Strategic Complementarities Between Different Types of ICT–expenditures [§]

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Abstract: This paper empirically tests for complementarities between three different types of expenditures in information and communication technologies (ICT). I find highly significant complementarities between expenditures in physical ICT capital and labor cost for ICT personnel as well as between physical ICT capital and ICT services. The results for the relationship between labor cost for ICT personnel and ICT services are mixed: while the indirect approach provides evidence for complementarity, the direct method does not.
The estimation results also show that the partial productivity effect of physical ICT capital is largest, followed by ICT services and ICT personnel.
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1 Introduction

That "the whole is more than the sum of its parts" has been recognized by business economists for decades. It captures the very intuitive idea of synergies and system effects. Indeed, much theoretical and empirical research on synergies between firm strategies has been completed in recent years. These papers basically focus on complementarities between (i) innovation strategies — as discussed by Arora and Gambardella (1990), Cassiman and Veugelers (2002), Cockburn and Henderson (1998) as well as Miravete and Pernias (2000) —, (ii) human resource practices — as discussed by Bertschek and Kaiser (2004) as well as Ichniowski et al. (1997) — and (iii) new technologies and the demand for heterogeneous labor — as surveyed by Chennels and van Reenen (1999).

Surprisingly, given the importance of information and communication technology (ICT) to date and the fact that economic theory, with the work of Milgrom and Roberts (1990), has laid the fundament for empirical research more than a decade ago, the relationship between different ICT–components has not been studied empirically so far. A large strand of research has focused on the relationship between ICT and labor productivity (Brynjolfsson et al., 2002; Bresnahan et al., 2002; Powell and Dent–Micallef 1997; Stiroh 2002) but does not differentiate between different types of ICT expenditures.

The aim of this paper hence is twofold: it (i) analyzes the complementary (or substitutional) relationships between three ICT–investment components using a large sample of German firms[1] and (ii) provides estimates for the partial productivity effects of each of the three ICT expenditure components.

The empirical analysis is based on a large cross–sectional survey data set for German manufacturing industries and services. My test strategy is twofold: I apply a "direct" production function based approach (where significant coefficients on interactions of any two ICT expenditures are indicators of complementarities) and an "indirect" method (where significant correlations between the unobserved components of a system of ICT expenditure equations are indicators of complementarities).

This paper finds empirical evidence for the presence of complementarities between expenditures in physical ICT capital and labor cost for ICT personnel as well as between physical ICT capital and ICT–services. These results are supported by both the direct and the indirect approach to identify complementarities. The indirect approach also finds significant correlations between labor cost for ICT personnel and ICT services, even after controlling for observed firm heterogeneity. These correlations are, however, much less pronounced here than between

[1]The three ICT–expenditure components considered are: (1) expenditures in physical ICT–capital (hardware, software and telecommunication equipment), (2) expenditure for ICT–personnel (including freelance–workers) and (3) expenditures for ICT–services that are bought externally (e.g. programming services, fees paid to internet providers or payments to ICT–consultants). My data initially included a fourth category that is labelled "other" (non–specified) ICT–expenditures. I leave this category out since its inclusion is not informative in any economic sense.

the other two combinations of ICT expenditures.

The estimation results also show that the partial productivity effect of physical ICT–capital is largest, followed by ICT–services and ICT–labor.

2 Testing strategy, data and econometrics

My testing procedure involves two different methods. I perform a “direct” test where I regress interactions of the three ICT–expenditure components on a firm performance indicator and an “indirect” test where I interpret significant correlations between the ICT–expenditures as an indicator for the presence of complementarity. The direct method also produces estimates for the partial productivity contributions of each of the three ICT–expenditure components.

2.1 Direct method

Complementarity means that a firm can improve its payoff, Π_i (where the subscript i is a firm index), from an investment in activity A_k by additionally investing in activity A_{-k}; the cross–partial effect of the investment activities is positive: $\frac{\partial^2 \Pi_i}{\partial {A_i}^k \partial A_i^{-k}} > 0$. Translated into a regression framework, directly testing for complementarity implies to estimate a payoff equation as a function of interactions of the different activities so that estimates for the cross–partials are obtained.

