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INFORMATIONAL MOBILITY AND PRODUCTIVITY – FINNISH EVIDENCE*

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ABSTRACT: Labor productivity effects of portability as well as wireline and wireless connectivity of information and communication technology (ICT) are studied with Finnish firm-level data. It is found that a computer with only processing and storage capabilities boosts labor productivity by 9% (corresponding to 5% output elasticity), portability by 32%, wireline connectivity by 14%, and wireless connectivity by 6%. Findings are in line with previous literature and comparisons to ICT costs suggest that firms equate marginal costs and returns. While increasing ICT penetration can no longer be a major source of productivity growth in developed economies, the studied new characteristics can.

Keywords: Productivity, Computer, ICT, Information and communication technology, LAN, Local area network, Mobility, Portability, Wireless

JEL codes: D24, J24, L23, O33

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TIIVISTELMÄ: Tässä paperissa tutkitaan tieto- ja viestintäteknologialaitteiden kannettavuuden sekä langallisten ja langattomien tietoliikenneominaisuuksien tuottavuusvaikutuksia suomalaisella yritysaineistoilla. Tulokset osoittavat, että digitaalisen tiedon prosenssointi- ja tallennusominaisuudet nostavat työn tuottavuutta 9 % (vastaten 5 % tuotosjoustoa), kannettavuus 32 %, langallinen tietoliikenne 14 % ja langaton 6 %. Tulokset ovat yhdenmukaisia aiemman kirjallisuuden kanssa ja niiden mukaan yritykset investoivat tietotekniikkaan tasolla, jolla rajakustannukset ja -hyödyt muodostuvat yhtäsuuriksi. Tietotekniikan käytön leviäminen sinänsä ei enää voi olla tuottavuuskasvun lähde kehittyneissä talouksissa, mutta käsitellyt uudet ominaisuudet voivat.

Avainsanat: Tuottavuus, tietokone, ICT, tieto- ja viestintäteknologia, LAN, lähiverkko, liikkuvuus, kannettavuus, langaton.

INTRODUCTION

Information and communication technology (ICT) devices have become increasingly portable and (inter)connectable at least since the mid-1990s, which in many circumstances have made it possible to create and access digitally coded information independent of time and place. Does this increasing "informational mobility" have consequences on labor productivity? In order to answer the question, this paper operationalizes the concept of informational mobility and quantifies its effects on labor productivity in Finnish business.

In what follows, portability refers to the use of laptop personal computers (PCs), tablet PCs, or similar portable data processing and storage devices (due to data limitations, however, personal digital assistants, mobile phones, or similar handhelds are excluded). Connectivity refers to wireline (e.g., via a local area network, LAN) or wireless (e.g., via a public access mobile telephony network or a wireless local area network, WLAN) access to remotely stored data.

Olariu (2003) notes that both portability and wireless connectivity have grown explosively in recent years in terms of both available technologies and services offered. Perhaps the most important drivers have been rapidly dropping prices and user costs.[1]

Leading trade publications, see e.g. Gartenberg (2003), have repeatedly suggested – albeit without empirical evidence – that portability and wireless connectivity offer significant cost savings and boost productivity. Anecdotal support can be found in business press; see e.g. Green (2003) and Nasaw (2003). For example Altimier et al. (2002) have document the benefits of portability and wireless connectivity in health care and Zurita and Nussbaum (2003) in education. While studies in other or across sectors are nearly non-existent, portability and wireless connectivity might boost productivity in virtually any activity where immediate information storage, processing, retrieval, and exchange are beneficial. As this is the case in many management, sales, and logistics activities, most businesses could be affected.

[1] While reliable statistics are unavailable, for instance Cahners InStat/MDR (as cited in Rao & Parikh, 2003) states that the U.S. WLAN equipment sales increased by 65% in 2002. Chwelos' (2003) findings suggest that the quality-adjusted price of a laptop dropped roughly twice as fast as that of a desktop computer in the 1990s.

MODEL

The three basic principles of Lancaster's (1991) consumer theory may be given a "dual" reinterpretation in a production context as follows: (1.) goods do not boost productivity – they possess characteristics that do, (2.) goods may possess many characteristics and many of them are shared by more than one good, and (3.) goods used in conjunction with others may possess characteristics different from the same goods used separately. Any good may be seen as a bundle of its characteristics, each having a separate productivity effect. Even though – as noted by Gordon (2000) – diminishing returns on ICT might be discovered rather soon as its usage expands, it is possible that new characteristics added to old goods and new goods working in conjunction with older ones may continuously shift the productivity frontier.

