IT-investment as a percent of gross sales amounts to 1.3 % in 1994 corresponding to 18.8 % of total average investment.

A number of firm-specific heterogeneity control variables are included in the regression equations, among them sector and size dummies. Firm size is defined by number of employees and firms are divided into five size classes: the reference group has up 24 employees, the three medium-sized classes are defined as 25-49, 50-249, and 250-499 employees, while large firms are defined to have more than 500 employees.

Table 3–2 contains information on industry affiliation, size classes, export behaviour and innovation variables. In 1994, 36 percent of West German and 23 percent of East German firms belonged to a corporate group. The share of exporting firms is 24 percent. Furthermore, most of the companies in the sample have introduced new or improved products during the period 1993-1995 (for product innovations 63 percent in West and 60 percent in East Germany). The corresponding figures for process innovations are 53 for West Germany and 48 percent for East Germany.

One potential data problem is that IT spending is self reported. Another potential problem with the data set is a selection problem. The survey's low response rate of 25 percent suggests that firms participate selectively. Since the questionnaire contains a number of innovation-related questions, it is likely that the sample is disproportionally comprised of innovators. To examine the represenativeness of the survey participants, we compare the average skill structure revealed by the firms in the MIP-S data set to the average skill structure by service sector indicated by participants in the 1995 German Micro Census at the level of the individual. As Table 3-3 shows, there is little difference between the qualification structure of the two data sources. In 1994, the share of employed workers possessed no qualification ranged from 17 percent both in retail trade to 6.5 percent in Computer/software firms. The most skill-intensive sectors are as expected the computer/software and R&D laboratories/technical consulting sectors. In both sectors, the share of university graduates exceeds 40% (on Micro Census basis as well as MIP data set).

Table 3-3: Qualification structure in German service industries – comparison of different sources (West)

	Qualification Structure							
	MIP-S 95 [a]				Mikrozensus 95 [a]			
	University graduates	vocational school graduates	workers w/o adv. degree [b]	OBS	University graduates	vocational school graduates	workers w/o adv. degree [b]	OBS
wholesale trade	0.094	0.656	0.249	216	0.078	0.746	0.128	5557
retail trade and repairs	0.039	0.728	0.233	158	0.042	0.781	0.168	35276
transport	0.043	0.519	0.437	161	0.177	0.779	0.103	3507
banking/insurance	0.148	0.718	0.134	208	0.113	0.821	0.066	5127
computer/software	0.448	0.443	0.108	82	0.397	0.539	0.065	1069
R&D labs, consultancy	0.441	0.438	0.120	61	0.427	0.586	0.072	3356
other services	0.156	0.527	0.316	344	0.287	0.586	0.116	46166

[a] Data refers to 1994. [b] apprentices included.

4 Empirical results

4.1 Determinants of the skill structure

In order to quantify the main factors behind a firm's skill intensity, the employment shares are regressed against the potential determinants discussed above. Since the IT impact on the various employment shares varies by sector, interaction effects of the IT investment to sales ratio or non-IT investment to sales ratios and the sector dummies are included. There is evidence that the IT impact is not uniform across sectors. While banking, insurance and real estate have been the most intensive user of IT, retail trade shows the slowest rate of adoption (Lefebvre and Lefebvre 1996).

Table 4-1: Share equations for university graduates (OBS=1230)

	Tobit		Mult. het. Tobit		OLS	
	Coeff. [a]	t-stat	Coeff. [a]	t-stat	Coeff	t-stat [b]
Log IT investment to sales ratio, log(ITQ)	0.011	6.7	0.011	7.3	0.008	5.0
Log Non-IT inv. to sales ratio, log(IQ)	-0.002	-1.8	-0.003	-2.0	-0.003	-2.2
Interaction terms						
Log(ITQ) × banking/insurance	-0.010	-2.4	-0.008	-2.5	-0.007	-1.3
Log(ITQ) × computer/software	0.017	2.5	0.018	2.5	0.034	3.5
Log(ITQ) × R&D lab,. Techn. Cons.	0.035	3.7	0.040	4.4	0.044	4.7
Log(IQ) × computer/software	-0.010	-2.5	-0.013	-2.7	-0.014	-1.9
Dummy variables						
Wholesale trade [c]	-0.057	-4.1	-0.054	-4.1	-0.068	-4.2
Retail trade and repairs [c]	-0.097	-6.4	-0.095	-5.1	-0.109	-8.8
Transport [c]	-0.105	-6.7	-0.104	-6.1	-0.109	-8.0
Banking/insurance [c]	-0.067	-2.3	-0.059	-2.1	-0.063	-1.7
Computer/software [c]	0.174	4.2	0.167	4.4	0.295	4.3
R&D labs, consultancies [c]	0.331	7.1	0.358	8.1	0.449	6.8
Exporter	0.046	4.3	0.046	4.4	0.049	3.7
Ind. Conglomerate	0.029	3.0	0.027	2.7	0.002	0.2
R&D	0.055	4.7	0.052	4.2	0.058	3.8
Constant	0.118	7.1	0.119	7.7	0.176	10.1
Heteroscedasticity Terms						
Log (ITQ) [e]			0.011	7.3		
Log (IQ) [e]			-0.003	-2.0		
Disturbance standard error	0.213	40.4	0.203	23.2		
Wad test firm size ($\chi 2[4]_{.95}$=9.49)	1.45		0.73		52.5**	
Log likelihood function	-137.8		-117.8			
Breusch Pagan Het ($\chi 2[15]_{.95}$=25.0)					404**	
Pseudo R^2/ Adj. R^2	0.621				0.384	

**Significant at the 5 percent level. Dependent variable: share of university graduates out of total workers. Observation summary for the Tobit models: 345 left-censored observations with $E_H \leq 0$ and 6 right-censored observations with $E_H \geq 1$. [a] Displayed coefficients are marginal effects, the partial derivatives of expected value with respect to the vector of characteristics. Marginal effects are computed at the means of the left hand variables. [b] Value of t-statistics based on Whites standard errors. [c] Reference group is other business service. [d] Reference group is size 1. [e] Zero values are replaced by 0.000001.

