Productivity, Technological Innovations, and Broadband Connectivity: Firm-level Evidence for Ten European Countries

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Abstract

This study investigates the link between productivity and innovations (technological as well as non-technological), taking into account the information and communication technology (ICT) intensity of firms, measured as the proportion of broadband internet connected employees. The analysis is based on official firm-level data on innovation activities and ICT usage in firms for the years 2002-2010, linked to the business registers and the production statistics in ten European countries. The datasets encompass 117,000 firm-year observations. Estimation results reveal that firm productivity is significantly related to product innovations, but to a lesser extent than broadband connected employees. The strength of the association varies across countries and between manufacturing and service firms. As a contrast, process, marketing and organisational innovations are not significantly related to productivity in the majority of countries. Overall, broadband usage appears to be a better predictor of productivity than product innovations.

Keywords: Firm-level data, broadband usage, technological innovations, productivity, firm behaviour.

JEL codes: C81, D22, O33

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1. Introduction

Technological innovations, such as information and communication technology (ICT), have long since been identified as important drivers of productivity in firms. Studies (mainly of manufacturers) based on data from the European Community Innovation Survey (CIS) show significant correlations between firm productivity and technological innovations, while the association with process innovations is more ambiguous (Crépon, Duguet & Mairesse, 1998; Griffith et al., 2006, Mansury & Love, 2008; see Hall, 2011 and Mohnen & Hall, 2013 for recent surveys).

Another strand of the literature demonstrates the significant link between investments in ICT (measured as ICT capital or ICT usage) and firm productivity (Greenan & Mairesse, 2000; Black & Lynch, 2001; Bresnahan, Brynjolfsson & Hitt, 2002; Brynjolfsson & Hitt, 2003; Arvanitis, 2005; Hempell, 2005; Badescu & Garcés-Ayerbe 2009; for a survey see Cardona, Kretschmer & Strobel, 2013). In contrast, Acemoglu et al. (2014) find poor productivity effects in US ICT intensive manufacturing industries for the period 1980-2009, by measuring ICT usage as the ratio of industry computer expenditures to total capital expenditures. Firm-level analyses of the association between productivity and specific ICT usages such as broadband internet (or e-commerce applications) are less common (for exceptions see Bertschek, Cerquera & Klein, 2013; Colombo, Croce & Grilli, 2013; Hagsten, 2016; Hagsten & Kotnik, 2017).

In this study the relationship between innovations (technological and non-technological) and productivity is investigated, taking into account the ICT intensity of firms, measured as broadband internet connected employees. The analysis is based on multi-linked and internationally comparable firm-level data for ten European countries for the period 2002-2010 and the innovation variables follow the definitions of the Oslo manual distinguishing between technological, organisational and marketing innovations (OECD/Eurostat, 2005).

Due to data specifics, Ordinary least squares are used to estimate the parameters of the augmented Cobb-Douglas production function.

Few studies have investigated the productivity effects of innovation activities jointly with ICT investments or usage (see for exceptions, Polder et al., 2010; Hall, Lotti, & Mairesse, 2013; Bartelsman, van Leeuwen & Polder, 2017). Recently, Bartelsman, van Leeuwen & Polder (2017) find that ICT human capital and product innovations are significant drivers of productivity using micro-aggregated panel data for 13 European countries (sub-industry or firm-size level). There is also evidence that ICT investments facilitate technological innovations (Hempell & Zwick, 2008). Similarly, Bertschek et al. (2013) demonstrate that internet broadband in firms is significantly positively related to innovation activities. Given the indication of a correlation between ICT usage and innovation activities, these factors are important to account for simultaneously.

Changes in the statistical laws have made it legally possible to link data across sources, but there are still many limitations. Previous studies have linked the Eurostat ICT usage in enterprise survey with production statistics (Hagsten, 2016), Dutch CIS with production data (Klomp & van Leeuwen, 2001), Estonian CIS data with the Business register (Masso & Vahter, 2012), Italian CIS with balance sheets information (e.g. Barbieri, Piva & Vivarelli, 2018), Swedish CIS with production and other firm-level data (Baum et. al., 2017) and United Kingdom CIS with the annual business inquiry (Criscuolo, Haskel & Martin, 2003).

Linked firm-level datasets offer several advantages and possible new research insights compared to single surveys (see Wagner, 2012 for Germany), because they include more information about firm characteristics and firm behaviour. However, analyses of datasets linked at the level of the firm may also be inconclusive, due to large heterogeneity even in narrowly defined industries (Bartelsman & Doms, 2000; Syversen, 2011). Another disadvantage of linked firm-level data often originates from measures to ease the response

burden of firms (Hagsten & Sabadash, 2017). This means that different surveys do not necessarily overlap and that there is a high degree of panel attrition over time (Raymond et al., 2015) restricting the choice of estimation methods that can be used.

The main contribution of this study is the simultaneous estimation of the relationship between productivity and four types of innovations and ICT intensity of firms, based on comparable data for manufacturing and service firms in a large group of European countries. Another strength of the study is the uniquely multi-linked datasets, covering several surveys as well as an uninterrupted period of time. Research based on linked firm-level data is not uncommon, although it is usually confined to a single country. The inclusion of more than two surveys is rare, as is the use of longer periods of time or more than one wave (three-year average) of innovation data.

The estimations reveal that, while there is a significant and positive link between firm productivity and product innovations, both in manufacturing and services, this link is weakened when ICT intensity, measured as the proportion of broadband internet connected employees, is included.

The study is organised as follows: The next section introduces the conceptual background and the empirical model. Then the data underlying the analysis is presented, followed by a discussion of the results and some concluding remarks.

2. Conceptual background and empirical model

Literature describes several alternative empirical approaches to investigate productivity effects of ICT or technological innovations. One method is to calculate total factor productivity (TFP) indirectly and then regress the TFP indicator on the innovation or ICT variables (see for instance, Black & Lynch, 2001; Rochina-Barrachina, Mañez & Sanchis-Llopis, 2010; Aiello & Ricotta, 2016). Another approach uses an augmented Cobb-Douglas production function to estimate the relationships (Tampe & Hitt, 2012). Parisi, Schiantarelli

and Sembenelli (2006) compare both approaches and find few differences in the results. If innovation activities are treated as endogenous, simultaneous equation frameworks are often employed (Crépon et al., 1998). Studies solely based on the Community Innovation Survey commonly use labour productivity as the dependent variable, since this information is available in the survey itself (Crépon, Duguet & Mairesse, 1998; Crespi, & Zuniga, 2012).