The goal here is to capture the productivity effects of various ICT characteristics on an individual worker. The problem is, however, that these characteristics – or more precisely, the ICT goods that bundle them – are only observed at the firm level, i.e., data is "grouped". Assuming that workers are – after controlling for observable individual qualities – perfect substitutes, a firm-level model revealing these effects can nevertheless be devised and estimated. An extended Cobb-Douglas production function of firm i can be written as

$$Y_i = A_i K_i^{\beta_K} L_i^{\beta_L} \boldsymbol{Z}_i^{\beta_Z} \tag{1}$$

where Y is net output, A is disembodied technology, K is capital, L is labor, and $\boldsymbol{Z}$ is a vector of other relevant firm and individual qualities. Workers may have different marginal productivities depending on the set of ICT characteristics they use. Let $\boldsymbol{L}_{ICT}$ be a vector indicating the number of workers using each of the ICT characteristics of interest. Adding this to (1) yields

$$Y_i = A_i K_i^{\beta_K} \left(L_i \left(1 + \boldsymbol{\theta}_{ICT} \left(\frac{\boldsymbol{L}_{ICT,i}}{L_i} \right) \right) \right)^{\beta_L} \boldsymbol{Z}_i^{\beta_Z}, \tag{2}$$

where $\boldsymbol{\theta}_{ICT}$ is a parameter vector capturing the possible additional productivity effects associated with the ICT characteristics. Slight manipulation yields a labor productivity specification

$$\ln\left(\frac{Y_i}{L_i}\right) = \ln A_i + \beta_K \ln\left(\frac{K_i}{L_i}\right) + \beta_L \ln\left(1 + \boldsymbol{\theta}_{ICT}\left(\frac{\boldsymbol{L}_{ICT,i}}{L_i}\right)\right) + \left(\beta_K + \beta_L - 1\right)\ln L_i + \boldsymbol{\beta}_{\boldsymbol{Z}} \ln \boldsymbol{Z}_i, \tag{3}$$

where $(\beta_K + \beta_L - 1)\ln L_i$ accounts for deviations from constant returns to scale. Approximating $\ln\left(1+\boldsymbol{\theta}_{ICT}\left(\frac{\boldsymbol{L}_{ICT,i}}{L_i}\right)\right)$ with $\boldsymbol{\theta}_{ICT}\left(\frac{\boldsymbol{L}_{ICT,i}}{L_i}\right)$ yields

$$\ln\left(\frac{Y_i}{L_i}\right) \approx \ln A_i + \beta_K \ln\left(\frac{K_i}{L_i}\right) + \beta_L \boldsymbol{\theta}_{ICT}\left(\frac{\boldsymbol{L}_{ICT,i}}{L_i}\right) + (\beta_K + \beta_L - 1)\ln L_{it} + \boldsymbol{\beta_Z} \ln \boldsymbol{Z_i}, \qquad (4)$$

which is estimable once the variables and a stochastic error structure have been specified.[2]

DATA

After eliminating a few unusable observations (see below), the sample for year 2001 consists of 2,358 manufacturing and service firms that are left after linking the ICT survey data with Financial Statements and Employment Statistics as well as Business Register data. While Statistics Finland has conducted its ICT surveys since 1998, only the year 2001 survey includes sufficient information for the isolation of the desired ICT characteristics.

Table 1 lists the ICT bundles and the characteristics they possess. Note that wireless is seen as an extension of wireline connectivity, which becomes important upon interpreting the results – the reference for WLAN is a similar computer with LAN. As Table 1 suggests, portability and connectivity cannot exist without processing and storage capabilities. As the ICT characteristics are always embodied in one or more of the ICT bundles, their effects cannot be estimated directly. By comparing two bundles that are identical in other respects except the characteristic to be isolated, its effects can nevertheless be assessed. The possible comparisons for isolating the ICT characteristics can be found at the bottom of Table 1: portability can be isolated via three different comparisons; both wireline and wireless connectivity via two.

[2] Greenan and Mairesse (2000) consider a similar model in ICT and, e.g., Dearden et al. (2000) and Ilmakunnas and Maliranta (2003) in other contexts.

Table 1. The ICT bundles, their characteristics and ways of distinguishing them.

Bundle id.	ICT bundle:	ICT characteristic: Processing and storage capab.	Portability	Wireline connectivity	Wireless connectivity
0	Not using computer at work	–	–	–	–
a	Desktop	Yes	–	–	–
b	Laptop	Yes	Yes	–	–
c	Desktop with LAN	Yes	–	Yes	–
d	Laptop with LAN	Yes	Yes	Yes	–
e	Desktop with WLAN	Yes	–	Yes	Yes
f	Laptop with WLAN	Yes	Yes	Yes	Yes
	Characteristic distinguishable by comparing bundle(s):	$a - 0$	$b - a$ $d - c$ $f - e$	$c - a$ $d - b$	$e - c$ $f - d$

Note: The empirical definitions of the bundles discussed in the data section. In some estimations below various ways of calculating bundle coefficients are constrainted to be equal.