My direct test thus estimates extended Cobb–Douglas production functions (or, equivalently, restricted translog production functions) that include interactions between the three different types of ICT–expenditures.[2] An ideal measure of "payoff" of course is firm's profit since profit data combine information on both revenues and cost. Profit data is, however, reported by firms only on rare occasions such as in balance sheet data. If they are reported, then detailed information on firms' expenditures such as their spending on different types of ICT–components is missing. In the empirical analysis I therefore approximate profits by total sales (assuming that both are highly correlated).[3]

My payoff variable thus is the natural logarithm of total sales, $ln(S_i)$. Factor inputs are the three types of ICT expenditures as well as labor, L_i (total number of employees), and capital, K_i (proxied by total investment in physical assets), and a set of variables that captures observed firm heterogeneity, vector $\boldsymbol{x_i}$. The extended Cobb–Douglas production function is:

$$\begin{aligned} \ln(S_i) = {} & \alpha_L ln(L_i) + \alpha_K ln(K_i) + \alpha_{ICT_P} ln(ICT-physical) + \alpha_{ICT_L} ln(ICT-labor) \\ & +\alpha_{ICT_S} ln(ICT-services) + \delta_{ICT_P/ICT_L} ln(ICT-physical) ln(ICT-labor) \\ & +\delta_{ICT_P/ICT_S} ln(ICT-physical) ln(ICT-services) \\ & +\delta_{ICT_S/ICT_L} ln(ICT-services) ln(ICT-labor) + \boldsymbol{x_i\beta} + u_i, \end{aligned}$$

where u_i is an i.i.d. normally distributed error term and the cross–partials are δ_{ICT_P/ICT_L}, δ_{ICT_P/ICT_S} and δ_{ICT_S/ICT_L}.

[2]The reason for not estimating the more flexible translog production functions is the high correlation between the input factors; Appendix A provides a detailed discussion of this issue. All Appendices appear at URL www.ulrichkaiser.com/papers/compl.html.

[3]I have used Danish data that I employ in Kaiser (2004) to calculate bivariate correlation coefficients between total sales and total accounting profits. The correlation between unscaled sales and profits is 0.6853 the correlation between per employee sales and per employee profits is 0.6364.

The vector of firm heterogeneity variables, $\boldsymbol{x_i}$, accounts for differences of firms from different sectors, firm size, firms' regional affiliation and firm age. Apparently, there should be significant differences between firms from different sectors so that I include twelve dummy variables for sector affiliation.[4] It is well known that East German firms are less productive than West German ones so that I include a dummy variable for East German firms as well. Two dummy variables for being part of a larger conglomerate and for having a foreign parent firm are also used as control variables.

It is certainly possible that there are marked differences in the productivity coefficients between manufacturing and services which is why I split the sample between the two sectors. The provision of services crucially hinges upon an intense producer/consumer interaction, many products are customized and the production process in services is very labor intensive.

[4]These are: manufacture of metallic products and machinery equipment, manufacture of chemical products, manufacture of basic chemical products, manufacture of electrical equipment, manufacture of instruments, manufacture of motor vehicles, wholesale trade, retail trade, transport, banking and insurance, architectural and engineering services, "other" business–related services (e.g. advertising, vehicle renting etc.) and manufacture of consumer products as base category.

2.2 Indirect method

My direct approach to identify complementarities suffers from the drawback that I proxy the target variable, Π_i, by total sales and do not use profits which seems more appropriate. In order to illuminate the issue of complementarity further I also use an indirect method that follows Holmström and Milgrom (1994, part B): an expenditure in one activity is a complement to another activity if the expenditure levels are correlated (provided that agents act rationally). This is a necessary condition for the presence of complementarity. Due to heterogeneity across firms, the correlation between the investment expenditures decisions could be biased and lead to a false acceptance of the hypothesis of complementarity, as pointed out by Athey and Stern (1998). For example, large firms are likely to have large expenditures in all three types of ICT–expenditures. Consequently, if it is not controlled for firm size, all three types of ICT–expenditures will be highly correlated. This correlation would, however, be "spurious" since it might be primarily caused by firm size.