Product innovations are expected to have a positive impact on labour productivity given other inputs (Griffith et al., 2006). A novel product generates new demand and thereby increases output in the case of a single product, but with multiple products, the overall effect is unclear (Van Reenen, 1997). Process innovations often occur in form of introduction of new machines (Edquist, Hommen & McKelvey, 2001). Such innovations can increase productivity and efficiency of firms. Huergo and Jaumandreu (2004) find that process innovations lead to extra productivity growth based on firm-level data for Spanish manufacturers.

Organisational innovations consist of many diverse activities including adoption of new business practices, new work practices, knowledge management systems and changes in external relations (outsourcing and contracting-out activities) (Edquist, Hommen & McKelvey, 2001; OECD/Eurostat, 2005). Changes in work practices and new human resource management systems can lead to increases in productivity by reducing costs or improving the quality of existing products (Bresnahan, Brynjolfsson & Hitt, 2002; Ichniowski, Shaw & Premushi, 1997). Bloom & Van Reenen (2011) find that certain types of human resource management practices, such as changes in work organisation raise productivity at the firm-level.

In addition to technological and organisational innovations there are also innovations in the marketing of goods and services. According to the Oslo manual, marketing innovations consist of significant changes in product design or packaging, new techniques for product

promotion, new methods for product placement or new methods of pricing (OECD/Eurostat, 2005). The productivity effects of marketing innovations is an unexplored field. Marketing innovations can have a positive influence on output given inputs. However, the magnitude of this effect is likely to be small since the functional characteristics of the products are not necessarily affected by new marketing methods. The business literature finds that marketing capability is important for firm performance (Krasnikov & Jayachandran, 2008, based on a meta-analysis).

Besides innovations, the ICT intensity may have a positive influence on productivity. For instance, broadband internet usage among employees facilitates higher speed in business transactions and streamlines the production activities (Haller & Lyons, 2015). In this context, ICT intensity is measured as the proportion of broadband internet connected employees in firms. This variable is superior to many other commonly used broadband measures because it is continuous and reflects both a minimum quality of the technology and a human capital element in the diffusion within and across firms over time.

Previous studies often use dummy variables to measure broadband internet access at the firm-level, implying that changes in intensity cannot be investigated, even if several studies distinguish between high and low speed (Grimes, Ren & Stevens, 2012; Bertschek, Cerquera & Klein, 2013; Colombo, Croce & Grilli, 2013; Howell & Grimes, 2010; Haller & Lyons, 2015). The results of these studies are ambiguous, although with an indication that analyses based on data for the early 2000s exhibit fewer significant results than those employing more recent data. Hagsten (2016), for instance, uses the proportion of broadband connected employees as the main productivity determinant and find significant relationships for manufacturing and service firms in a majority of 14 European countries investigated, based on harmonised and linked firm-level data. However, this dataset only links one sample survey to the production statistics: the ICT in enterprise. An alternative approach to approximate the

ICT intensity of firms is to use the share of workers with an occupation or degree in information science or related fields such as mathematics, engineering and other natural science fields (Bartelsman, van Leeuwen & Polder, 2017; Hagsten & Sabadash, 2017).

The relationship between innovations and productivity, including the measure of ICT intensity of firms, is investigated by use of a Cobb-Douglas production function including output (*Y*), capital (*K*) and labour (*L*):

$$Y = f(A, K, L) = AK^{\alpha} L^{\beta}. \quad (1)$$

Coefficients (α) and (β) are the output elasticities of each input with a given technology (*A*). Transformed into log-linear form the production function reads:

$$lnY_{it} = lnA + \alpha \ln K_{it} + \beta lnL_{it} + \varepsilon_{it} \ . \quad (2)$$

where *i* denotes firm, *t* year, *ln( )* the natural logarithm and ε_{it} is the stochastic error term. The technology level is usually not directly observable and thus in the following assumed to depend on innovation activities ***(IN)***, ICT intensity *(BROADpct*), other specific firm characteristics (***Z***, $\boldsymbol{D}^{c}$) as well as time and industry fixed effects ($\boldsymbol{D}^{f}$):

$$lnA = \mathrm{f}(\boldsymbol{IN}, BROADpct, \boldsymbol{Z}, \boldsymbol{D}^{c}, \boldsymbol{D}^{f}). \quad (3)$$

Thus, the augmented standard Cobb-Douglas production function is specified as:

$$lnVA_{it} = c + \tilde{\alpha} lnK_{it} + \tilde{\beta} \ln L_{it} + \boldsymbol{IN_{it}}\gamma_1 + \gamma_2 BROADpct_{it} + \boldsymbol{Z_{it}}\gamma_3 + \boldsymbol{D}^{c}\gamma_4 + \boldsymbol{D}^{f}\gamma_5 + \tilde{\varepsilon}_{it}, \quad (4)$$

where c is the intercept and firm output is represented by value added (*VA*) in constant prices, capital (*K*) by the capital stock in constant prices and labour (*L*) by the number of employees. Technological and non-technological innovations are measured as a set of dummy variables encompassed in the vector ***(IN)***: (a) product innovations (*INPD*), (b) process innovations (*INPS*), (c) organisational innovations (*ORGIN*) and (d) marketing innovations (*MRKIN*). Variable (*BROADpct),* the proportion of employees with broadband internet access, indicates the ICT intensity of firms.

In addition to the main innovation and technology variables of interest, several factors accounting for firm heterogeneity are included (Bartelsman & Doms, 2000; Syversen, 2011). Age and its squared term is represented by vector (***Z***). The inclusion of firm age can be motivated by learning-by-doing effects that occur when firms become older and manage to optimise their production processes, and by doing this they are also more likely to stay in business than younger firms (Jovanovic, 1982). Old age might as well have a reverse effect, if the firms become less productive over time (Barron, West & Hannan, 1994). This indicates a possible inverted u-shaped relationship between productivity and firm age, represented by its square term. Besides age, the relationship with productivity is also controlled for by other firm characteristics $\boldsymbol{D}^c$, including dummy variables for size-class and international experience (exporter and foreign affiliation). Williamson (1967) was one of the first to derive a link between firm size and efficiency and thus also productivity, where large companies on average are more efficient than small ones. This is due to factors such as market power and economies of scale.

The hypothesis of learning by export states that companies acquire knowledge through export, which leads to an increase in productivity (Clerides, Lach & Tybout, 1998; Bernard & Jensen, 1999). However, the empirical evidence on the impact of internationalisation on firm productivity is ambiguous, and a reverse causality may exist, where above average productive firms are more likely to export (Wagner, 2007).