The empirical definition of the ICT bundles is complicated by the fact that only the workers using desktops and laptops are available as fractions; the use of LAN and WLAN are only observed as firm-level dummies. Thus, the bundles are derived under the assumption that implementing a LAN or WLAN involve solely a fixed cost, in which case every computer is connected once a network is introduced at the firm level. This is not entirely unreasonable and the relatively large data set used in the analysis alleviates problems that this might cause. The possible practical consequences of this assumption are studied in the Appendix.

Table 2 lists the variables along with weighted descriptive statistics. One tenth of employment in Finnish business uses a non-connected desktop and a little over one per cent a non-connected laptop at work. Roughly one third uses a LAN-connected desktop and one tenth a LAN-connected laptop at work. WLAN usage is quite rare. An extensive set of control variables in employed in order to avoid discovering spurious relationships. Earlier work by Maliranta and Rouvinen (2004) has shown that controlling for individuals' educational backgrounds is particularly important. Besides the variables in Table 2, also a constant term as well as 40 NACE rev. 1 two-digit industry and 20 NUTS level-three regional dummies are included.

Table 2. Variable definitions and descriptive statistics.

Variable	Description	Type[1]	Source[2]	Mean	St. dev.	Min.	Max.
CD: ln(value added/labor)	Log of real value added per labor input	R	FSS	10.846	0.468	8.259	13.677
ICT: Desktop	Sh. of workers w. non-connected desktop	F	ICT	0.106	0.236	0	1
ICT: Laptop	Sh. of workers w. non-connected laptop	F	ICT	0.014	0.054	0	1
ICT: Desktop+LAN	Workers w. LAN-connected desktop	F	ICT	0.356	0.344	0	1
ICT: Laptop+LAN	Workers w. LAN-connected laptop	F	ICT	0.090	0.156	0	1
ICT: Desktop+WLAN	Workers w. WLAN-connected desktop	F	ICT	0.068	0.200	0	1
ICT: Laptop+WLAN	Workers w. WLAN-connected laptop	F	ICT	0.017	0.075	0	0.850
CD: ln(capital/labor)	Real physical capital stock per labor input	R	FSS	10.636	1.389	3.026	18.039
CD: ln(labor)	Real labor input	L	FSS	5.619	1.281	0.742	7.560
Firm: young	Firm's establishments' avg. age 5 yrs or less	D	BR	0.064	0.244	0	1
Firm: old	Firm's establishments' avg. age 15 yrs or more	D	BR	0.259	0.438	0	1
Firm: multi-est.	Multi-establishment firm	D	BR	0.708	0.455	0	1
Edu: lo tech	Workers w. lower (bachelor eq.) technical ed.	F	ES	0.274	0.181	0	1
Edu: mi tech	Workers w. middle (master eq.) technical ed.	F	ES	0.115	0.124	0	1
Edu: hi tech	Workers w. higher (doctor eq.) technical ed.	F	ES	0.037	0.066	0	0.800
Edu: lo non-tech	Workers w. lower (bachelor eq.) non-tech ed.	F	ES	0.181	0.145	0	1
Edu: mi non-tech	Workers w. middle (master eq.) non-tech ed.	F	ES	0.141	0.140	0	1
Edu: hi non-tech	Workers w. higher (doctor eq.) non-tech ed.	F	ES	0.029	0.062	0	0.850
Labor: young	Workers that are under 35 years old	F	ES	0.320	0.166	0	1
Labor: old	Workers that are over 45 years old	F	ES	0.392	0.165	0	1
Labor: female	Female workers	F	ES	0.346	0.239	0	1

Note: Although not listed above, all estimations also include a constant term as well as NACE rev. 1 two-digit industry and NUTS level-three regional dummies.
[1] Variable types: D = dummy (1 if true, 0 otherwise), F = fraction (share of all workers at the firm), L = natural logarithm, and R = natural logarithm of a ratio.
[2] Sources: BR = Business Register, ES = Employment Statistics, FSS = Financial Statements Statistics, and ICT = ICT survey.

ESTIMATION

Since labor weights are employed, the dominating effect of very large firms on the results is an issue of concern. Thus, 23 firms with over two thousand employees are eliminated. Outliers are eliminated by using the standardized or Pearson residuals: a preliminary regression is performed and 23 observations with the standardized residuals over four standard deviations away from the mean are dropped, which with normally distributed errors is roughly equivalent of eliminating 3 out of 100,000 observations. White (1980) heteroskedasticity consistent standard deviations are reported. Consequences of these choices are discussed in the Appendix.

Three sets of regression results are reported in Table 3: unconstrainted ordinary least squares (OLS) in Column (1), OLS with the constraint that LAN should have a symmetric effect in Column (2) (i.e., the following constraint is imposed on the ICT bundle coefficients:

$c-a=d-b$; also implies a constraint on portability), and OLS with the constraints that both LAN and WLAN should have symmetric effects in Column (3) (i.e., $e-c=f-d$ also imposed). As can be seen, imposing constraints leads to gains in efficiency but qualitatively the results remain the same. The null hypothesis that constraints are valid cannot be rejected.