The estimation results are reported in Table 4-1 to Table 4-3. Table 4-1 represents the estimates for the university graduates share equation. The first two columns show the results for the Tobit models, where column (1) contains the results for the standard homoscedastic model and column (2) allowes the disturbances to be heteroscedastic. For both Tobit specifications marginal effects are computed. The university graduates employment share is censored below since 28 % of the 1230 firms do not employ highly skilled labour. The OLS estimates with heteroscedasticity consistent standard errors results are presented for comparison purposes only (see column 3).

Table 4-1 shows a significant, positive relationship between the share of university graduates and IT-investment. This suggests that highly skilled labour and IT-investment are complements in production similar to results established for the US (Berman et al 1994). For the Tobit model the partial derivatives (the marginal effects) of the graduates share with respect to IT-investment is 0.011. This means that an increase of IT-Investment ratio by twenty percent (from 1.3 to 1.56 percent) would raise the graduates employment share by 1.5 percent ($=0.011/0.148\times2$) from 14.8 to 15.0 percent. The IT-investment effect remains significant and is robust to the different models applied here, namely OLS and the multiplicative heteroscedastic tobit model. However, OLS slightly underestimates the IT-effect. The coefficient is decreasing to around 0.008.

The coefficients on the interaction terms (product of sector dummy and IT investment to sales ratio as well as non-IT investment to sales ratio) are statistically significant in four cases. Therefore, the model assuming a uniform IT impact on the university graduates employment share can be rejected. For sector which have historically been IT intensive, namely computer/software and R&D labs/consultancies, we find that IT investment is associated with greater demand for skills. For R&D laboratories and technical consultancy the partial derivative with respect to IT is 0.028. This implies an IT elasticity of 0.11 (=(0.035+0.011)/0.441).

For the 24 percent of firms which export in the 1994 period, we find that exporting reinforces the positive relationship found between IT investment and the employment of highly skilled labour. This finding is consistent with our conjecture that exporting firms concentrate extensively on human-capital-intensive products relative to firms that do not engage in exporting activities. The coefficient on the ownership dummy indicates that firms in an industrial conglomerates use more skill-intensive labour than their counterparts. However, skill intensity tends to decrease with the number of employees. A firm's R&D activities may also induce it to employ a more skilled labour force as the positive coefficient on R&D engaging firms shows. (18 % of the firms in the sample continuously or occasionally engage in R&D).[4]

Table 4-2 shows the estimates for medium-skilled labour, namely vocational school graduates. Except for retail trade and software the IT investment to sales ratio is not significantly related to employment share of medium skilled workers. For software firms and in retail trade a higher IT investment to sales ratio is associated with a lower medium skilled employment share. The coefficients on the size dummy variables indicate that the medium skilled share is negatively related to firm size. The only other significant coefficients are the sector dummies. Skill-intensive sectors such as computers/software or R&D labs and consultancies employ less workers who have completed vocational school.

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[4] In a previous version of the paper we include dummies for process and product innovations as well as a dummy variable for organisational change. Since these variables are indicators of the technological change rather the technological level, we excluded these dummy from the share equations.

Table 4-2: Share equations for workers with vocational degree (OBS=1230)

	Tobit		Mult. het. Tobit		OLS	
	Coeff. [a]	t-stat	Coeff. [a]	t-stat	Coeff	t-stat [b]
Log IT investment to sales ratio, log(ITQ)	0.002	0.9	0.006	1.9	0.003	1.0
Log Non-IT inv. to sales ratio, log(IQ)	-0.002	-0.8	-0.001	-0.6	-0.001	-0.5
Interaction terms						
Log(ITQ) × banking/insurance	-0.014	-2.0	-0.014	-1.5	-0.009	-1.6
Log(ITQ) × computer/software	-0.033	-2.7	-0.036	-1.8	-0.037	-4.7
Log(ITQ) × R&D lab,. Techn. Cons.	0.012	2.1	0.011	2.0	0.01	1.5
Log(IQ) × computer/software	0.017	2.4	0.017	2.6	0.016	2.3
Dummy variables						
Wholesale trade [c]	0.126	5.4	0.121	5.0	0.134	5.6
Retail trade and repairs [c]	0.111	2.0	0.116	1.8	0.147	3.2
Transport [c]	0.059	1.7	0.051	1.7	0.046	1.1
Banking/insurance [c]	0.183	7.9	0.178	6.6	0.193	9.1
Computer/software [c]	-0.116	-1.6	-0.127	-1.4	-0.144	-2.2
R&D labs, consultancies [c]	-0.094	-2.6	-0.098	-2.9	-0.099	-2.6
Exporter	-0.015	-0.8	-0.018	-1.0	-0.012	-0.7
Ind. Conglomerate	0.004	0.3	0.005	0.3	0.009	0.6
R&D	-0.027	-1.3	-0.027	-1.2	-0.025	-1.2
Size 2: $25 \leq L \leq 49$ [d]	-0.023	-1.0	-0.018	-0.8	-0.014	-0.6
Size 3: $50 \leq L \leq 249$ [d]	-0.078	-4.0	-0.078	-3.8	-0.067	-3.5
Size 4: $250 \leq L \leq 499$ [d]	-0.137	-4.5	-0.126	-3.8	-0.133	-4.3
Size 5: $L \geq 500$ [d]	-0.130	-5.2	-0.124	-4.8	-0.121	-4.8
Constant	0.538	20.8	0.527	18.4	0.585	22.1
Heteroscedasticity Terms						
Log (ITQ) [e]			0.006	1.9		
Log (IQ) [e]			-0.001	-0.6		
Disturbance standard error	0.284	45.5	0.232	17.3		
Wad test firm size ($\chi2[4]_{.95}$=9.49)	41.1**		35.4**		38.0**	
Log likelihood function	-330.8		-323.2		-79.4	
Breusch Pagan Het ($\chi2[19]_{.95}$=30.1)					88.5	
Pseudo R^2/ Adj. R^2	0.239				0.159	