Another stylised fact is that multinational enterprises (domestic or foreign-owned) on average are more productive due to superiority in terms of knowledge, use of advanced technologies and managerial skills (Blomström and Kokko, 1998). Based on firm level data for the United Kingdom, Griffith, Redding and Simpson (2004) show that foreign-owned firms have higher value added per employee than domestic ones. The theoretical model by Melitz (2003) predicts that the most productive firms are multinational, followed by exporting

firms, while the least productive ones are domestic. Vector $\boldsymbol{D}^f$ encompasses time and industry fixed effects.

The production function will be estimated by OLS on data pooled across industries and over time. Separate estimations are provided by country, distinguishing between manufacturing and service firms. The choice of estimation method is data driven. More information on data sources and characteristics is found in Section 3.

Based on literature, positive relationships are expected to be found between product innovations and productivity. In the short run it is even possible that a stronger link will be found for ICT intensity, since how firms use an innovation might be of larger importance for productivity than the creation of one. The more seldom researched marketing and organisational innovations are expected to show a smaller magnitude of the association, if at all significant. Organisational changes tend to take some time to become effective, implying that a direct link may not be possible to find, or that even a negative association appears. The broadband variable could also harbour effects of unmeasured organisational assets not captured by the innovation variables, as suggested by Bartelsman (2013).

3. Data sources and stylised facts

Data for this analysis originate from the ESSLait project and encompass approximately 117,000 firm-year observations for ten European countries over the period 2002-2010 (Table 1).[1] These datasets hold linked and harmonised official information on manufacturing and service firms (see Graph 1 in the Appendix for a description of the data linking procedure) sourced from business registers, production statistics (Structural business statistics, SBS) and the EU harmonised surveys on innovation activities and ICT usage in enterprises.[2] In some countries, the underlying production statistics originate from total surveys while in others they are based on large samples. In addition, the export statistics (either goods or both goods and

[1] See https://ec.europa.eu/eurostat/cros/content/esslait-0_en.
[2] See http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database.

service exports) and the foreign affiliate statistics (FATS) is matched to the dataset. Access to confidential linked firm-level data is legally restricted in most countries and forbidden in others. In this specific case, access have been granted through a common protocol that is run separately on each harmonised and linked country dataset held at the national statistical offices (Bartelsman, Hagsten & Polder, 2018). The full project database covers 14 European countries, but Ireland, Luxembourg and Slovenia are excluded from this analysis because of absent information on capital or too few observations in the linked datasets.

Table 1. Data availability, number of firm-year observations

Country	Manufacturing firms		Service firms	
	Time period	Number	Time period	Number
Austria (AT)	2002-2010	3665	2002-2010	1905
Denmark (DK)	2005-2010	2315	2005-2010	3303
Finland (FI)	2002-2010	4690	2002-2010	2753
France (FR)	2006-2010	6728	2006-2010	5779
Italy (IT)	2002-2008	9377	2002-2008	7278
The Netherlands (NL)	2002-2010	7272	2002-2010	5996
Norway (NO)	2002-2010	5173	2002-2010	4650
Poland (PL)	2002-2010	21498	2003-2010	9411
Sweden (SE)	2006-2010	2750	2006-2010	2300
The United Kingdom (UK)	2002-2010	3369	2002-2010	6686

Note: Manufacturing covers NACE rev 1.1 industries 15 to 37 and services encompasses industries 50 to 74.

Source: ESSLait Databases and own calculations.

Production statistics contain information on outputs (gross production and value added) and inputs (number of employees, materials and capital). In this study value added, defined as gross output minus intermediate purchases of services and goods, is the output variable favoured. Capital is measured either as the capital stock calculated by the perpetual inventory method, the depreciation cost or the book value. Number of employees, age and NACE rev 1.1 two-digit industry classification originate from the business register. Data on exporters stem from the VAT register or trade statistics and information about international affiliation (being part of a domestic or foreign enterprise, MNE) is derived from either the production or foreign affiliate statistics. Nominal prices (value added, capital) have been deflated by EUKLEMS or WIOD two-digit price indexes.[3]

[3] See www.euklems.net and www.wiod.org.

The CIS is the main origin of information on innovation activities in firms. This survey is a representative random sample of firms that is stratified by industry, size, and region. The survey includes manufacturing, mining, energy, water supply, and a selection of service industries (wholesale trade, transport, banking and insurance, computer and related activities, architectural and engineering businesses as well as technical testing and analysis). However, retail trade and hotels and restaurants are only covered on a voluntary basis while construction is excluded.

The four innovation variables employed in this study are all binary and inform on what activities the firms engage in during a three-year period: (a) product innovations (introduction of new or significantly improved goods or services), (b) process innovations (implementation of a new or significantly improved production process, distribution method, or support activity for your goods or services), (c) organisational innovations (for instance business practices, knowledge management, workplace organisation or external relations) and (d) marketing innovations (a new marketing concept or strategy).

The harmonised survey on ICT usage in enterprises includes a wide range of information on how ICT is employed in firms (internet use, ICT applications such as enterprise resource planning systems and e-commerce activities). In addition, the ICT survey is stratified by industry and firm size, which guarantees both representativeness and comparability. This survey has a broader industry coverage than the innovation questionnaire, including retail trade, hotels and restaurants as well as personal services.

Fazio, Lam and Ritchie (2006) conclude that a linking of the ICT usage survey to the production statistics may affect the descriptive statistics due to limited overlapping samples, but the influence on marginal analysis is negligible. In this case, where multiple datasets are linked, a certain bias towards larger firms should be expected, because the sampling schemes used by most statistical offices imply that those firms are the only ones regularly selected.

Neither the CIS nor the ICT usage survey target firms with less than 10 employees (although countries can do this on a voluntary basis), which is a shortcoming since in certain industries the innovative activities are high in the smallest firms.

The proportion of broadband internet connected employees is used to reflect the ICT intensity of firms. This composite variable includes information on firm broadband connectivity beyond a minimum speed both within and across firms as well as the proportion of employees with internet access. Thus, the variable is more informative than the commonly employed sole measure of broadband adoption in firms (Bertschek et al., 2013; Haller & Lyons, 2015, for instance), since it also relates to human capital and the intensity of usage over time.

Table 2. Main estimation variables, averages across countries and over time

Variable	Unit	Manufacturing	Services
Value added per employee, constant prices	Euro, median	50,523	56,736
Product innovations (INPD)	Proportion of firms, per cent	38.5	25.4
Process innovations (INPS)	Proportion of firms, per cent	34.9	24.4
Marketing innovations (MRKIN)	Proportion of firms, per cent	25.5	22.9
Organisational innovations (ORGIN)	Proportion of firms, per cent	36.1	33.2
Broadband connected employees (BROADpct)	Proportion of employees, per cent	33.7	49.0

Note: Value added per employee is reported as the median of the country averages.
Source: ESSLait Databases and own calculations.