Table 3. Estimation results of the labor productivity equation (the ICT bundle coefficients not adjusted for the output elasticity of labor).

ln(value added/labor) regressed on…	(1) Unconstrainted	(2) LAN constr.	(3) W/LAN constr.
ICT: Desktop	0.069	0.078 *	0.081 **
	(0.057)	(0.040)	(0.040)
ICT: Laptop	0.462 ***	0.394 ***	0.369 ***
	(0.145)	(0.067)	(0.065)
ICT: Desktop+LAN	0.207 ***	0.204 ***	0.209 ***
	(0.054)	(0.034)	(0.034)
ICT: Laptop+LAN	0.512 ***	0.520 ***	0.498 ***
	(0.110)	(0.060)	(0.059)
ICT: Desktop+WLAN	0.181 **	0.180 ***	0.134 ***
	(0.092)	(0.053)	(0.043)
ICT: Laptop+WLAN	0.269	0.270 **	0.423 ***
	(0.256)	(0.121)	(0.065)
CD: ln(capital/labor)	0.108 ***	0.108 ***	0.109 ***
	(0.015)	(0.007)	(0.007)
CD: ln(labor)	-0.002	-0.002	-0.002
	(0.012)	(0.008)	(0.008)
Firm: young	-0.036	-0.035	-0.035
	(0.060)	(0.032)	(0.032)
Firm: old	-0.002	-0.002	-0.003
	(0.029)	(0.019)	(0.019)
Firm: multi-est.	-0.097 ***	-0.097 ***	-0.096 ***
	(0.032)	(0.020)	(0.020)
Edu: lo tech	0.132	0.133	0.131
	(0.122)	(0.103)	(0.103)
Edu: mi tech	0.247 *	0.249 **	0.247 **
	(0.143)	(0.099)	(0.099)
Edu: hi tech	0.587 **	0.584 ***	0.546 ***
	(0.251)	(0.157)	(0.155)
Edu: lo non-tech	-0.012	-0.013	-0.021
	(0.142)	(0.116)	(0.116)
Edu: mi non-tech	0.334 **	0.334 ***	0.329 ***
	(0.142)	(0.098)	(0.098)
Edu: hi non-tech	1.118 ***	1.113 ***	1.120 ***
	(0.224)	(0.155)	(0.155)
Labor: young	-0.386 **	-0.386 ***	-0.384 ***
	(0.159)	(0.084)	(0.084)
Labor: old	-0.171 +	-0.170 *	-0.170 *
	(0.117)	(0.087)	(0.087)
Labor: female	-0.276 ***	-0.276 ***	-0.276 ***
	(0.079)	(0.054)	(0.054)
Adjusted R-squared	0.49	–	–
H0: Constraint(s) are	–	0.087	0.218
valid (t-test)	–	(0.172)	(0.309)

Note: Also including (not reported due to space limitations) a constant term as well as NACE rev. 1 two-digit industry and NUTS level-three regional dummies. Weighted OLS with White (1980) heteroskedasticity consistent standard errors in the parentheses. A subsample of 2,358 year 2001 observations with very large firms and outliers eliminated as discussed in the text. ***, **, *, and + respectively indicate significance at 1, 5, 10, and 15 per cent level.

The results in Table 3 do not take into account the output elasticity of labor, i.e., $\beta_L \boldsymbol{\theta}_{ICT}$ rather than $\boldsymbol{\theta}_{ICT}$ is reported. In the upper section of Table 4 the ICT bundle coefficients have been adjusted for the output elasticity of labor by dividing through with β_L to get $\boldsymbol{\theta}_{ICT}$.

Table 4. The ICT bundle coefficients (adjusted for the output elasticity of labor) and the estimated effects of the ICT characteristics.

Labor productivity effects of the ICT bundles

	(1) Unconstrainted	(2) LAN constr.	(3) W/LAN constr.
(a) ICT: Desktop	8%	9% *	9% **
(b) ICT: Laptop	52% ***	44% ***	42% ***
(c) ICT: Desktop+LAN	23% ***	23% ***	24% ***
(d) ICT: Laptop+LAN	58% ***	58% ***	56% ***
(e) ICT: Desktop+WLAN	20% **	20% ***	15% ***
(f) ICT: Laptop+WLAN	30%	30%	48% ***

Labor productivity effects of the ICT characteristics (also see Table 1)

		(1) Unconstrainted	(2) LAN constr.	(3) W/LAN constr.
Processor, storage	$a-0$	8%	9% *	9% **
Portability	$b-a$	44% **	35% ***	32% ***
	$d-c$	34% ***		
	$f-e$	10%		
Wireline connectivity	$c-a$	15% ***	14% ***	14% ***
	$d-b$	6%		
Wireless connectivity	$e-c$	-27%	-28% **	-8% **
	$f-d$	-3%	-3%	

Note: Calculations with the delta method. ***, **, and *, respectively indicate significance at 1, 5, and 10 per cent level.