**Significant at the 5 percent level. Dependent variable: share of workers with a vocational degree out of total workers. Observation summary for the Tobit models: 27 left-censored observations with $E_M \leq 0$ and 108 right-censored observations with $E_M \geq 1$.. [a] Displayed coefficients are marginal effects, the partial derivatives of expected value with respect to the vector of characteristics. Marginal effects are computed at the means of the left hand variables. [b] Value of t-statistics based on Whites standard errors. [c] Reference group is other business service. [d] Reference group is size 1. [e] Zero values are replaced by 0.000001.

Table 4-3 shows that the unskilled labour share is significantly negatively related to the IT investment to sales ratio. The negative relationship between the IT investment to sales ratio and unskilled labour, on the one hand, and the positive relationship between the IT investment to sales ratio and highly skilled labour, on the other hand, indicate a complementarity between IT capital and the firm's labour force skill structure. Accumulation of IT capital favours skilled labour.

We also find that the coefficient on the non-IT investment to sales ratio is significant at the five percent level, suggesting that unskilled labour and non-IT investment are complements in production. Exporting firms and firms that are part of a larger corporate group use less unskilled labour which is in line with a concentration on skill-intensive products by these firms.

Table 4-3: Share equations for unskilled labour (OBS=1230)

	Tobit		Mult. het. Tobit		OLS	
	Coeff. [a]	t-stat	Coeff. [a]	t-stat	Coeff	t-stat [b]
Log IT investment to sales ratio, log(ITQ)	-0.012	-5.0	-0.013	-4.5	-0.014	-4.6
Log Non-IT inv. to sales ratio, log(IQ)	0.004	2.0	0.004	2.0	0.002	1.2
Interaction terms						
Log(ITQ) × banking/insurance	0.016	2.4	0.017	1.8	0.015	2.8
Log(ITQ) × computer/software	0.012	1.8	0.013	1.5	0.014	2.7
Log(ITQ) × R&D lab,. Techn. Cons.	-0.008	-1.6	-0.005	-1.1	-0.005	-0.8
Log(IQ) × computer/software						
Dummy variables	-0.052	-2.4	-0.049	-2.3	-0.067	-2.9
Wholesale trade [c]	0.023	0.4	0.022	0.4	-0.005	-0.1
Retail trade and repairs [c]	0.051	1.6	0.067	2.4	0.078	1.8
Transport [c]	-0.074	-1.5	-0.063	-1.1	-0.086	-2.3
Banking/insurance [c]	-0.151	-4.7	-0.144	-5.0	-0.128	-4.6
Computer/software [c]	-0.127	-3.7	-0.128	-3.6	-0.135	-4.7
R&D labs, consultancies [c]	-0.027	-1.6	-0.027	-1.6	-0.031	-1.9
Exporter	-0.024	-1.6	-0.024	-1.5	-0.030	-2.0
Ind. Conglomerate	-0.039	-2.1	-0.039	-2.0	-0.047	-2.6
R&D	0.048	2.2	0.043	1.9	0.024	1.2
Size 2: $25 \le L \le 49$ [d]	0.148	8.2	0.144	7.8	0.118	6.3
Size 3: $50 \le L \le 249$ [d]	0.233	8.4	0.219	7.2	0.227	7.1
Size 4: $250 \le L \le 499$ [d]	0.215	9.4	0.206	9.0	0.199	7.4
Size 5: $L \ge 500$ [d]	0.075	3.0	0.085	3.5	0.185	6.9
Constant						
Heteroscedasticity Terms			-0.013	-4.5		
Log (ITQ) [e]			0.004	2.0		
Log (IQ) [e]	0.307	40.8	0.230	17.0		
Disturbance standard error	143.5**		136.0**		104.4**	
Wad test firm size ($\chi2[4]_{.95}$=9.49)	-476.2		-461.4		-248.8	
Log likelihood function					187.4	
Breusch Pagan Het ($\chi2[19]_{.95}$=30.1)	0.252				0.218	
Pseudo R^2/ Adj. R^2						

**Significant at the 5 percent level. Dependent variable: share of workers without advanced degree. Observation summary for the Tobit models: 303 left-censored observations with $E_U \le 0$ and 12 right-censored observations with $E_U \ge 1$. [a] Displayed coefficients are marginal effects, the partial derivatives of expected value with respect to the vector of characteristics. Marginal effects are computed at the means of the left hand variables. [b] Value of t-statistics based on Whites standard errors. [c] Reference group is other business service. [d] Reference group is size 1. [e] Zero values are replaced by 0.000001.

5 Output contributions of human capital and IT

5.1 Output elasticities

As stated in section 2, two specifications for the production function will be investigated, the Cobb-Douglas production function as well as the translog production function. Results for the Cobb-Douglas specification are reported in Table 5-1. In addition the CD-production function is estimated by a median regression model. T-statistic are based on bootstrapped estimates of the variance covariance matrix of the estimators. Estimates from the median regression model are obtained by minimising the sum of the absolute rather than the sum of the squared residuals. This approach aims to correct for possible outliers, which are likely to arise on a firm level data set.

For the Cobb-Douglas specification estimated by OLS or by a median regression model, the parameters for the different types of labour, as well as the coefficients on non-IT investment and IT investment have the expected signs and are significant at conventional levels. The regression results are thus not overly sensitive to the use of the OLS or the median regression models. However, the output-elasticity of both non-IT and IT investment is only about 3.7 percent.[5] One reason for this finding may be that the Cobb-Douglas specification forces the output elasticities to be the same over heterogeneous firms. The elasticities are therefore biased towards zero since a large share of our sample does not have IT or non-IT investment expenditures at all (15.5% of West German firms report an IT investment of zero and 14.7% report a non-IT investment of zero).