Descriptive statistics reveal that there is a clear difference in innovation activities and ICT intensity between manufacturing and service firms (Table 2). Generally, manufacturing firms engage more often in innovation activities than their service counterparts. Almost two out of five manufacturing firms are involved in product innovations and slightly fewer in process innovations. Similar activities appear in one fourth of the service firms. Marketing innovations and organisational change are less discriminating across industries and occur in between approximately one fourth and one third of the firms. Although the extent of the innovation and ICT activities may vary somewhat across countries, the patterns between manufacturing and service firms are relatively robust. In contrast to the innovation activities,

the service firms have a stronger representation of broadband connectivity than the manufacturers, almost every second employee.

Both the CIS and the ICT usage surveys commonly follow a rotating design to reduce the response burden of firms, a measure that regularly leads to small overlaps between datasets and a high degree of attrition over time. This restricts the choice of econometric approaches, for instance the use of fixed effects as well as first- or long-differences estimators, as they vastly reduce the number of observations. However, Mairesse and Mohnen (2010) conclude that the main results of CIS based analyses are quite robust to the use of such methods. This situation occurs because the CIS is performed every second year and refers to a three-year period, leading to a limited time variation in the main explanatory variables.

4. Estimation results

The estimations reveal that there is a significant and positive association between product innovations and productivity for manufacturing firms in seven out of ten countries (Table 3). In contrast, process and other non-technological innovations are not generally not significant. Similar results can be observed for service firms (Table 4). I three out of ten cases, there is a significant negative relationship between organisational innovations and productivity in manufacturing firms. Possibly, this relates to time delays in the implementation of new practices, where improvements do not necessarily transform into direct positive associations with productivity. Due to data specifics, however, the relevance of lagged innovation variables cannot be tested.

Overall, manufacturing firms introducing new products exhibit a productivity level between 3 and 9 percent higher than non-innovators. The corresponding magnitude for service firms ranges between 5 and 21 percent, implying that service firms are assumedly more flexible than manufacturing ones, for instance in scaling operations and adapting new practices, to be able to benefit directly from new goods or services. Output elasticities of capital and labour

show the expected signs and magnitudes in all cases, that is, positive, and with a larger share for labour, ranging between 0.56 and 0.95, depending on country and sector of the firms.

Table 3. Association between innovation activities and productivity in manufacturing firms OLS estimations on data pooled across industries and over time, 2002-2010

	AT			DK			FI			FR			IT		
	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat
lnK	0.268	***	27.97	0.068	***	8.25	0.099	***	19.29	0.190	***	29.75	0.161	***	31.39
lnL	0.749	***	31.75	0.946	***	35.62	0.875	***	51.62	0.799	***	58.72	0.805	***	45.97
INPD	0.041	**	2.09	0.039	**	1.98	0.038	**	2.28	0.056	***	3.93	0.030	**	2.14
INPS	-0.003		-0.17	0.014		0.73	-0.006		-0.41	-0.015		-1.12	0.030	**	2.23
MRKIN	0.022		1.36	0.015		0.78	0.029	*	1.72	0.040	***	3.02	0.002		0.12
ORGIN	0.006		0.33	-0.041	**	-2.12	-0.059	***	3.76	0.012		0.91	0.012		0.99
Size, 1-9 employees	-0.188		-1.18	0.189		1.06	-0.084		-0.86	0.400		1.50	-0.351	**	-2.41
10-19 employees	-0.193	**	-2.09	-0.098		-0.84	-0.268	***	-3.47	-0.295	*	-1.65	-0.446	***	-6.15
20-49 employees	-0.144	*	-1.89	-0.066		-0.72	-0.249	***	-3.91	-0.204	***	-3.63	-0.363	***	-5.99
50-99 employees	-0.123	**	-2.11	-0.029		-0.40	-0.193	***	-3.84	-0.168	***	-3.80	-0.247	***	-5.16
100-249 employees	-0.098	**	-2.29	-0.049		-0.92	-0.182	***	-4.75	-0.211	***	-5.67	-0.165	***	-4.50
250-499 employees	-0.070	**	-2.51	-0.064	*	-1.65	-0.107	***	-3.36	-0.178	***	-5.97	-0.097	***	-3.61
AGE				-0.002		-1.19	0.002	*	1.78	-0.002	**	-2.56	0.004	***	4.48
AGE squared				0.00001		0.54	-0.00002	**	-2.54	0.00002	***	2.76	-0.00002		-1.45
Non-exporter	-0.119	***	-4.46	-0.071	**	2.35	-0.081	***	-4.09	-0.039	**	-2.22			
Non-MNE				0.037	*	1.84									
Constant	3.41	***	23.49	-0.66	**	-2.01	4.05	***	32.08	3.45	***	35.49	3.41	***	28.86
Turning point age				367			157			199			486		
Observations	3665			2317			4690			6728			9377		
R^2	0.93			0.91			0.90			0.93			0.90		
	NL			**NO**			**PL**			**SE**			**UK**		
	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat
lnK	0.223	***	36.41	0.112	***	20.49	0.114	***	39.45	0.100	***	13.97	0.278	***	20.78
lnL	0.727	***	47.58	0.907	***	38.74	0.939	***	58.18	0.981	***	48.90	0.751	***	26.53
INPD	0.034	**	2.58	0.008		0.47	0.005		0.37	0.029		1.49	0.092	***	3.41
INPS	0.024	*	1.84	-0.008		0.48	0.130	***	9.30	-0.014		-0.78	-0.045		-1.60
MRKIN	0.026	*	1.80	0.003		0.15	-0.001		-0.04	0.010		0.54	-0.057	**	-2.26
ORGIN	-0.039	***	-3.07	-0.019		1.19	0.071	***	5.37	0.044	**	2.36			
Size, 1-9 employees	-0.682	***	3.69	-0.115		0.93	0.175	*	1.92	0.315	***	3.25	-0.070		-0.37
10-19 employees	-0.772	***	7.17	-0.157		1.54	0.160	**	2.34	0.246	***	2.98	0.193		0.88
20-49 employees	-0.527	***	8.11	-0.146	*	1.77	0.106	*	1.89	0.128	*	1.84	0.041		0.48
50-99 employees	-0.334	***	6.31	-0.123	*	1.89	-0.085	*	-1.94	0.042		0.72	-0.011		-0.17
100-249 employees	-0.294	***	6.86	-0.078		1.56	-0.072	**	-2.25	0.024		0.55	-0.020		-0.51
250-499 employees	-0.230	***	6.96	0.014		0.35	-0.028		-1.27	-0.006		-0.17	0.012	***	2.64
AGE	0.005	***	3.12	0.006	***	3.14	0.009	***	6.14	0.007	**	2.49	-0.00037	***	-3.25
AGE squared	-0.00009	**	2.22	-0.00016	***	3.59	-0.0003	***	-12.21	-0.0001	*	-1.88	-0.063	**	-2.19
Non- exporter	0.011		0.66	-0.084	***	4.05	-0.211	***	-16.52	-0.120	***	-4.34	-0.164	***	-5.46
Non-MNE							-0.367	***	-6.94	-0.134	***	-5.56			
Constant	4.04	***	38.93	5.66	***	34.46	3.60	***	29.22	5.34	***	39.50	2.65	***	13.79
Turning point age	124			81			57			116			62		
Observations	7272			5173			21498			2750			3410		
R^2	0.87			0.88			0.82			0.95			0.76		