Indeed, if variables that represent firm heterogeneity are added and if adding these variables removes the correlation between the activities, these added variables are the *sources* of complementarity.[5]

[5] Cross–sectional analyzes such as the present one can only take into account *observed* firm heterogeneity. There might of course also be a significant *unobserved* heterogeneity, for example due to differences in management abilities. Panel data can potentially take care of these effects, at least if we believe that these effects are time–invariant (implying that management does not

I include three sets of variables that account for heterogeneity across firms: (i) "standard" control variables that are used in almost every empirical firm–level analysis, (ii) variables that represent firms' skill mix and (iii) variables that represent firms' ICT–structure mix. These sets of variables are discussed in detail in Appendix B.

There might of course be a problem of endogeneity related to the ICT–structure variables. Although it is straightforward to write the estimation problem in terms of moment conditions and to estimate the system of equations using GMM, it is much harder — and even impossible given the data at hand — to find appropriate instruments for the potentially endogenous variables. Since the main interest is in correlations and not on causalities endogeneity is a minor problem here, however. Moreover, as it will turn out later, the ICT–structure variable have modest effects on the reduction of correlations between the ICT–components which clearly does not suggest that severe endogeneity problems are present.

The empirical strategy is to successively add explanatory variable to the estimation equations. I then check to what extent adding the explanatory variables reduces the correlation between unobserved components of the ICT–expenditure equations (i.e. the error terms correlation between the error terms). There are seven possibilities to combine the three different sets of explanatory variables: (i) adding 'standard' firm heterogeneity controls only, (ii) adding skill structure

change). The data used here is cross–sectional only so that panel data estimation is not an option.

only, (iii) adding ICT–structure only, (iv) adding 'standard' firm heterogeneity and skill structure, (v) adding skill structure variables and ICT–structure, (vi) adding 'standard' firm heterogeneity and ICT–structure and (vii) adding all three sets of control variables.

2.3 Data

The data stem from a computer aided telephone interview survey by *sample qm*, Mölln, Germany, in commissioned work for the Centre for European Economic Research (Zentrum für Europäische Wirtschaftsforschung, ZEW), Mannheim. The firms contacted were randomly drawn from a stratified sample of about 11,000 German firms. The sample was stratified with respect to sector affiliation, firm size and region (East/West Germany). Only firms with at least five employees were included in the survey. The sample was drawn from data material made available by Germany's largest credit rating agency Creditreform. Creditreform has the most comprehensive database of German firms at its disposal. The survey was conducted in fall 2000. About 4,400 firms participated in the survey, which corresponds to a response rate of approximately 43%.[6] After performing consistency checks, due to item non–response, and due to leaving out the ICT–producing sector (139 are lost by dropping these firms) I am left with 984 firms in

[6]The data set used in this study is confidential. The ZEW does, however, grant researchers who wish to use the data for scientific purposes access upon request. Inquiries should be sent to `info@zew.de`.

the empirical analysis. The severe drop in the number of observations might lead to a sample selection bias which is why an econometric test on non–randomly missing observations is conducted in Appendix C. This test cannot reject the absence of a sample selection bias.

Appendix D displays detailed descriptive statistics for the three ICT–expenditure variables and Appendix E provides descriptive statistics for all variables involved in the estimations.

2.4 Estimation technique

The extended Cobb–Douglas production function is estimated by Ordinary Least Squares (OLS) using a variance–covariance matrix that is robust to heteroscedasticity.

All three ICT–expenditures are left–censored at zero which forbids to directly correlate the three ICT–expenditure components to one another as required by the indirect approach to the detection of complementarities. I therefore use multivariate Tobit models (Lee, 1992), to calculate the correlation coefficients between the three ICT–expenditure levels. The idea of the multivariate Tobit model is to jointly estimate a multi–equation Tobit model that allow for the error terms of each equation to be correlated. Separate estimation generates consistent but, if the error terms are truly correlated, inefficient parameter estimates.