The lower section of Table 4 reports the effects for the ICT characteristics. The results with respect to wireless connectivity are somewhat unstable, although it is perhaps not surprising that trying to infer its productivity effect by comparing two otherwise similar desktops does not generate intuitive results, as with an inherently immobile computer the benefits of wireless over wireline connectivity are perhaps primarily limited to arguably faster network deployment as well as to increased flexibility in office floor plan design and its alternations. As also the test statistics indicate that the constraints imposed are valid (see above), the rightmost Columns (3) in Tables 2, 3, and 4 are the preferred set of results.

The above results suggest that processing and storage capabilities themselves increase a workers productivity by 9%. Portability boosts productivity by nearly one third. Wireline connectivity boosts productivity 14% and wireless by 6%.[3]

DISCUSSION

The results derived in the above section are not directly comparable to the previous literature, as the output elasticity of ICT is the most commonly reported measure in these contexts. As ICT investment flows and capital stocks are unobserved in the data, alternative ways of deriving the results cannot be compared directly. In any case the above approach is arguably better, as they directly measure ICT usage as well as avoid the immense difficulties in constructing real ICT investment flows and capital stocks. The relationship of the above results to those found in previous literature can nevertheless be studied by considering a simplified version of the above model

$$Y = \left(L + \theta_{ICT} L_{ICT}\right)^{\beta_L} . \tag{5}$$

Taking a logarithm yields

$$\ln Y = \beta_L \ln\left(L + \theta_{ICT} L_{ICT}\right), \tag{6}$$

the derivate of which is

$$\frac{dY}{Y} = \beta_L \frac{\theta_{ICT} dL_{ICT}}{L + \theta_{ICT} L_{ICT}}, \tag{7}$$

which can be used to derive output elasticity

$$\chi_{ICT} = \frac{dY}{dL_{ICT}} \frac{L_{ICT}}{Y} = \beta_L \frac{\theta_{ICT}}{\left(L + \theta_{ICT} L_{ICT}\right)/L_{ICT}} = \beta_L \frac{\theta_{ICT}}{L/L_{ICT} + \theta_{ICT}} . \tag{8}$$

The descriptive statistics in Table 2 suggest that 65.2% of employment in Finnish business use at least the basic ICT characteristic – processing and storage capabilities – at work. The pre-

[3] Note that the comparison point of wireless is wireline connectivity, and thus the negative sign on wireless indicates that it boosts productivity less than wireline.

ferred estimate of $\beta_L \theta_{ICT}$ for a plain desktop is 8.1% in Table 3 and the corresponding estimate for θ_{ICT} is 9.1% in Table 4. Simply plugging these numbers into (8) yields an ICT output elasticity estimate of 5.0%. This is the mean ICT output elasticity estimate across internationally available comparable studies considered by Stiroh (2002). Obviously this only refers to the key characteristic – not to ICT usage at large – unlike most studies considered by Stiroh, although this is arguably what the estimates of these studies capture not least because the average sample year of 1988. In order to get an overall measure of the ICT output elasticity in the current context, the above model is re-estimated with a single measure of ICT usage derived as a sum of the six ICT bundles above. The respective estimates of $\beta_L \theta_{ICT}$ and θ_{ICT} become 21.7% and 24.2%. Plugging these in into (8) yields an overall ICT output elasticity estimate of 12.2%, which is still well within Stiroh's 90% confidence interval.

Assuming that firms are rational, they will continue to invest in ICT until associated marginal costs and returns are equal, at which point also the average costs and revenues should be similar. The year 1999 ICT survey by Statistics Finland includes information on ICT-related costs. Their estimated mean ratio to labor costs ranges from 11.2% to 14.2% according to Maliranta and Rouvinen (2003). If the ICT bundle coefficients in Column (3) of Table 3 are weighted by their means in Table 2, the estimated return on the overall ICT usage relative to labor input becomes 16.8%; if one were to take into account that especially portability but also connectivity were less common in 1999, the estimated return would be towards the middle of the above range. While the two data sets refer to different points in time and are not entirely comparable, also this comparison suggests that the derived results are quite reasonable.

As above results show, portability – in essence the fact that one can carry processing power and storage capacity and possibly other characteristics around – has a considerable effect on productivity. While employed measure of portability is rather specific, it undoubtedly proxies for the overall organizational agility, which is unobserved. Due to portability many tasks are not tied to hours spent physically at the office, which may possibly lead to an increasing amount of unmeasured and unpaid work. On the other hand, it may well have the opposite effect, as – in the absence of "punching in timecards" – remote work is harder to monitor. In brainwork the distinction between work and leisure has always been blurry and doing at least some unmeasured and unpaid work during after hours is often unavoidable regardless of available technology – a laptop can nevertheless raise the productivity of those same hours by an order of magnitude. Great ideas often comes in unexpected bursts and they are easily lost unless a suitable recording technology – anything from a paper napkin to a laptop computer – is available. A mobile worker can more easily make his/her efforts to coincide with these erratic eruptions of ingenuity.