Note: Log value added (VA) in constant prices is the dependent variable. (L) means number of employees, (K) denotes capital stock and innovation activities in the field of products, processes, marketing or organisation are illustrated by (INPD), (INPS), (MRKIN) and (ORGIN), respectively. Reference category for the size-classes is 500 or more employees. Included but not reported are fixed industry (2-digit NACE rev. 1.1) and time effects. The turning point of age is calculated as the coefficient of age divided by the coefficient of its squared term multiplied by minus 1. Empty cell means that data are not available. Significance at the 1, 5 and 10 per cent levels are denoted by ***, ** and *.
Source: ESSLait Databases and own calculations.

When the ICT intensity variable is added to the production function, the strength of the association between product innovations and productivity decreases considerably for both manufacturing and service firms. Now only three out of ten countries exhibit significant

relationships, at the five per cent level (Table 5). Service firms are affected analogously (Table 6). Process innovations are significant and positive for three countries in manufacturing and two in services.

Table 4. Association between innovation activities and productivity in service firms
OLS estimations on data pooled across industries and over time, 2002-2010

	AT			DK			FI			FR			IT		
	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat
lnK	0.279	***	22.61	0.055	***	13.35	0.074	***	15.07	0.189	***	42.37	0.191	***	39.77
lnL	0.762	***	20.93	0.939	***	47.05	0.918	***	38.19	0.750	***	68.40	0.789	***	38.82
INPD	0.123	***	3.71	0.053	***	3.12	0.092	***	3.86	0.187	***	10.91	0.148	***	6.55
INPS	-0.024		0.71	0.016		1.01	-0.051	**	-2.22	-0.006		-0.37	0.019		0.92
MRKIN	0.026		0.81	-0.002		-0.14	0.045	*	1.72	0.001		0.08	-0.027		1.30
ORGIN	0.041		1.35	-0.006		-0.42	-0.019		0.88	-0.002		-0.15	0.025		1.38
Size, 1-9 employees	0.021		0.09	-0.033		0.20	-0.028		-0.20	-0.295	**	2.51	-0.373	**	-2.22
10-19 employees	0.086		0.55	-0.045		0.50	0.056		0.51	-0.249	***	4.61	-0.189	**	-2.06
20-49 employees	0.113		0.85	-0.079		1.08	-0.006		-0.06	-0.236	***	5.46	-0.135	*	-1.73
50-99 employees	0.174	*	1.65	-0.028		0.50	0.047		0.63	-0.183	***	4.90	0.006		0.09
100-249 employees	0.087		1.05	-0.031		0.71	0.112	*	1.94	-0.156	***	4.74	-0.067		-1.33
250-499 employees	-0.052		-0.85	-0.045		1.38	0.086	*	1.83	-0.133	***	6.35	-0.016		-0.40
AGE				0.003	***	2.87	0.001		0.63	-0.003	***	3.30	0.005	***	3.85
AGE squared				-0.00004	***	3.30	-0.00001		-0.56	0.000	***	2.59	-0.00004	***	-2.73
Non-exporter	-0.090	***	-2.86	-0.032	**	2.10	-0.028		-1.17	-0.117	***	8.29			
Non-MNE				0.008		0.55									
Constant	2.99	***	8.65	-0.01		-0.05	3.23	***	6.35	4.22	***	49.04	3.53	***	21.68
Turning point age				139			247			281			224		
Observations	1905			3265			2753			5779			7278		
R^2	0.90			0.93			0.90			0.92			0.86		
	NL			**NO**			**PL**			**SE**			**UK**		
	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat
lnK	0.263	***	48.67	0.110	***	23.76	0.118	***	23.19	0.094	***	15.23	0.251	***	36.48
lnL	0.559	***	44.98	0.924	***	40.64	0.851	***	33.74	0.917	***	30.68	0.639	***	45.29
INPD	0.066	***	3.74	0.027		1.26	-0.061	**	-2.21	0.043		1.62	0.072	***	3.02
INPS	-0.009		-0.51	-0.065	***	-2.89	0.148	***	5.59	-0.020		-0.73	0.078	***	2.93
MRKIN	-0.014		0.78	0.046	**	2.18	-0.092	***	3.82	-0.012		-0.47	0.004		0.18
ORGIN	0.052	***	3.33	0.015		0.76	0.073	***	3.08	0.033		1.28			
Size, 1-9 employees	-0.662	***	-6.93	0.078		0.64	-0.241	*	-1.71	0.139		0.88	0.170		0.24
10-19 employees	-0.764	***	-12.39	0.113		1.11	-0.253	**	-2.24	0.109		0.81	-0.193		-1.12
20-49 employees	-0.622	***	-13.01	0.086		1.04	-0.201	**	-2.10	0.135		1.17	-0.230	*	-1.93
50-99 employees	-0.446	***	-11.74	0.078		1.19	-0.193	**	-2.47	0.116		1.21	-0.113	**	-2.04
100-249 employees	-0.276	***	-9.19	0.058		1.14	-0.247	***	-3.96	0.047		0.65	-0.134	***	-2.75
250-499 employees	-0.129	***	-4.69	-0.055		-1.33	-0.147	***	-3.09	0.062		1.13	-0.062	**	-2.13
AGE	-0.0004		-0.21	0.008	***	3.82	0.005	**	2.16	0.009	**	2.32	0.023	***	5.27
AGE squared	0.00000		0.08	-0.00019	***	3.95	0.000	***	3.24	-0.0002	**	-2.29	-0.001	***	-4.57
Non-exporter	-0.076	***	-4.89	-0.133	***	6.99	-0.218	***	-11.77	-0.064	**	-2.31	-0.274	***	-10.72
Non-MNE							-0.036		-0.30	-0.179	***	-6.53	-0.287	***	-14.34
Constant	4.91	***	49.33	5.42	***	31.03	3.31	***	8.71	5.96	***	26.27	3.92	***	30.25
Turning point age	n.a			91			61			83			61		
Observations	5996			4654			9411			2300			6717		
R^2	0.86			0.87			0.80			0.93			0.76		

Note: Significance at the 1, 5 and 10 per cent levels are denoted by ***, ** and *. See Table 3.
Source: ESSLait Databases and own calculations.