3 Results

3.1 Direct method

Table 1 displays OLS estimation results for the extended Cobb–Douglas production function. The upper panel refers to the complete sample while the middle panel corresponds to services and the lower panel to manufacturing.

My empirical approach is to first estimate a standard Cobb–Douglas production function without interactions and then leave out any input factor that is insignificantly different from zero in the extended production function in order to reduce dimensionality and the correlation between the input factors. The estimation results indeed cannot reject insignificance of labor cost for ICT personnel so that this input factor is left out in the extended version. I also substitute the natural logarithm of ICT services by its inverse to further avoid collinearity problems.

There are positive and statistically highly significant effects of the interactions between physical ICT expenditures and labor cost for ICT personnel as well as between physical ICT expenditures and ICT services. This indicates significant complementarities between these two combinations of ICT expenditures. The coefficient on interactions between physical ICT expenditures and labor cost for ICT personnel is quantitatively smaller than for the combination physical ICT expenditures/ICT services; the difference is, however, insignificant (test not shown in the table).

There are no significant effects of the interaction between labor cost for ICT personnel and ICT services, pointing at an absence of complementarities between these ICT components. ICT personnel and ICT services is the combination that is least suspicious of being complements since externally brought ICT services could very well substitute ICT personnel, as firms for example outsource ICT activities. A complementary relationship could be caused by the additional labor cost arising from implementing a new and/or maintaining an existing ICT infrastructure. My finding of insignificant effects thus might just indicate that the two effects balance out one another.

Highly significant effects of the interaction between physical ICT expenditures and ICT services remain being present in the separate estimations for services and manufacturing. For services, the degree of complementarity increased relative to the joint estimation while it remains roughly the same for manufacturing. The numerical effect of the interaction physical ICT expenditures and labor cost for ICT personnel also remaines about the same in both sectors. Since the standard error of the estimated coefficient increases considerably, the effect is no longer significant. This might well be due to the fact that splitting the sample leads to a substantial reduction in sample size which in turn induces a reduction in the precision with which the coefficients are estimated.

Table 1 also shows evidence for the economic significance of differentiated ICT–expenditures. The partial productivity effect is largest for physical ICT–investment, followed by ICT–services and ICT–personnel. This finding underscores the importance of differentiating between different ICT expenditures activities and coincides with earlier results of Licht and Moch (1999). Compared to the partial productivity effects of non–ICT capital and labor, the productivity contributions of the ICT–components are relatively low, however. This result also holds if total ICT expenditures are used instead of the three different components: the partial productivity coefficient for total ICT expenditures is 0.04 compared to 0.74 for labor and 0.16 for ordinary capital. This result is somewhat in contrast to findings of the earlier literature on the ICT/productivity relationship that usually shows that ICT capital is more productive than ordinary capital. Those studies are, however, not fully comparable to this paper most importantly since ICT expenditures are completely differently measured. There are also differences in country choice and the considered time periods.

Insert Table 1 about here!

3.2 Indirect method

Univariate correlations

My indirect analysis of complementarities starts with the calculation of simple correlation coefficients between the log ICT–expenditure levels. Bivariate correlation coefficients (correlation coefficients that do not consider any explanatory variables) are displayed in Table 2. The correlation coefficients are all highly significantly different from zero and positive. Hence, the necessary condition for the three ICT–expenditure levels to be complementary is satisfied.

Insert Table 2 about here!

The correlations are particularly large between physical ICT–capital and labor cost for ICT personnel. Physical ICT–capital and ICT–services as well as labor cost for ICT personnel and ICT–services are correlated to a lesser extent. These results clearly indicate that investment in one type of ICT–component is very likely to be associated with investment in another ICT–component.

Now that the necessary condition for complementarity is established, I turn to the sufficient condition: ICT–expenditure levels need still to be correlated if it is accounted for observable firm heterogeneity.