As compared to portability, returns on wireless connectivity seem less stellar, although nevertheless positive in the preferred specification. It should be kept in mind, however, that, as of year 2001, wireless connectivity was in its infancy; the immediate effect of introducing a new technology is almost surely negative, as resources are tied to purchasing, installing, and learning the technology – not to mention co-invention, e.g., in the form of organizational changes – and some current production is forgone. It should also be noted that less than ten per cent of employment uses wireless connectivity at all and less than two per cent use it bundled with portability. The modest usage suggests that the technology was still at an experiment stage as of 2001.[4] Furthermore, as noted in the introduction, important and more prevalent forms of wireless connectivity are not captured by the measures employed.

As discussed by e.g. Wooldridge (2002), results derived as above are consistent in large samples with a relatively weak set of assumptions. It is nevertheless true that simultaneity might bias the results, although causality running from productivity to ICT investment seems to suggest that the firms were not profit maximizers. In lack of panel data and external instruments the issue of simultaneity cannot be studied further here. As ably pointed out by DiNardo and Pischke (1997), selectivity might also bias the results in these contexts: more skilled and productive workers might also be the ones using ICT at work. Above this problem is hammered down

[4] There are obvious problems in measuring the productivity gains associated with a given piece of technology at an early stage. Likewise there are problems in measuring the productivity gains associated with a technology that is nearly completely diffused.

by including detailed controls on various aspects of labor quality. Sample selectivity should not be an issue of concern, although the data does not include self-employed or one-person firms. Especially these "one-person-shows" might gain enormously from portability and wireless connectivity. Upon deriving the above results several choices had to be made on the empirical setup, the consequences of which are studied in the Appendix. Considering the complexity of the issues at hand and the early development stage of especially wireless connectivity, the findings seem quite robust.

CONCLUSION

Informational mobility is truly transforming white-collar work, which has is essence remained the same since the dawn of the industrial revolution. While it is likely that the still relatively little used ICT characteristics – portability and wireless connectivity – have been employed in uses where their net returns are the highest, it is also clear that the current ways of organizing white-collar work do not exploit these characteristics to the fullest.

As virtually all firms are already using computers and the Internet for some of their business processes, simply exposing more firms to ICT cannot be a source of productivity growth in developed economies. Portability and wireless connectivity remain relatively rare at work, yet the above findings suggest they have potentially large productivity effects in the shorter run and undoubtedly more so in the longer run, once work practices have fully adjusted to their presence.

This paper has studied the general magnitude of productivity effects of various ICT characteristics. Data permitting, it would also be interesting to study how firms differ in their abilities to benefit from various ICT characteristics. Previous work by Maliranta and Rouvinen (2004) has shown, that younger firms seem to be better able to make most of their ICT investments. Preliminary experiments with this data suggest, that especially multi-establishment firms benefit from portability.

REFERENCES

Altimier, L., Besuner, P., Hasselfeld, K. and Johannemann, T. (2002), Go wireless to Spark Productivity, *Nursing Management 33*, 43–44.

Chwelos, P. (2003), Approaches to Performance Measurement in Hedonic Analysis: Price Indexes for Laptop Computers in the 1990's, *Economics of Innovation and New Technology 12*, 199–224.

Dearden, L., Reed, H. and Van Reenen, J. (2000), Who Gains When Workers Train? Training and Corporate Productivity in a Panel of British Industries, *IFS Working Paper 00/04*.

DiNardo, J. and Pischke, J.-S. (1997), The Returns to Computer Use Revisited: Have Pencils Changed the Wage Structure Too?, *Quarterly Journal of Economics 112*, 291–303.

Gartenberg, M. (5 Dec. 2003), Wi-Fi: Why and Why Not, *Computerworld 31*, 21.

Green, H. (24 Nov. 2003), TaylorMade, *Business Week 3859*, 94–99.

Greenan, N. and Mairesse J. (2000), Computers and Productivity in France: Some Evidence, *Economics of Innovation and New Technology 9*, 275–315.

Ilmakunnas, P. and Maliranta M. (2003), Technology, Labor Characteristics and Wage-Productivity Gaps. *ETLA Discussion Paper 860*.

Lancaster, K. (1991), *Modern Consumer Theory*, Edward Elgar, Aldershot.

Maliranta, M. and Rouvinen P. (2003), Tieto- ja viestintäteknologian tuottavuusvaikutukset Suomen liike-elämässä. *Kansantaloudellinen aikakauskirja 99*, 164–180.

