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INFORMATIONAL MOBILITY AND PRODUCTIVITY: FINNISH EVIDENCE

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The labor productivity effects of portability and 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%. The findings are in line with previous literature and comparisons to ICT costs suggest that firms equate marginal costs and returns. Although increasing ICT penetration can no longer be a major source of productivity growth in developed economies, the relatively new characteristics studied can.

Keywords: Productivity; Information and communication technology; Local area network; Mobility; Portability; Wireless

JEL codes: D24, J24, L23, O33

1 INTRODUCTION

Information and communication technology (ICT) devices have become increasingly portable and interconnectable at least since mid-1990s, which in many circumstances have enabled the creation of and access to digitally coded information independent of time and place. Does this increasing 'informational mobility' affect labor productivity? In order to answer the question, this paper operationalizes the concept of informational mobility and quantifies its effects in Finnish business.

In what follows, portability refers to the use of laptop personal computers or similar portable data processing and storage devices (due to data limitations, however, personal digital assistants 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 telephone network or a wireless local area network, WLAN) access to remotely stored data. We are unaware of the previous attempts to quantify the productivity effects of these ICT characteristics via an econometric analysis.

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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 that portability and wireless connectivity offer significant cost savings and boost productivity. Anecdotal support can be found in the business press (see, e.g., Green, 2003; Nasaw, 2003). For example, Altimier *et al.* (2002) have documented the benefits of portability and wireless connectivity in health care and Zurita and Nussbaum (2004) in education. Although studies in other sectors or across sectors are almost non-existent, portability and wireless connectivity might boost productivity in virtually any activity where immediate information storage, processing, retrieval, and exchange are beneficial, which is the case in many management, sales, and logistics activities.

2 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, 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 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, that is, the 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

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

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

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

where θ_{ICT} is a parameter vector capturing the possible additional productivity effects associated with the ICT bundles. Slight manipulation yields a labor productivity

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

specification

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

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

$$\ln\left(\frac{Y_i}{L_i}\right) \approx \ln\, A_i + \beta_K \ln\left(\frac{K_i}{L_i}\right) + \beta_L \theta_{\mathrm{ICT}}\left(\frac{\boldsymbol{L}_{\mathrm{ICT},i}}{L_i}\right) + (\beta_K + \beta_L - 1)\ln\, L_i + \beta_Z\, \ln\, \boldsymbol{Z}_i + \varepsilon_i, \tag{4}$$

which is estimable once the variables and a stochastic error structure have been specified.[2] Below disturbances are assumed to be uncorrelated across observations but arbitrary differences in their variances (heteroscedasticity) are allowed.

3 DATA

After eliminating a few unusable observations, the sample for 2001 consists of 2358 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.

Table I 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 I 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 I: portability can be isolated via three different comparisons; both wireline and wireless connectivity via two.

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 is only observed as firm-level dummies. Thus, the bundles are derived under the assumption that implementing a LAN or a WLAN solely involves 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 Appendix A.

Table II lists the variables along with weighted descriptive statistics. As of year 2001, one-tenth of those employed in Finnish business use a non-connected desktop and a little over 1% 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 is employed to avoid discovering spurious relationships. Maliranta and Rouvinen (2004) have shown that controlling for individuals' educational backgrounds is particularly important. Besides the variables in Table II, a constant term as well as 40 industry and 20 regional dummies are also included.

[2] Greenan and Mairesse (2000) consider a similar model in ICT and, for example, Dearden *et al.* (2000) as well as Ilmakunnas and Maliranta (2005) in other contexts.

TABLE I The ICT bundles, their characteristics, and ways of distinguishing them.

		ICT characteristics			
	ICT bundle	*Processing and storage capability*	*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 bundles defined in the leftmost column above		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 constrained to be equal.

4 ESTIMATION

As labor weights are employed, the dominating effect of very large firms on the results is an issue of concern. Thus, 23 firms with over 2000 employees are eliminated. Outliers are eliminated 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 would be roughly equivalent to eliminating three out of 100,000 observations. White (1980) heteroscedasticity consistent standard deviations are reported. Possible consequences of these choices are discussed in Appendix A.

Three sets of regression results are reported in Table III: unconstrained ordinary least squares (OLS) in Column (1), OLS with the constraint that LAN should have a symmetric effect in Column (2) (i.e., $c - a = d - b$)[3], 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 the constraints are valid cannot be rejected.

The results in Table III do not take into account the output elasticity of labor, that is, $\beta_L \theta_{\mathrm{ICT}}$ rather than θ_{ICT} is reported. In the upper section of Table IV, the ICT bundle coefficients have been adjusted for the output elasticity of labor by dividing $\beta_L \theta_{\mathrm{ICT}}$ through with β_L to get θ_{ICT}.[4] The lower section of Table IV 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

[3] Also implies a constraint on portability.