Multivariate correlations

Since the key interest is in the correlation between the three ICT–expenditure levels, Table 3 only displays the correlation coefficients for the model that contains all three sets of control variables because this is the model where the correlation coefficients are lowest. All other regression output is moved to Appendix F. Table 4 shows by how much the correlation coefficients are reduced in magnitude once the control variables for observed firm heterogeneity relative to the correlation coefficients that do not control for observable firm heterogeneity.

Insert Table 3 about here!

Insert Table 4 about here!

A main result of Table 3 is that the ICT–expenditure levels are still highly significantly correlated with one another even after explanatory variables are considered. Thus, evidence is given that the three ICT–components are indeed complements — at least if we want to believe that firms act rationally (which we usually do) and that the firm heterogeneity variables adequately capture difference across firms (which is debatable).

The correlation again is particularly large between physical ICT and labor cost for ICT personnel and, to a lesser extent, between ICT capital and ICT services. To an even lesser extent, labor cost for ICT personnel and ICT services are also significantly correlated.

Table 4 shows that the correlations between the different types of ICT expenditures decreases dramatically once control variables for observable firm heterogeneity are added. The drop is particularly large (66 percent) for the combination labor cost for ICT personnel and ICT services, it is less pronounced for the combination labor cost for ICT personnel and physical ICT.

The most substantial contribution to the reduction in correlation is due to the "standard" variable for observable firm heterogeneity, pointing at plain firm firm heterogeneity being a main cause for complementarities. Neither the ICT–structure variables nor the set of skill structure variables nor the can to an equally large extent explain the initial correlations.

The contribution of firms' skill structure is astonishingly small. If considered separately from the other two sets of control variables, the reduction in correlation is close to zero. This shows that a highly skilled workforce does not necessarily go along with large spendings on all different types of ICT.

Firms' ICT–structure by contrast makes a considerable contribution to the reduction in the initial complementarity levels. Taken alone, it reduces correlations by between 8 and 20 per cent. If used in addition to the "standard" control variables, it's marginal contribution is reduced. This indicates that parts of the ICT–structure's effect is absorbed by accounting for sector–specific differences and firm size.

An indirect test of the robustness of the estimation results is that the quantitative results, most importantly the results with respect to the reduction of the correlation between the ICT–expenditure level remains the same even if ICT–expenditures are scaled by the number of employees or by total sales.

4 Implications

4.1 Strategic management implications

What does the finding of strategic complementarities between the combinations physical ICT/ICT personnel and physical ICT/ICT services for strategic management? It is obvious that it means that instead of focussing on of either ICT–component, for example on ICT–hardware alone, firms should invest in ICT services and ICT personnel as well. Firms fully benefit from their ICT–investments only if one type of ICT–spending is joined by a bundle of accompanying expenditures. This is somewhat in contrast to current business practice especially among very small enterprizes that tend to invest in one ICT–component only but do not make the complementary investments (Licht et al. 2002). At a less general level, these results make a point in favor of a hierarchical organizational structure since making complementary investments requires a high degree of coordination. According to Milgrom and Roberts (1995) this makes hierarchical structures preferable over flat ones since coordination cost are lower.

4.2 Economic policy implications

Complementarities between ICT–components also have clear implications for ICT–policies. It indicates that governments should promote a bundle of ICT–diffusion enhancement measures instead of focussing on one measure only, most often the diffusion of the internet, only. To give a real–life example: the German Federal Ministry for Economics and Technology (Bundesministerium für Wirtschaft und Technologie, BMWi) as well as the Ministry for Education and Research (Bundesministerium für Bildung und Forschung, BMBF) recently published a list of ten targets with respect to Germany's competitive position in ICT that should be reached until 2005 (BMWi/BMBF 1999). Seven of these targets are directly related to the diffusion and technical improvement of the internet. The other three targets concerns the promotion of multi–media firms, the development of a supervisory framework for firms operating in ICT and media and the enhancement of apprenticeship training in ICT–related professions. The pay-off of the German government from investing in ICT would probably be higher if it invested in potentially complementary activities such as in education, and training of ICT users as well.