The OLS results for the translog production function are shown in Table 5-1. An unrestricted model is contrasted with a restricted model which imposes homogeneity of degree one on the production function parameters. Both specifications include industry dummy variables and heterogeneity control indicators. The implications of the alternative specifications have been statistically tested, and the test-statistics for homogeneity of degree one and the Cobb-Douglas form are reported. The chi-squared of 302 for the specification test of a Cobb-Douglas versus translog functional form allows us to reject the appropriateness of the Cobb-Douglas specification. Similarly, we also reject linear homogeneity. Nevertheless, for the sake of completeness, Table 5-1 also includes estimated elasticities under linear homogeneity. The output elasticities reported in Table 5-1 have been evaluated at the mean of the inputs, thus

$$\eta_i = \alpha_i + \Sigma_j \gamma_{ij} \ln(\overline{X}_j)$$

All output elasticities are positive and statistically significant.

Although some of the parameters of the translog production function are insignificant, they have not been excluded from the calculation of output elasticities to sustain flexibility of the output elasticities. Our results justify the assumption of a strictly quasi-concave production function. Under quasi-concavity, the Hessian matrix $D^2Y = D^2f(H, M, U, IT, K)$ has to be negative definite. The percentage of observations which satisfy this regularity condition ranges from 64 % for the unrestricted model to 85 % for the restricted model.[6] Monotonicity of the production function (i.e. positive firm specific input-output elasticities) is satisfied by 79 % and 98 % of the observations for the unrestricted and restricted models, respectively.[7] Since the Breusch-Pagan heteroscedasticity statistic indicates that the residual variance depends on the explanatory variables, t-statistics are based on heteroscedasticity-consistent standard errors. To conserve space, we report only input-output elasticities based on the sample mean and median as well as the 25th and 75th percentiles (see Table 6–3 in the appendix).

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[5] Griliches (1979) notes that using different functional forms, such as the translog production function, will have little effect on the output elasticities.

[6] The determinants are calculated for each data point.

[7] For example, 255 out of 1228 firms show negative capital output elasticities. For IT investment and unskilled labour, negative output elasticities were found in 15 percent of total observations.

The key results of Table 5-1 can be summarised as follows. The most important result is the relatively high output elasticity of IT-expenditures and university graduates. For the unconstrained translog-specification, the IT-elasticity is about 0.16 (evaluated at sample means).[8] The IT-elasticity under linear homogeneity is very similar. If information technology is efficiently used, a one percent increase of IT would thus raise the output level by 0.16 percent. Concerning the non-IT factors, medium skilled labour (vocational school graduates as well as foremen and technicians) is the most important production factor. The output elasticity of vocational school graduates is 0.44. University graduates are the third most important factor of production. The highly skilled labour elasticity is 0.11 and 0.16 for the unrestricted and restricted models, respectively. The output elasticity of university graduates shows a considerable variability across firms (see figure 2 in the appendix). This is not surprising given the high number of firms which employ few or no university graduates. The contribution of non-IT capital to output is about 0.10. The coefficients for firm size dummies are positive but not significant. Exports are associated with a higher productivity level.

For a number of reasons the output elasticities of non-IT and IT investment should be regarded with caution. First, as noted by Hall and Mairesse (1995), the use of flow rather than stock data tends to overestimate the output elasticities. However our own previous results suggests that the output elasticity of capital is not particular sensitive to the choice of flow or stock data. Second, the results are sensitive to the inclusion of firm effects. Using panel data, Brynjolfsson and Hitt (1995) report that the elasticity of IT capital drops from 10% to 5 % once firm effects are included. A last concern arises out of the use of gross sales rather than value-added as our proxy for output. However, in one of the few studies that used data on both gross sales and value-added, Hall and Mairesse (1995) found only small differences with respect to the use of value added rather than sales.

Since there is evidence that the production process may vary by firms operating in different service sectors, we estimate the production function separately for each sector.[9] To account for this potential heterogeneity, we allow the output elasticities to vary over different sectors and reestimate the translog production function for sectoral subsamples of our data set.

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[8] The relative high value of the output elasticity of IT capital may partly be due to the omission of materials as an input into production.

[9] In contrast to section 4 the parameters of the production function are not interacted with the sector dummies because this procedure would create an excessive number of parameters.