Maliranta, M. and Rouvinen P. (2004), ICT and Business Productivity: Finnish Micro-Level Evidence, in OECD (ed.), *ICT and Economic Growth*, Organisation for Economic Co-Operation and Development, Paris.

Nasaw, D. (23 Oct. 2003), Wi-Fi Is Becoming Popular at the Office, *Wall Street Journal*, B.4.

Olariu, S. (2003), An Issue Dedicated to Wireless Networks and Mobile Computing, *International Journal of Foundations of Computer Science 14*, 167–168.

Rao, B. and Parikh, M. (2003), Wireless Broadband Drivers and Their Social Implications, *Technology in Society 25*, 477–489.

Stiroh, K. (2002). *Reassessing the Impact of IT in the Production Function: A Meta-Analysis*, Federal Reserve Bank of New York.

White, H. (1980), A Heteroscedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroscedasticity, *Econometrica 48*, 817–838.

Wooldridge, J. (2002), *Econometric Analysis of Cross Section and Panel Data*, MIT Press, Cambridge, MA.

Zurita, G. and Nussbaum M. (2004), Computer Supported Collaborative Learning Using Wirelessly Interconnected Handheld Computers, *Computers & Education 42*, 289–314.

APPENDIX

Various specifications of the derived model are estimated in Table 5. Column (1) is derived using an unweighted and homoskedastic OLS estimator with data including both very large firms

Table 5. Estimation results of the labor productivity equation with alternative specifications.

ln(value added/labor) regressed with the following options on…	(1) Simplest	(2) Reference	(3) Unweighted	(4) Homosked.	(5) W. large	(6) W. outliers
Labor weights:	–	Yes	–	Yes	Yes	Yes
Heteroskedasticity consistent:	–	Yes	Yes	–	Yes	Yes
Large firms dropped:	–	Yes	Yes	Yes	–	Yes
Outliers dropped:	–	Yes	Yes	Yes	Yes	–
ICT: Desktop	0.134 ***	0.069	0.136 ***	0.069 +	0.039	0.061
	(0.043)	(0.057)	(0.036)	(0.044)	(0.058)	(0.060)
ICT: Laptop	0.471 ***	0.462 ***	0.388 ***	0.462 ***	0.364 **	0.512 ***
	(0.121)	(0.145)	(0.103)	(0.152)	(0.160)	(0.183)
ICT: Desktop+LAN	0.193 ***	0.207 ***	0.172 ***	0.207 ***	0.167 ***	0.210 ***
	(0.045)	(0.054)	(0.039)	(0.035)	(0.053)	(0.062)
ICT: Laptop+LAN	0.493 ***	0.512 ***	0.544 ***	0.512 ***	0.405 ***	0.300 +
	(0.088)	(0.110)	(0.103)	(0.062)	(0.128)	(0.194)
ICT: Desktop+WLAN	0.106 +	0.181 **	0.136 **	0.181 ***	0.077	0.119
	(0.069)	(0.092)	(0.061)	(0.053)	(0.089)	(0.097)
ICT: Laptop+WLAN	0.308 *	0.269	0.447 ***	0.269 **	0.199	0.206
	(0.158)	(0.256)	(0.170)	(0.121)	(0.264)	(0.265)
CD: ln(capital/labor)	0.091 ***	0.108 ***	0.085 ***	0.108 ***	0.117 ***	0.118 ***
	(0.007)	(0.015)	(0.009)	(0.007)	(0.016)	(0.016)
CD: ln(labor)	0.008	-0.002	0.014 *	-0.002	0.012	-0.006
	(0.009)	(0.012)	(0.008)	(0.008)	(0.012)	(0.014)
Firm: young	-0.104 ***	-0.036	-0.097 ***	-0.036	-0.019	-0.107
	(0.032)	(0.060)	(0.032)	(0.032)	(0.072)	(0.089)
Firm: old	0.011	-0.002	-0.005	-0.002	-0.010	0.030
	(0.024)	(0.029)	(0.019)	(0.019)	(0.033)	(0.034)
Firm: multi-est.	-0.064 **	-0.097 ***	-0.078 ***	-0.097 ***	-0.082 **	-0.048
	(0.026)	(0.032)	(0.021)	(0.020)	(0.034)	(0.046)
Edu: lo tech	0.083	0.132	0.071	0.132	0.253 *	0.343 *
	(0.086)	(0.122)	(0.070)	(0.103)	(0.143)	(0.190)
Edu: mi tech	0.442 ***	0.247 *	0.392 ***	0.247 **	0.385 **	0.413 **
	(0.096)	(0.143)	(0.085)	(0.099)	(0.159)	(0.201)
Edu: hi tech	0.290 **	0.587 **	0.290 *	0.587 ***	0.825 ***	0.632 *
	(0.145)	(0.251)	(0.154)	(0.157)	(0.281)	(0.336)
Edu: lo non-tech	0.047	-0.012	0.052	-0.012	0.082	-0.052
	(0.091)	(0.142)	(0.075)	(0.116)	(0.164)	(0.171)
Edu: mi non-tech	0.337 ***	0.334 **	0.329 ***	0.334 ***	0.416 ***	0.408 **
	(0.086)	(0.142)	(0.078)	(0.098)	(0.159)	(0.167)
Edu: hi non-tech	1.022 ***	1.118 ***	1.044 ***	1.118 ***	1.213 ***	1.215 ***
	(0.133)	(0.224)	(0.149)	(0.156)	(0.231)	(0.282)
Labor: young	-0.179 ***	-0.386 **	-0.166 ***	-0.386 ***	-0.302 **	-0.446 ***
	(0.067)	(0.159)	(0.063)	(0.084)	(0.153)	(0.172)
Labor: old	0.025	-0.171 +	0.034	-0.171 **	-0.144	-0.038
	(0.070)	(0.117)	(0.063)	(0.087)	(0.131)	(0.146)
Labor: female	-0.213 ***	-0.276 ***	-0.223 ***	-0.276 ***	-0.283 ***	-0.177 *
	(0.054)	(0.079)	(0.044)	(0.054)	(0.081)	(0.102)
Observations	2,404	2,358	2,358	2,358	2,381	2,381
Adjusted R-squared	0.31	0.49	0.40	0.49	0.63	0.38
H0: Homoskedastic [1]	–	–	280.038 ***	–	–	–
(degr. of freedom)	–	–	(2)	–	–	–