5 Summary and conclusions

This paper tests for the presence of complementarities between three different types of expenditures in ICT (expenditures in physical ICT capital, labor cost for ICT personnel and ICT services) using a large cross–section of German manufacturing and service sector firms. Two different approaches are used, a "direct" test that is based on the estimation of a production function and an "indirect" test that considers the correlations between the different types of ICT expenditures.

The direct test for complementarities finds significant complementarities between expenditures in physical ICT capital and labor cost for ICT personnel as well as between expenditures in physical ICT capital and ICT services. There is no significant evidence for complementarities between labor cost for ICT personnel and ICT services.

The indirect test for complementarities finds that the unobserved (to the econometrician) components of all three different types of ICT–expenditures are highly correlated with one another even if it is controlled for a large set of variables that represent firm heterogeneity, thus generating evidence for complementarities between all types of ICT expenditures. The degree of correlation between expenditures in ICT personnel and ICT services is, however, considerably (and significantly) lower than between the other two types of ICT expenditures.

Both approaches thus arrive at the conclusion that there exist complementarities between expenditures in physical ICT capital and labor cost for ICT personnel as well as between expenditures in physical ICT capital and ICT services.

The strategic management implication of the presence of complementarities between ICT–expenditure levels is that firms need to invest into a bundle of (complementary) ICT–component to fully reap the benefits of their investments. This bundling of efforts might by easier achieved if organizational structures are hierarchical as pointed out by Milgrom and Roberts (1995). The economic policy implication of strategic complementarities is that governments should invest in a bundle of ICT–promotion measures instead of focussing on specific subgroups such as, for example, the diffusion and improvement of the internet.

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Table 1: Production function estimation results

	Restricted Cobb–Douglas		Extended Cobb–Douglas	
	Coeff.	Std. Err.		
Both manufacturing and services				
ln(ICT–physical)·ln(ICT–labor)	—	—	0.2178**	0.1125
ln(ICT–labor)·ln(ICT–services)	—	—	-0.0357	0.0733
ln(ICT–physical)·ln(ICT–services)	—	—	0.2952***	0.1046
ln(ICT–physical)	0.0339***	0.0129	0.0422***	0.0129
1/ln(ICT–services)	—	—	0.0026*	0.0016
ln(ICT–labor)	0.0059	0.0050	—	—
ln(ICT–services)	0.0173***	0.0050	—	—
ln(labor)	0.7160***	0.0380	0.7090***	0.0380
ln(capital)	0.1592***	0.0238	0.1540***	0.0241
F–tests of joint significance, # of obs. And adj. R^2				
Entire spec.	168.34	0.00	169.65	0.00
Sector dummies	13.45	0.00	13.56	0.00
# of obs.	984		984	
Adj. R^2	0.8018		0.8023	
Services only				
ln(ICT–physical)·ln(ICT–labor)	—	—	0.1868	0.5450
ln(ICT–labor)·ln(ICT–services)	—	—	0.0005	0.9970
ln(ICT–physical)·ln(ICT–services)	—	—	0.4088**	0.0330
ln(ICT–physical)	0.0245	0.0214	0.0359*	0.0930
ln(ICT–labor)	0.0165*	0.0090	0.0119	0.3490
1/ln(ICT–services)			0.0033	0.1970
ln(ICT–services)	0.0239***	0.0084		
ln(labor)	0.6657***	0.0555	0.6576***	0.0000
ln(capital)	0.1792***	0.0343	0.1767***	0.0000
F–tests of joint significance, # of obs. And adj. R^2				
Entire spec.	79.27	0.00	71.13	0.00
Sector dummies	0.75		29.86	0.00
# of obs.	453		453	
Adj. R^2			0.7481	
Manufacturing only				
ln(ICT–physical)·ln(ICT–labor)	—	—	0.1208	0.1040
ln(ICT–labor)·ln(ICT–services)	—	—	-0.0576	0.0811
ln(ICT–physical)·ln(ICT–services)	—	—	0.1941*	0.1043
ln(ICT–physical)	0.0385***	0.0124	0.0388***	0.0118
ln(ICT–labor)	-0.0013	0.0056		
1/ln(ICT–services)			0.0011	0.0017
ln(ICT–services)	0.0106**	0.0049	0.7873	
ln(labor)	0.7920***	0.0462	0.1170***	0.0468
ln(capital)	0.1239***	0.0284	-0.3111***	0.0287
East Germany	-0.3178***	0.0657	0.2796***	0.0661
Subsidiary	0.2784***	0.0621	0.2607***	0.0630
Foreign mother	0.2635***	0.0636	0.1005***	0.0634
F–tests of joint significance, # of obs. and adj. R^2				
Entire spec.	241.55	0.00	219.10	0.00
Sector dummies	2.78	0.01	2.90	0.01
# of obs.	531		531	
Adj. R^2	0.8619		0.8622	