Table 5-1: Production function estimates, Translog and Cobb-Douglas

	TL, Unrestricted specification [a]		TL, Linear Homogeneity imposed [a,b]		CD		CD, Median regression	
	coeff.	t-stat	coeff.	t-stat	coeff.	t-stat [c]	coeff.	t-stat [h]
Wald-test: H_o: $\partial \ln Q/\partial \ln X_i = 0$ [d]								
$\eta_H = \partial \ln Q/\partial \ln H$	0.114	5.6	0.158	8.6	0.164	7.8	0.124	5.3
$\eta_M = \partial \ln Q/\partial \ln M$	0.102	8.2	0.092	8.7	0.034	4.8	0.032	4.1
$\eta_U = \partial \ln Q/\partial \ln U$	0.444	11.8	0.482	21.8	0.341	7.2	0.373	7.0
$\eta_{IT} = \partial \ln Q/\partial \ln IT$	0.098	5.6	0.131	9.0	0.067	3.7	0.084	3.8
$\eta_K = \partial \ln Q/\partial \ln K$	0.162	9.3	0.137	8.9	0.037	3.9	0.029	2.4
dummy variables								
wholesale trade [e]	0.710	8.1	0.750	7.9	0.789	7.8	0.967	6.9
retail trade and repairs [e]	0.474	5.3	0.513	4.9	0.481	4.9	0.608	3.9
transport [e]	-0.012	-0.1	0.059	0.6	0.211	2.2	0.295	3.3
banking/insurance [e]	1.650	13.7	1.721	17.8	1.820	13.7	1.930	10.2
computer/software [e]	-0.109	-1.0	-0.143	-1.0	-0.096	-0.8	0.015	0.1
R&D labs, consultancies [e]	-0.190	-1.7	-0.211	-1.4	-0.235	-2.0	-0.184	-1.5
Exporter	0.218	3.1	0.205	2.8	0.153	2.0	0.186	2.0
ind. Conglomerate	0.189	2.7	0.182	2.7	0.192	2.5	0.158	2.0
R&D	-0.130	-1.7	-0.125	-1.5	-0.098	-1.2	0.038	0.5
Constant	1.746	9.5	1.675	9.7	0.641	5.0	0.436	2.4
Wald test size $\chi 2[4]_{.95}=9.49$	9.0		2.1		38.7			
Log Likelihood function	-1737.9		-1767.2		-1950.4			
Breusch-Pagan Het ($\chi 2[15]_{.95}=25.0$; $\chi 2[33]_{.95}=43.0$)	259.5**				97.3**			
Adj-R^2/Pseudo R^2	0.806		0.797		0.760		0.543	
Wald-Test: $\gamma_{ij} = 0\ \forall$ i, j, $\chi 2[15]_{.95}=25.0$ [g]	302.3**							
Wald-Test: $\Sigma_i\, \alpha_i + \Sigma_i \Sigma_j\, \gamma_{ij} = 1$, ($\chi 2[6]_{.95}=12.6$) [h]	13.3**							

Dependent variable is log sales. IT and K denote IT investment and non-IT investment, respectively. H, M, and U denote university graduates, vocational school graduates and unskilled workers. Zero values for IT and K have been replaced by 0.000001 = DM 1. Zero values for H, M, or U have been replaced 0.1. **Significant at the 5 percent level.

[a] Technology is given by: $\ln Q = \ln \alpha_0 + \sum_i \alpha_i \ln X_i + \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln X_i \ln X_j$

[b] Homogeneity of degree one directly imposed. [c] Value of t-statistics based on Whites standard errors. [d] Wald tests are used to test following hypotheses: H_0: $\partial \ln Q/\partial \ln X_i = 0$. [e] Reference group is other business service. [f] Reference group is size 1. [g] Specification test, Cobb-Douglas vs. translog specifications. [h] Test for homogeneity of degree one. [h] T-statistic are based on bootstrapped estimates of the covariance matrix.

Table 5-2 gives estimates of the translog production function for the seven sectors.[10] All estimated output-elasticities are positive, but in a few cases not significant at the 5 percent level. The IT-elasticity varies significantly across sectors, the most IT intensive sectors (banking/insurance and other business service) having the highest output elasticities of IT. In banking and insurance and in other business services, IT is the second most important production factor with an output elasticity of between 0.17 and 0.19.

[10] For R&D/technical consultancy sector with 61 observations and more than 25 unknown parameters we realize that output-elasticities are not reliable. Therefore linear homogeneity of degree 1 have to be imposed.

Table 5-2: Sectoral Input-Output elasticities based on the translog specification

	Wholesale Trade		Retail Trade/Repairs		Transport		Banking/Insurance	
	Coeff.	t-stat	coeff.	t-stat	coeff.	t-stat	Coeff.	t-stat
$\eta_H = \partial lnQ/\partial lnH$	0.046	1.0	0.032	0.7	0.084	2.3	0.149	1.9
$\eta_M = \partial lnQ/\partial lnM$	0.270	2.7	0.771	6.9	0.323	4.5	1.055	7.3
$\eta_U = \partial lnQ/\partial lnU$	0.137	3.6	0.261	7.6	0.186	3.2	-0.000	-0.1
$\eta_K = \partial lnQ/\partial lnK$	0.063	1.4	0.006	0.3	0.096	2.0	0.097	3.1
$\eta_{IT} = \partial lnQ/\partial lnIT$	0.105	2.8	0.040	1.0	0.075	2.6	0.187	3.8
Chow test: equal parameters		1.67**		3.27**		3.18**		0.71
Critical value	F[1013,186]=1.28		F[1071,128]=1.37		F[1067,132]=1.33		F[1020,179]=1.28	
Observations	216		158		161		208	

	Computer/Software		R&D/Consultancy [a]		Other Services			
	coeff.	t-stat	coeff.	t-stat	coeff.	t-stat		
$\eta_H = \partial lnQ/\partial lnH$	0.376	3.7	0.301	2.7	0.122	3.6		
$\eta_M = \partial lnQ/\partial lnM$	0.542	8.0	0.411	3.7	0.330	6.3		
$\eta_U = \partial lnQ/\partial lnU$	0.058	1.8	0.127	1.7	0.070	2.1		
$\eta_K = \partial lnQ/\partial lnK$	0.027	0.8	0.032	0.8	0.133	7.6		
$\eta_{IT} = \partial lnQ/\partial lnIT$	0.042	0.5	0.129	1.1	0.166	5.0		
Chow test: equal parameters		3.40**		3.68**		1.47**		
Critical value	F[1146,53]=1.64		F[1167,32]=1.96		F[884,315]=1.19			
Observations	82		61		344			

Output elasticities are based on the estimated unrestricted translog specification parameters, except R&D/Consultancy. Dependent variable is log sales. IT and K denote IT investment and non-IT investment, respectively. H, M, and U denote university graduates, vocational school graduates and unskilled workers. Zero values for IT and K have been replaced by 0.000001 = DM 1. Zero values for H, M, or U have been replaced 0.1. All regression include dummies for exporter, change in corporate structure, size, R&D, and industrial conglomerate. [a] Homogeneity of degree one directly imposed since unrestricted functional form yields implausible elasticities for the sector.