In addition, marketing innovations are hardly significant anywhere while organisational innovations are still mainly negatively related to productivity in manufacturing firms. In contrast to the innovation variables, there is a highly significant association between broadband connected employees and productivity across industries and countries (except in

Denmark), given an otherwise identical specification. The average coefficient of broadband connected employees is identical for both manufacturing and service firms: 0.36, although the span is larger for the former. This coefficient indicates that a surge in the share of broadband internet connected employees by one percentage point is associated with an increase in productivity by approximately 0.36 percent.

Overall, the results are consistent with Hagsten (2016) who uses a larger dataset where the ICT usage survey is linked to the structural business statistics for 14 European countries. The more sizable coefficients of the ICT variable found in this analysis may be explained by the fact that the CIS excludes certain parts of the business sector such as less innovative industries (retail trade and partly hotels and restaurants) and that the multi-merged dataset is somewhat biased towards larger firms. In addition, these results might also indicate that the ability to use innovations is more important for productivity than to generate them and that a certain degree of ICT maturity is a prerequisite for more advanced applications.

Presumably, and given the weaker predictive strength of the binary innovation variables, the ICT intensity variable may harbour effects associated with specific unmeasured intangible assets each connected employee makes use of (Bartelsman, 2013). Although the relationships cannot be interpreted as causal, the findings indicate that the link between broadband connectivity and productivity is more powerful than that of different types of innovations. As compared with the literature, these new findings down-emphasise the role of technological and organisational innovations for productivity in the short term.

Table 5. Associations between innovation activities, broadband internet connected employees and productivity in manufacturing firms

OLS estimations on data pooled across industries and over time, 2002-2010

	AT			DK			FI			FR			IT		
	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat
lnK	0.260	***	26.01	0.068	***	8.24	0.093	***	17.65	0.186	***	29.21	0.156	***	31.02
lnL	0.767	***	31.62	0.946	***	35.61	0.876	***	51.41	0.800	***	59.37	0.814	***	47.25
BROADpct	0.276	***	8.22	-0.005		-0.19	0.142	***	5.38	0.274	***	13.27	0.503	***	18.13
INPD	0.040	*	1.94	0.039	**	1.99	0.033	*	1.96	0.045	***	3.22	0.005		0.35
INPS	-0.008		-0.41	0.014		0.72	-0.006		-0.35	-0.008		-0.58	0.039	***	2.97
MRKIN	0.011		0.63	0.016		0.78	0.024		1.44	0.029	**	2.23	-0.017		-1.17
ORGIN	0.001		0.07	-0.041	**	2.12	-0.064	***	-4.02	0.010		0.80	-0.003		0.22
Size, 1-9 employees	-0.134		-0.82	0.189		1.07	-0.125		1.26	-0.319	*	-1.69	-0.341	**	-2.38
10-19 employees	-0.142		-1.50	-0.098		-0.84	-0.279	***	-3.60	-0.221	***	-3.97	-0.416	***	-5.84
20-49 employees	-0.110		-1.41	-0.066		-0.72	-0.258	***	-4.04	-0.170	***	-3.88	-0.333	***	-5.57
50-99 employees	-0.085		-1.42	-0.029		-0.41	-0.196	***	-3.87	-0.209	***	-5.68	-0.226	***	-4.80
100-249 employees	-0.091	**	-2.07	-0.049		-0.92	-0.186	***	-4.82	-0.177	***	-6.01	-0.155	***	-4.30
250-499 employees	-0.063	**	-2.18	-0.064	*	-1.66	-0.111	***	-3.47	-0.157	***	-8.45	-0.082	***	-3.10
AGE				-0.002		-1.19	0.002	**	2.10	-0.002	**	-2.36	0.004	***	4.69
AGE squared				0.00001		0.55	-0.00002	***	-2.78	0.00002	**	-2.42	-0.00002	*	-1.92
Non-exporter	-0.101	***	-3.68	-0.071	**	-2.36	-0.076	***	-3.81	-0.027		-1.56			
Non-MNE				0.036	*	1.82									
Constant	3.23	***	21.50	-0.67	**	-2.02	4.04	***	31.83	3.39	***	35.16	3.29	***	28.25
Turning point age							85			104			192		
Observations	3270			2315			4625			6704			9377		
R^2	0.93			0.92			0.90			0.93			0.91		
	NL			**NO**			**PL**			**SE**			**UK**		
	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat
lnK	0.222	***	34.33	0.109	***	20.01	0.095	***	34.17	0.100	***	14.03	0.249	***	18.82
lnL	0.731	***	45.44	0.899	***	38.44	0.970	***	62.91	0.977	***	48.93	0.755	***	27.39
BROADpct	0.290	***	11.93	0.292	***	11.62	1.129	***	45.84	0.174	***	6.51	0.614	***	13.69
INPD	0.007		0.53	-0.004		-0.27	-0.024	*	-1.80	0.022		1.13	0.060	**	2.26
INPS	0.035	**	2.52	-0.006		-0.36	0.115	***	8.66	-0.011		-0.57	-0.030		-1.09
MRKIN	0.010		0.67	-0.003		-0.15	-0.018		-1.42	0.011		0.61			
ORGIN	-0.052	***	-3.91	-0.028	*	-1.73	0.033	***	2.63	0.038	**	2.07	-0.079	***	-3.20
Size, 1-9 employees	-0.746	***	-6.49	-0.150		-1.22	0.204	**	2.34	0.292	***	3.03			
10-19 employees	-0.502	***	-7.33	-0.168		-1.65	0.197	***	3.02	0.227	***	2.76	-0.132		-0.72
20-49 employees	-0.312	***	-5.60	-0.152	*	-1.85	0.153	***	2.87	0.120	*	1.74	0.053		0.25
50-99 employees	-0.262	***	-5.80	-0.120	*	-1.86	-0.033		-0.79	0.036		0.62	0.033		0.40
100-249 employees	-0.213	***	-6.09	-0.092	*	-1.84	-0.042		-1.38	0.017		0.39	-0.025		-0.40
250-499 employees	-0.095	***	-3.20	0.005		0.12	-0.013		-0.61	-0.012		-0.37	-0.006		-0.16
AGE	0.005	***	2.96	0.008	***	3.73	0.008	***	5.66	0.008	**	2.54	0.013	***	3.10
AGE squared	-0.0001	*	-1.87	-0.0002	***	-4.14	-0.0003	***	-11.66	-0.0001	*	-1.96	-0.0004	***	-3.60
Non-exporter	0.009		0.52	-0.062	***	-2.98	-0.184	***	-15.02	-0.109	***	-3.94	-0.050	*	-1.78
Non-MNE							-0.350	***	-6.94	-0.124	***	-5.16	-0.131	***	-4.46
Constant	3.92	***	35.68	5.59	***	34.11	3.41	***	29.02	5.28	***	39.11	2.64	***	14.12
Turning point age	70			42			28			57			33		
Observations	6448			5108			21498			2742			3408		
R^2	0.87			0.88			0.84			0.95			0.77		