[4] As one does not get direct estimates of β_L upon performing the regressions in Table III, they have to be calculated indirectly. As the estimates of $(\beta_K + \beta_L - 1)$ (CD: ln(labor) in Tab. III) and β_K (CD: ln(capital/labor) in Tab. III) are available, straight forwardly $\beta_L = (\beta_K + \beta_L - 1) - \beta_K + 1$. Although this is linear, the actual calculations of interest are not. We employ the delta method (see, e.g., Greene, 2000, pp. 298, 357, 437) to perform the non-linear calculations (Stata's `nlcom` command) reported in Table IV. The significance levels refer to Wald-tests (H0: transformed coefficient = 0).

TABLE II Variable definitions and descriptive statistics.

Variable	*Description*	*Type*[1]	*Source*[2]	*Mean*	*Standard deviation*	*Minimum*	*Maximum*
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 years or less	D	BR	0.064	0.244	0	1
Firm: old	Firm's establishments' avg. age 15 years 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 under 35 years old	F	ES	0.320	0.166	0	1
Labor: old	Workers 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: All estimations also include a constant term as well as 40 two-digit industry dummies (NACE rev. 1) and 20 regional (NUTS level-three) 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.

TABLE III 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 constrainted*	*(3) W/LAN constrainted*
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 a constant term as well as industry and regional dummies. Weighted OLS with White (1980) heteroscedasticity consistent standard errors in the parentheses. A subsample of 2358 year 2001 observations with very large firms and outliers eliminated as discussed in the text.
***indicates significance at 1% level.
**indicates significance at 5% level.
*indicates significance at 10% level.
†indicates significance at 15% level.

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 the test statistics also indicate that the constraints imposed are valid (as mentioned earlier), the rightmost Columns (3) in Tables III–IV are the preferred set of results.

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

		(1) Unconstrained (%)	*(2) LAN constrainted (%)*	*(3) W/LAN constrainted (%)*
Labor productivity effects of the ICT bundles (θ)				
(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 I)				
Processor, storage	a–0	8	9*	9**
	b–a	44**		
Portability	d–c	34***	35***	32***
	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: Calculated with the delta method.
The reported significance levels refer to Wald-tests (H0: transformed coefficient = 0):
***indicates significance at 1% level.
**indicates significance at 5% level.
*indicates significance at 10% level.
†indicates significance at 15% level.

These results suggest that processing and storage capabilities themselves increase a worker's productivity by 9%. Portability boosts productivity by nearly 32%. Wireline connectivity boosts productivity 14% and wireless by 6%.[5]

5 DISCUSSION

The results derived in Section 4 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 approach implemented here is arguably better, as it directly measures the ICT usage as well as avoids the immense difficulties in constructing real ICT investment flows and capital stocks. The relationship of the earlier mentioned results to those found in the previous literature can nevertheless be studied by considering a simplified version of the aforementioned model:

$$Y = (L + \theta_{\mathrm{ICT}} \boldsymbol{L}_{\mathrm{ICT}})^{\beta_L}. \tag{5}$$

Taking a logarithm yields

$$\ln\, Y = \beta_L\, \ln(L + \theta_{\mathrm{ICT}} \boldsymbol{L}_{\mathrm{ICT}}), \tag{6}$$

the derivate of which is

$$\frac{\mathrm{d}Y}{Y} = \beta_L \frac{\theta_{\mathrm{ICT}}\, \mathrm{d}\boldsymbol{L}_{\mathrm{ICT}}}{L + \theta_{\mathrm{ICT}} \boldsymbol{L}_{\mathrm{ICT}}}, \tag{7}$$

[5] 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.

which can be used to derive output elasticity

$$\chi_{\mathrm{ICT}} = \frac{\mathrm{d}Y}{\mathrm{d}\boldsymbol{L}_{\mathrm{ICT}}}\frac{\boldsymbol{L}_{\mathrm{ICT}}}{Y} = \beta_L \frac{\theta_{\mathrm{ICT}}}{(\boldsymbol{L} + \theta_{\mathrm{ICT}}\boldsymbol{L}_{\mathrm{ICT}})/\boldsymbol{L}_{\mathrm{ICT}}} = \beta_L \frac{\theta_{\mathrm{ICT}}}{L/\boldsymbol{L}_{\mathrm{ICT}} + \theta_{\mathrm{ICT}}}. \tag{8}$$