In wholesale trade, IT is the third most important input factor. In contrast, in software/computer and in retail trade the contribution of IT capital to output is unexpectedly low. Office work is not very capital intensive, in most of the sectors the output-elasticity of capital is therefore smaller than the IT-elasticity ranging from 0.006 in retail trade to about 0.10 in banking, transport and other business services (real estate, personal services and other market related business activities). Software/computer and R&D and technical consultancies show the highest output elasticity for university graduates. In contrast to theoretical predictions, a comparison of the input-output elasticities for university graduates and IT reveals that the skill intensity of the three most intensive users of IT (wholesale trade, banking and insurance and other services) is rather modest.

Finally a Chow-test is used to test parameter stability of each subsample compared to the model assuming equal slopes across sectors.[11] In all cases except banking/insurance equal coefficients across sectors have to be rejected.

[11] The Chow test is based on $F=(RSS-RSS1)/RSS1\times(n1-k-1)/(n-n1)$, where RSS1 and RSS denotes the residual sum of squares for the subsample, and for the total sample, n1 the number of observations in the total sample, n the number of observations in subsample and k the number of regressors.

5.2 Elasticities of substitution

The elasticities of substitution based on the translog production function provide little support for a complementarity of IT capital and highly skilled labour. As indicated by the positive technical rate of substitution, IT capital is in fact a substitute for each of the three types of labour (see Table 5-3). Because IT-capital is found to be a substitute for more expensive skilled labour, computerisation may imply a decline of all three skill classes, but the changes will be rather small (σ_{HIT}, σ_{MIT}, $\sigma_{UIT} < 0.35$). Thus, substitutability alone is not sufficient to fully explain different skill intensities. Furthermore, a dominant pattern of substitutability can be observed between different types of labour. In particular, unskilled and medium skilled labour are good substitutes while highly skilled and unskilled labour are neither substitutes nor complements (σ_{HU}=0.01). One medium skilled labour (completed vocational training) can be approximately substituted for one highly skilled worker (σ_{HM}=0.88). The results for the Allen partial elasticities of substitution should be interpreted with caution since they appear unusually large. While this has also been found in previous studies (Bughin 1993, Huang 1998), elasticities of substitution based on the primal approach can be criticised for several reasons. In particular, Allen Partial Elasticities are based on marginal products which can hardly be observed and are difficult to measure. Furthermore, while the production function approach uses only information on quantities, the dual approach is based on both quantities and prices.

Table 5-3: Elasticities of substitution

	Allen Partial Elasticities of Substitution [a]	Cross-price Elasticities of demand [b]	t-stat
σ_{HK}	1.73	0.16	6.10
σ_{HM}	1.83	0.88	6.90
σ_{HU}	0.05	0.01	5.80
σ_{HIT}	2.40	0.33	5.50
σ_{KM}	7.10	3.42	7.60
σ_{KU}	1.10	0.14	5.90
σ_{KIT}	0.67	0.09	5.90
σ_{MU}	3.22	0.42	7.20
σ_{MIT}	1.21	0.17	7.30
σ_{UIT}	1.33	0.18	6.10

Elasticities are evaluated at sample means. H, M, U denotes high-, medium-skilled and unskilled labour, K and IT denote Non-IT investment and IT investment, respectively.

[a] As defined in part 2.2, the AES are computed as $\sigma_{ij}^{A} = \left|G_{ij}\right| / \left|G\right|$.

[a] The cross-price elasticities are defined as $\sigma_{ij}^{C} = \sigma_{ij}^{C}\,\eta_{j}$.

6 Conclusions

This paper has presented a number of factor demand and production function models to estimate the contribution of human and IT capital to output and to infer the implied elasticities of substitution between different types of skills and IT capital. Factor demand equations suggests that IT capital is the dominant factor in explaining the skill intensity across firms. At the aggregate level for the service sector, investment in IT appears complementary to highly skilled labour and a substitute for unskilled labour. The result for medium skilled labour is less clear cut. Within the banking, insurance and computer software sectors, IT investment appears to be weakly substitutable for medium skilled labour such as the clerical staff. A more detailed study of the factors which affect the firm's skill structure indicates that a firm's export orientation or ownership characteristics have positive effects on the chosen skill intensity of the firm.

The results for the translog production function show that the contributions to output of university graduates and information capital are about 0.12 and 0.17, respectively. For half of the firms in the data set, IT is the second most important factor of production. Medium skilled labour (vocational school graduates as well as foremen and technicians) is the most important production factor. In contrast, non-IT capital and unskilled labour play only a minor role in the service production process. Elasticities of substitution based on the translog production function did not confirm the IT capital-skill complementarity suggested by the factor demand equations. However, elasticities of substitution based on the production function approach should be regarded with caution.

Appendix

Table 6-1: Missing values

	West (participating firms =1629)		East (participating firms=924)	
	Data available (number of firms)	Missing values (in percent)	Data available (number of firms)	Missing values (in percent)
University graduates, H	1433	0.120	835	0.096
Workers with vocational degree, M	1477	0.093	849	0.081
Workers without degree/apprentices, U	1470	0.098	852	0.078
Gross investment, incl. IT	1498	0.080	854	0.076
Investment in communication and information technology	1492	0.084	846	0.084
exporter, 1994	1617	0.007	914	0.011
change in corporate structure, 1993-95	1629	0.000	924	0.000
part of industrial conglomerate, 1994	1614	0.009	916	0.009
product innovator, 1993-95	1629	0.000	924	0.000
process innovator, 1993-95	1629	0.000	924	0.000
R&D	1575	0.033	893	0.034
IT investment = 0, 1994	1498	0.080	854	0.076
Non-IT investment = 0, 1994	1492	0.084	846	0.084
Complete information for all variables	1231			
Observations used	1230	0.245	721	0.220

Source: Mannheim Service Innovation Panel 1995.