Note: Log value added (VA) in constant prices is the dependent variable. (L) means number of employees, (K) denotes capital stock, (BROADpct) broadband internet-enabled employees and innovation activities in the field of products, processes, marketing or organisation are illustrated by (INPD), (INPS), (MRKIN) and (ORGIN), respectively. Reference category for the size-classes is 500 or more employees. Included but not reported are fixed industry (2-digit NACE rev. 1.1) and time effects. The turning point of age is calculated as the coefficient of age divided by the coefficient of its squared term multiplied by minus 1. Empty cell means that data are not available, except turning point for Danish manufacturers, which is not significant. Significance at the 1, 5 and 10 per cent levels are denoted by ***, ** and *.
Source: ESSLait Databases and own calculations.

The output elasticities of labour and capital are not affected by the inclusion of ICT intensity, despite the fact that this leads to a slight reduction in the number of observations, due to variations in the overlap between the innovation and ICT usage surveys across countries. Unreported results show that age and age squared are jointly significant in all cases (as

calculated by the Wald-test). Larger firms are more productive in a majority of countries and the relationship between productivity and firm age is non-linear, of an inverted u-shaped pattern. However, the turning point is 50 years or older in most cases, which de facto means that productivity increases with firm age. R-squared is close to or above 0.9 on average in most countries, implying a good fit of the model.

Table 6. Associations between broadband internet-enabled employees, innovation activities and productivity in service firms

OLS estimations on data pooled across industries and over time, 2002-2010

	AT			DK			FI			FR			IT		
	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat
lnK	0.272	***	21.41	0.055	***	13.29	0.069	***	14.17	0.180	***	41.61	0.176	***	37.45
lnL	0.781	***	20.94	0.939	***	47.06	0.926	***	38.54	0.766	***	71.93	0.817	***	41.43
BROADpct	0.487	***	11.58	-0.018		-1.09	0.268	***	8.62	0.361	***	19.87	0.561	***	22.09
INPD	0.068	*	1.95	0.053	***	3.14	0.063	***	2.67	0.148	***	8.84	0.102	***	4.63
INPS	-0.032		-0.93	0.016		1.02	-0.041	*	-1.79	-0.008		-0.46	0.025		1.20
MRKIN	-0.009		-0.26	-0.002		-0.15	0.043	*	1.67	-0.005		-0.36	-0.038	*	-1.88
ORGIN	0.014		0.46	-0.007		-0.42	-0.039	*	-1.80	-0.006		-0.36	-0.013		-0.73
Size, 1-9 employees	0.131		0.58	-0.037		-0.23	-0.004		-0.03	-0.307	***	-2.71	-0.400	**	-2.47
10-19 employees	0.123		0.77	-0.045		-0.51	0.074		0.67	-0.301	***	-5.73	-0.182	**	-2.05
20-49 employees	0.140		1.02	-0.079		-1.08	-0.005		-0.06	-0.254	***	-6.05	-0.137	*	-1.80
50-99 employees	0.187	*	1.73	-0.029		-0.51	0.042		0.58	-0.192	***	-5.29	-0.007		-0.11
100-249 employees	0.081		0.94	-0.031		-0.72	0.119	**	2.07	-0.158	***	-4.97	-0.068		-1.41
250-499 employees	-0.050		-0.80	-0.045		-1.39	0.090	*	1.92	-0.130	***	-6.42	-0.013		-0.33
AGE				0.003	***	2.85	0.001		0.81	-0.002	**	-2.45	0.005	***	4.15
AGE squared				-0.00004	***	-3.26	-0.00001		-0.81	0.00002	*	1.96	-0.00004	***	-2.95
Non-exporter	-0.066	**	-2.02	-0.032	**	-2.11	-0.016		-0.67	-0.071	***	-5.10			
Not part of MNE				0.007		0.47									
Constant	2.41	***	6.91	0.110	*	1.80	2.98	***	5.92	3.95	***	46.77	3.15	***	19.87
Turning point age				70			111			137			112		
Observations	1704			3303			2728			5762			7277		
R^2	0.90			0.93			0.90			0.92			0.87		
	NL			**NO**			**PL**			**SE**			**UK**		
	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat	Coeff.		t-stat
lnK	0.257	***	45.62	0.114	***	25.00	0.113	***	22.51	0.090	***	14.57	0.228	***	34.01
lnL	0.558	***	43.58	0.925	***	41.68	0.866	***	34.89	0.920	***	30.93	0.686	***	49.96
BROADpct	0.289	***	13.87	0.264	***	10.35	0.502	***	17.55	0.180	***	5.48	0.616	***	23.11
INPD	0.049	***	2.69	0.018		0.83	-0.074	***	-2.70	0.037		1.41	0.042	*	1.82
INPS	-0.011		-0.64	-0.072	***	-3.26	0.130	***	4.99	-0.017		-0.63	0.070	***	2.72
MRKIN	-0.029		-1.54	0.035	*	1.72	-0.100	***	-4.21	-0.015		-0.58			
ORGIN	0.041	**	2.52	0.017		0.89	0.046	**	1.99	0.029		1.11	-0.007		-0.39
Size, 1-9 employees	-0.642	***	-6.29	0.097		0.81	-0.178		-1.28	0.131		0.84	-0.041		-0.06
10-19 employees	-0.828	***	-12.93	0.127		1.28	-0.214	*	-1.92	0.098		0.73	-0.254		-1.53
20-49 employees	-0.668	***	-13.49	0.098		1.22	-0.176	*	-1.87	0.126		1.10	-0.183		-1.60
50-99 employees	-0.468	***	-11.98	0.083		1.29	-0.183	**	-2.38	0.104		1.09	-0.065		-1.22
100-249 employees	-0.297	***	-9.59	0.059		1.19	-0.238	***	-3.88	0.041		0.58	-0.133	***	-2.83
250-499 employees	-0.151	***	-5.29	-0.056		-1.38	-0.138	***	-2.96	0.055		1.00	-0.065	**	-2.32
AGE	0.001		0.45	0.008	***	3.60	0.004	*	1.72	0.009	**	2.28	0.025	***	5.88
AGE squared	-.00002		-0.35	-0.0002	***	3.60	-0.0002	***	-2.79	-0.0002	**	-2.27	-0.001	***	-5.02
Non-exporter	-0.073	***	-4.49	-0.093	***	-4.91	-0.173	***	-9.40	-0.049	*	-1.78	-0.158	***	-6.30
Non-MNE							-0.057		-0.49	-0.162	***	-5.93	-0.220	***	-11.28
Constant	4.73	***	45.72	5.10	***	29.41	2.92	***	7.78	5.85	***	25.81	3.22	***	25.03
Turning point age	53			47			28			41			31		
Observations	5454			4603			9411			2292			6717		
R^2	0.86			0.87			0.81			0.93			0.78		