Table 1 shows OLS estimation results for standard and extended Cobb–Douglas production functions. Standard errors are robust to heteroscedasticity. The estimation results also contain a set of sector dummy variables. The asteriks ***,** and * indicate statistical significance at the one, five and ten per cent marginal significance level. The abbreviations used are: ICT_p for physical ICT expenditures, ICT_i for labor cost for ICT and ICT_s for ICT services.

Table 2: Bivariate correlation coefficients between ICT expenditure types, control variables not included

	ICT–physical	ICT–labor	ICT–services
ICT–physical	1		
ICT–labor	0.7323	1	
ICT–services	0.6197	0.5809	1

Table 2 shows bivariate correlation coefficients between the three different types of ICT expenditures. The correlation coefficients are estimated from a multivariate Tobit model that used a total of 984 observations. The abbreviations used are: ICT–physical is for expenditures for physical ICT expenditures, ICT–labor is for expenditures for labor cost for ICT personnel and ICT–services is for expenditures for ICT services. All correlation coefficients are significant at the one percent marginal significance level.

Table 3: Bivariate correlation coefficients between ICT expenditure types, full set of control variables included

	ICT–physical	ICT–labor	ICT–services
ICT–physical	1		
ICT–labor	0.5262	1	
ICT–services	0.3835	0.3519	1

Table 3 shows bivariate correlation coefficients between the three different types of ICT expenditures after controlling for observed firm heterogeneity. The correlation coefficients are estimated from a multivariate Tobit model that used a total of 984 observations. The abbreviations used are: ICT–physical is for expenditures for physical ICT expenditures, ICT–labor is for expenditures for labor cost for ICT personnel and ICT–services is for expenditures for ICT services. All correlation coefficients are significant at the one percent marginal significance level.

Table 4: Reduction in correlations due to addition of explanatory variables (in per cent)

	ICT–physical	ICT–labor	ICT–services
Adding "standard" firm heterogeneity controls only			
ICT–physical	1		
ICT–labor	21.5768	1	
ICT–services	29.4319	31.3033	1
Adding skill structure only			
ICT–physical	1		
ICT–labor	0.8011	1	
ICT–services	0.0540	0.1844	1
Adding ICT–structure only			
ICT–physical	1		
ICT–labor	9.4748	1	
ICT–services	13.8086	16.4024	1
Adding "standard" firm heterogeneity and skill structure			
ICT–physical	1		
ICT–labor	23.6696	1	
ICT–services	28.9892	31.4509	1
Adding skill structure variables and ICT–structure			
ICT–physical	1		
ICT–labor	9.9253	1	
ICT–services	13.2656	15.4814	1
Adding "standard" firm heterogeneity and ICT–structure			
ICT–physical	1		
ICT–labor	28.0853	1	
ICT–services	35.6174	39.9532	1
Adding all three sets of control variables			
ICT–physical	1		
ICT–labor	28.6430	1	
ICT–services	37.4756	40.4977	1

Table 4 displays the percentage reduction in bivariate correlations between the three different types of ICT expenditures. A total of 984 observations are used in the analysis. The abbreviations used are: ICT–physical is for expenditures for physical ICT expenditures, ICT–labor is for expenditures for labor cost for ICT personnel and ICT–services is for expenditures for ICT services.