Table 6-2: Share of material and labour expenditures in total output

	Materials	Labour	Residual
Wholesale trade	0.86	0.09	0.05
Retail trade	0.82	0.13	0.05
Transport	0.50	0.29	0.21
Banking/insurance	0.35	0.31	0.34
Personal services	0.38	0.18	0.43
Market-services	0.61	0.20	0.19

Source: National accounts, own calculations.

Table 6-3: Input-output elasticities based on translog production function

	Percentile					
	Unrestricted specification			Linear Homogeneity imposed [a]		
	25th	Median	75th	25th	Median	75th
$\eta_H = \partial \ln Q / \partial \ln H$	0.059	0.109	0.164	0.089	0.153	0.225
$\eta_M = \partial \ln Q / \partial \ln M$	0.351	0.452	0.547	0.085	0.126	0.159
$\eta_U = \partial \ln Q / \partial \ln U$	0.038	0.094	0.154	0.366	0.469	0.595
$\eta_K = \partial \ln Q / \partial \ln K$	0.092	0.145	0.187	0.052	0.134	0.214
$\eta_{IT} = \partial \ln Q / \partial \ln IT$	0.162	0.211	0.247	0.135	0.178	0.207

Output elasticities are based on the estimated translog specification parameters. Dependent variable is log sales. IT and K denote IT investment and non-IT investment, respectively. H, M, and U denote university graduates, vocational school graduates and unskilled workers. Zero values for IT and K have been replaced by 0.000001 = DM 1. Zero values for H, M, or U have been replaced 0.1. All regression include dummies for exporter, change in corporate structure, size, R&D, and industrial conglomerate. [a] Homogeneity of degree one directly imposed.

Figure 1: Kernel density estimates for the output elasticity of unskilled skilled labour
$\eta_U = \partial lnQ/\partial lnU$

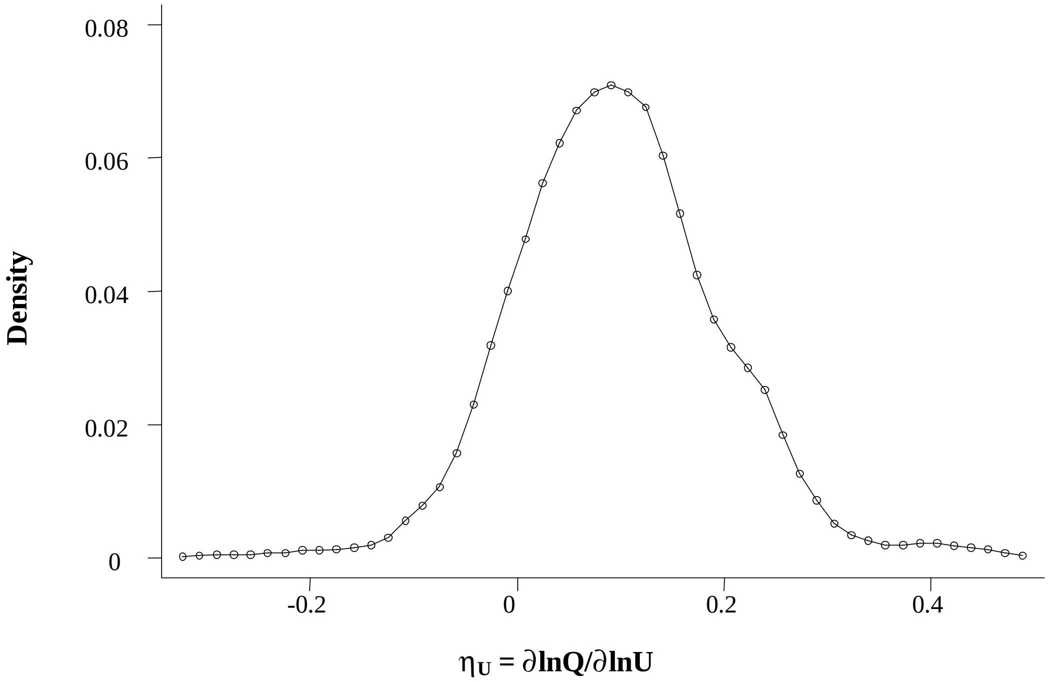


Figure 2: Kernel density estimates for the output elasticity of medium skilled labour
$\eta_M = \partial lnQ/\partial lnM$