Note: Significance at the 1, 5 and 10 per cent levels are denoted by ***, ** and *. See Table 5.
Source: ESSLait Databases and own calculations.

International experience turns out clearly related to productivity. The non-exporter dummy variable is significant and negative for manufacturing firms in six out of nine countries and in seven out of nine for service firms (exporter information on Italy not available). This indicates that exporting firms are more productive than their counterparts selling on the domestic market only, with a productivity differential of approximately ten percent. Not being part of a multinational firms is negative and significant when the variable is available, with estimates stronger than for non-exporting firms, implying that domestically owned firms are less productive.

Several robustness checks are performed. Firstly, the production function is re-estimated using a gross output specification with materials. Unreported results show that the main estimates are not affected by the choice of output measure, as demonstrated by Syverson (2011), for instance (results are available upon request). Secondly, the innovation variables are estimated in combinations, although this does not make them more powerful. Thirdly, given the possibility that influential observations might distort the estimation results, a generic outlier correction procedure has been performed, where possible outliers have been identified by a first stage regression of productivity on input factors and categorical dummy variables. This did not affect the estimates.

5. Concluding remarks

This study investigates the link between productivity and innovations (technological as well as non-technological), taking into account the ICT intensity of firms, measured as the proportion of broadband internet connected employees. The estimations are based on linked and internationally comparable official firm-level data from ten European countries covering the years 2002-2010 and show that there is indeed a direct, positive and significant relationship between innovation activities and productivity in manufacturing as well as in service firms in most countries. However, this is only valid for product innovations, while no

obvious pattern appears for process, organisational or marketing innovations. In contrast, the proportion of broadband internet connected employees is clearly related to productivity across industries in all but one country, with a magnitude distinctly larger than that of product innovations. The inclusion of the ICT intensity variable also diminishes the power and significance of the innovation variables. This could follow from the fact that broadband connected employees are capable to make use of additional unmeasured intangible assets. Although the approach does not allow causal effects to be interpreted, the results may indicate that ICT intensity, or the ability to use innovations, is more important for productivity than the innovative process in firms. Alternatively, there might be indirect links between innovation activities and productivity, or the innovations may need some time to establish the association. The direct significant negative effect of organisational innovations across industries in some countries may stress needs for a phase of adjustment before the firms benefit from the changes.

As is commonly the case, data characteristics drive the choice of estimation method, and this study is no exception. The high attrition of the data following response burden issues and the small time-variation of the innovation variables reduce the opportunities to employ dynamic modelling such as fixed effects estimations. Likewise, endogeneity of inputs in the production function are difficult to account for, and possible instrumental variables are scarce. Correcting for the simultaneity of inputs and outputs require either detailed information on the structure of investments (Olley & Pakes, 1996) or on material inputs (Levinsohn & Petrin, 2003). This information is not available in the ESSLait datasets, but the approaches may as well be less functional for datasets including large amounts of service firms, since they were initially developed for analyses of manufacturing firms. Another aspect of importance is the longevity of the measure of ICT intensity in firms. Presumably, the proportion of broadband connected employees reaches saturation at some not too distant point in time, while other

kinds of ICTs continue to be crucial to firms. Alternative approaches could be to interact human capital and ICT, or to focus on measures of automation or robotism.

Because of the possible presence of individual unobserved characteristics that might influence productivity, the relationships in this analysis are not interpreted as causal. One solution to overcome this shortcoming is to employ pseudo-panel methods using micro-aggregated data by industry or firm characteristics such as size (Bartelsman, Hagsten & Polder, 2018). Another limitation is that micro enterprises are excluded in the underlying innovation and ICT usage surveys. These firms would have been important to include, because in certain industries they typically show a high degree of innovativeness (Baumann & Kritikos, 2016).

There are several suggestions for future work. Analysis of linked firm-level data is promising, since it increases the amount of observable firm characteristics that can be controlled for. One idea is to match the research and development (R&D) survey to the structural business statistics. This survey contains information on R&D expenditures in firms whereas the CIS only includes information on innovation input, in cases when these activities are already ongoing or successful. The linked R&D and production statistics would make it possible to estimate a knowledge production function. There is also a need for improved innovation variables, preferably continuous ones. It cannot be excluded that less rough measures than those available would give a clearer picture of how innovations relate to productivity.

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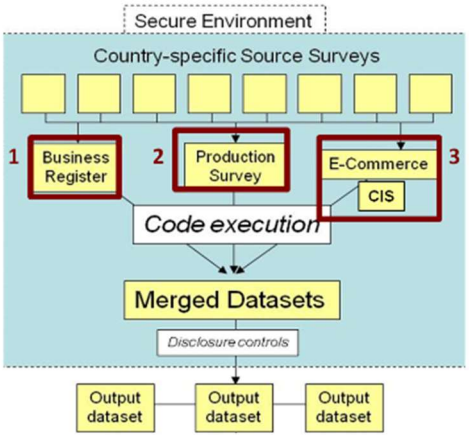
Appendix

Graph 1: Compilation of the harmonised and merged datasets

1. **Business Register BR (industry code, age, employment)**
2. **Augmented production Statistics PS (SBS, production values, exports, capital, employment, wage bill, educational achievement, ownership, affiliation)**
3. **E-commerce Survey (EC) and Community Innovation Survey (CIS)**



Source: ESSLait project.