Table II suggests that 65.2% of those employed in Finnish business use processing and storage capabilities. The preferred estimate of $\beta_L\theta_{\mathrm{ICT}}$ for a plain desktop is 8.1% shown in Table III and the corresponding estimate for θ_{ICT} is 9.1% as in Table IV. Simply plugging these numbers into equation (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), although here the figure refers to the effect of processing and storage. Arguably, this is what the studies considered by Stiroh mostly capture, not least because the average sample year of 1988, at which point in time the characteristics studied here were quite rare. In order to get an overall measure of the ICT output elasticity in the current context, the aforementioned 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 $\beta_L\theta_{\mathrm{ICT}}$ and θ_{ICT} become 21.7% and 24.2%. Plugging these into equation (8) yields an overall ICT output elasticity estimate of 12.2%, which is 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 the average costs and revenues should also be similar. The 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 III are weighted by their means in Table II, the estimated return on the overall ICT usage relative to labor input becomes 16.8%. Although 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 the presented results here indicate, portability – in essence the fact that one can carry processing power and storage capacity around – has a considerable effect on productivity. Although the measure of portability employed is rather specific, it undoubtedly proxies for the overall organizational agility, which is unobserved. Owing 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' – the remote work may be harder to monitor. In 'brainwork', the distinction between work and leisure has always been blurry and doing at least some unmeasured and unpaid work after hours is often unavoidable regardless of the available technology – a laptop can nevertheless raise the productivity of those hours considerably.

Compared to portability, returns on wireless connectivity seem less stellar, although nevertheless positive. It should be kept in mind, however, that, as of 2001, wireless connectivity was in its infancy; the immediate net effect of introducing a new technology is almost surely negative, as resources are tied up in purchasing, installing, and learning the technology – not to mention co-invention, for example, in the form of organizational changes – and some current production is forgone. It should also be noted that less than 10% of employees uses wireless connectivity at all and less than 2% use it bundled with portability. The modest usage suggests that the technology was still at an experiment stage as of 2001.[6]

As discussed by, for example, Wooldridge (2002), results derived are consistent in large samples with a relatively weak set of assumptions. As pointed out by DiNardo and Pischke (1997), however, selectivity might bias the results in these contexts: more skilled and productive

[6] 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 almost nearly completely diffused.

workers might also be the ones using ICT at work. This problem is hammered down by including detailed controls on various aspects of labor quality.

Upon deriving the presented results, several choices had to be made regarding the empirical setup, the consequences of which are studied in Appendix A. Considering the complexity of the issues at hand and the early development stage of wireless connectivity in particular, the findings seem quite robust.

6 CONCLUSIONS

Informational mobility is truly transforming white-collar work, which has in 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 already use computers and the Internet for some of their business, 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 presented findings suggest they have potentially large effects: 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%.

This paper has studied the general magnitude of the productivity effects of various ICT characteristics. Data permitting, it would also be interesting to study how firms differ in their ability to benefit from various ICT characteristics. The effects may, for instance, differ across industries.[7] Maliranta and Rouvinen (2004) have shown that younger firms seem to be better able to make the most of their ICT investments. Preliminary experiments with this data suggest that multi-establishment firms in particular benefit from portability.

It is plausible to suggest that the earlier findings may possibly be driven by unobserved firm effects.[8] As fixed effects models are infeasible with cross-sectional data, it cannot be formally shown that this is not the case. The performed regressions do, however, include quite extensive sets of firm-level control variables (as well as full sets of industry and regional dummies), so this is unlikely.

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[7] This was kindly pointed out by an anonymous referee. All the regressions reported in this paper control for industry effects.

[8] This was kindly pointed out by an anonymous referee.

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APPENDIX A

Various specifications of the derived model are estimated in Table AI. Column (1) is derived using an unweighted and homoscedastic OLS with data including both very large firms and outliers. Column (2) is a reproduction of Column (1) in Table III. In Columns (3)–(6), each of the four options is relaxed one at the time. As can be seen, qualitatively, the results remain the same regardless of the specification.

Only the workers using desktops and laptops are available as fractions; LAN and WLAN are 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 AII with information from earlier ICT surveys recording LAN usage as a fraction. The number of observations drops severely due to the smallish overlap of the samples. Column (1) in Table AII is a re-estimation of Column (1) in Table III 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.[9] The results do not seem to be particularly sensitive to the choices made upon coding the ICT bundles.

[9] WLAN is not observed as a fraction in any of the available ICT surveys.

TABLE AI 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) Homoscedastic*	*(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: Homoscedastic[1]	–	–	280.038***	–	–	–
(degree of freedom)	–	–	(2)	–	–	–

Note: Also including (not reported above in the interest of space) a constant term as well as industry and regional dummies. Estimated with OLS; standard errors in the parentheses.

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

***indicates significance at 1% level.

**indicates significance at 5% level.

*indicates significance at 10% level.

†indicates significance at 15% level.

TABLE AII Estimation results of labor productivity equation with alternative specifications of the ICT bundles.

	ICT bundles		
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)
Observations	755	755	755
Adjusted R-squared	0.49	0.49	0.49

Note: Weighted OLS with White (1980) heteroscedasticity consistent standard errors in the parentheses. Non-ICT coefficients not reported due to space limitations; thus, the regressions also include 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 term as well as industry and regional dummies.

***indicates significance at 1% level.

**indicates significance at 5% level.

*indicates significance at 10% level.

†indicates significance at 15% level.