Note: Also including (not reported above in the interest of space) a constant term as well as NACE rev. 1 two-digit industry and NUTS level-three regional dummies. Estimated with OLS; standard errors in the parentheses. ***, **, *, and + respectively indicate significance at 1, 5, 10, and 15 per cent level.

[1] A χ^2 distributed Lagrange multiplier test for heteroskedasticity as proposed by White (1980) but – due to large number of regressors – calculated using predicted values from the regression as discussed in Wooldridge (2002, p. 127).

and outliers (the "simplest" specification). Column (2) is a reproduction of Column (1) in Table 3, i.e., weighted heteroskedasticity consistent results with large firms and outliers eliminated (the "reference" specification). In Columns (3)–(6) each of the four options is relaxed one at the time. As can be seen, qualitatively results remain the same regardless of the specification.

As mentioned above, only the workers using desktops and laptops are available as fractions; LAN and WLAN are only observed as firm-level dummies. In the text it is assumed that once a network is introduced at the firm, every computer is connected. The consequences of this assumption are studied in Table 6 with information from earlier ICT surveys recording LAN usage as a fraction. The number of observations drops severely due to the lacking overlap of the samples. Column (1) in Table 6 is a re-estimation of Column (1) in Table 3 with the subsample for which the lagged LAN fraction is available. In Column (2) the lagged LAN fraction is used to recode the LAN bundles (information on WLAN ignored). In Column (3) the lagged LAN fraction is used but the WLAN bundles are derived as done in the text (WLAN is not observed as a fraction in any of the available ICT surveys). The results do not seem to be particularly sensitive to the choices made upon coding the ICT bundles.

Table 6. Estimation results of labor productivity equation with alternative ICT bundle specifications.

ln(value added/labor) regressed on…	(1) Reference	(2) Lag LAN	(3) Lag LAN, WLAN dmy
ICT: Desktop	0.041	0.052	0.068
	(0.100)	(0.152)	(0.151)
ICT: Laptop	0.404 +	-0.001	-0.080
	(0.247)	(0.343)	(0.318)
ICT: Desktop+LAN	0.245 ***	0.226 ***	0.239 ***
	(0.078)	(0.075)	(0.077)
ICT: Laptop+LAN	0.479 ***	0.504 ***	0.571 ***
	(0.155)	(0.180)	(0.169)
ICT: Desktop+WLAN	0.179		0.190
	(0.125)		(0.164)
ICT: Laptop+WLAN	0.134		0.147
	(0.318)		(0.361)
Also: CD: ln(capital/labor), CD: ln(labor), Firm: young, Firm: old, Firm: multi-est., Edu: lo tech, Edu: mi tech, Edu: hi tech, Edu: lo non-tech, Edu: mi non-tech, Edu: hi non-tech, Labor: young, Labor: old, Labor: female, a constant, as well as Ind. and reg. dummies.			
Observations	755	755	755
Adjusted R-squared	0.49	0.49	0.49

Note: Weighted OLS with White (1980) heteroskedasticity consistent standard errors in the parentheses. Non-ICT coefficients not reported due to space limitations. ***, **, *, and + respectively indicate significance at 1, 5, 10, and 15 per cent level.

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