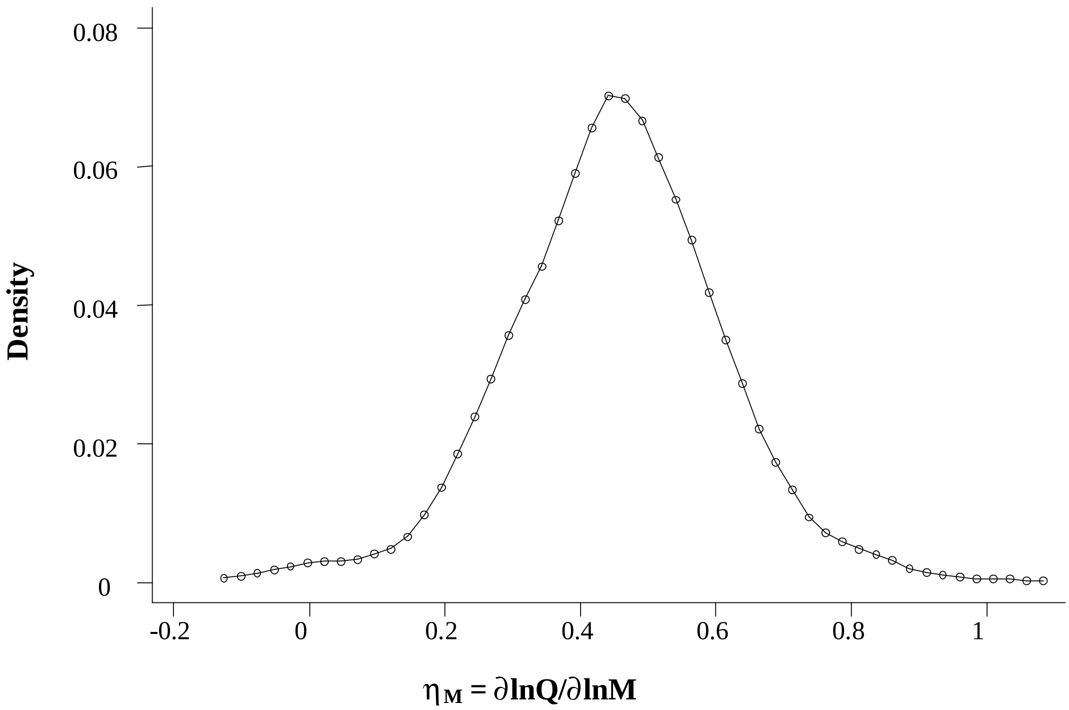


Figure 3: Kernel density estimates for the output elasticity of highly skilled skilled labour $\eta_H = \partial \ln Q / \partial \ln H$

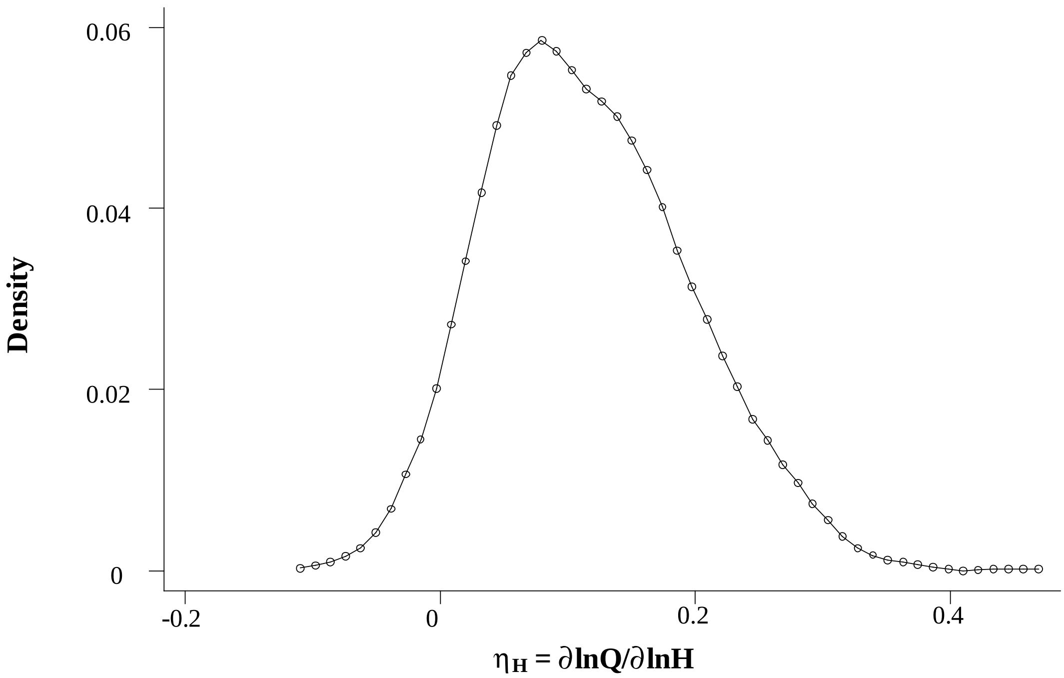
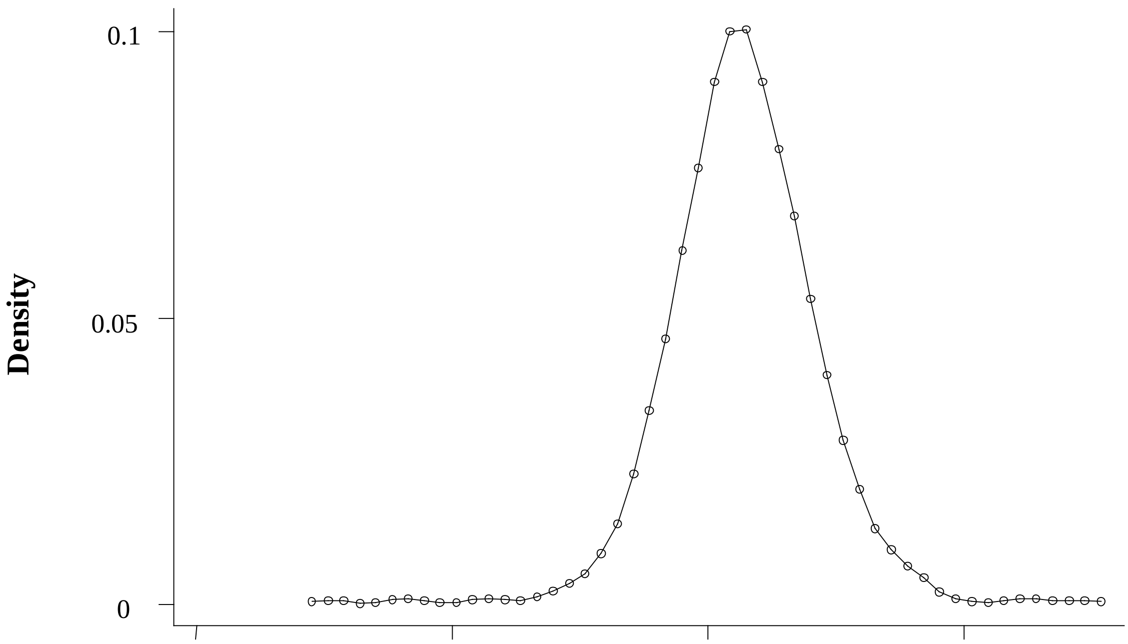


Figure 4: Kernel density estimates for the output elasticity of unskilled skilled labour $\eta_{IT} = \partial \ln Q / \partial \ln IT$



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