R&D, ICT and innovation

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Disclaimer

- These results do not necessarily represent the views of CBS.
- This is still ongoing work. These are preliminary results.

R&D and productivity

- Many studies showing that R&D earns a rate of return around .20 or that the output elasticity of R&D is around 0.07
- Social rate of return exceeds private rate of return (50% to 100% higher)
- Various literature surveys: Mairesse and Sassenou (1991), Mohnen (1992), Nadiri (1993), Griliches (1995), Hall (1996), Kafouros (2005), Congressional Budget Office (2005), Parsons and Phillips (2007), Sveikaukas (2007), McMorrow and Roeger (2009), Hall, Mairesse and Mohnen (2010), Becker (2015), Kokko et al. (2015), Wieser (2005) and Ugur et al. (2016).

ICT and productivity

- Now R&D “shows up in the productivity statistics”

- ICT capital deepening (Jorgenson et a. (2008)
- complementarity with organizational change (Brynjolfsson and Saunders, 2010)
- spillovers, network effects

Complementarity R&D - ICT

- Gathering information
- Storing information
- Computing speed
- More complex computations
- Sharing knowledge
- Possibility of collaborations without being face to face

Literature on ICT and R&D

- Hall, Lotti, Mairesse (2012)
  - neither complements nor substitutes
- Polder, van Leeuwen, Mohnen, Raymond (2009)
  - ICT and innovation (product, process, organizational) are complements in services only
- Spiezia (2011)concludes from his survey that there is no complementarity between ICT and the probability to come up with a new product
- Van Leeuwen and Farooqui (2008)
  - e-sales and broadband use increase innovation output

Literature on ICT and R&D

- Cerquera and Klein (2008)
  - ICT leads to creative destruction which stimulates R&D
- Kleis, Chwelos, Ramirez, Cockburn (2011)
  - IT increases the productivity of research in terms of patents
- Forman and van Zeebroeck (2012)
  - Internet increases not so much the productivity of researchers but R&D collaborations
- Corrado, Haskel and Jona-Lasinio (2017)
  - Average industry ICT over the countries increases the return to intangible investment in that industry
- Chen, Niebel and Saam (2014)
  - Output elasticity of intangibles (among which R&D) increases with ICT

Data

- Firm data, 2002-2010
- Statistics Netherlands
- manufacturing sector (NACE 15 to 37) and services sector (NACE 50 to 93)
- Community Innovation Survey (organisational innovation, R&D, export status)
- Investment survey (ICT hardware)
- Production statistics (value added, employment, depreciation costs)
- Business Register (age of the firm)
- Supply and Use tables (sector deflators)

Extensive margin

$$P_{it}^{j} = \left(\beta_j' x_{it}^{j} + \sum_{k \neq j} (\alpha_{jk}/2) y_{it}^{k} + \varepsilon_{it}^{j} \right) y_{it}^{j}. \qquad TP_{it} = \sum_{j} P_{it}^{j} y_{it}^{j}.$$

$$TP_{it}(1,1) \geq TP_{it}(0,0) \Rightarrow \beta_1' x_{it}^{1} + \alpha_{12} + \beta_2' x_{it}^{2} + \varepsilon_{it}^{1} + \varepsilon_{it}^{2} \geq 0$$

$$TP_{it}(1,1) \geq TP_{it}(1,0) \Rightarrow \beta_2' x_{it}^{2} + \varepsilon_{it}^{2} \geq 0$$

$$TP_{it}(1,1) \geq TP_{it}(0,1) \Rightarrow \beta_1' x_{it}^{1} + \varepsilon_{it}^{1} \geq 0.$$

The choice (1,1) is therefore associated to the likelihood that

$$\varepsilon_{it}^{2} \geq L_1 = -\beta_2' x_{it}^{2}$$

$$\varepsilon_{it}^{1} \geq L_2 = \max(-\beta_1' x_{it}^{1}, -(\beta_1' x_{it}^{1} + \alpha_{12} + \beta_2' x_{it}^{2} + \varepsilon_{it}^{2}))$$

in other words to $\int_{L_1}^{\infty} \int_{L_2}^{\infty} \varphi(\varepsilon_{it}^{1}, \varepsilon_{it}^{2}) d\varepsilon_{it}^{1} d\varepsilon_{it}^{2}$.

Estimation by maximum simulated likelihood.
Standard errors obtained by bootstrapping.

Estimation

- Estimation by simulated maximum likelihood
- Standard errors obtained by bootstrapping
- Dummies refer to an investment somewhere in the current and the two preceding years
  - For organizational innovation as in the data
  - For R&D constructed as such
  - For ICT constructed as such with ICT taking place if ICT>average macro figure for replacement investment (1250 Euro/person)
- Control for age, industry fixed effects, export status, size

Table 1. Summary statistics for the investment equation sample

	Manufacturing			Services		
	mean	median	st. dev.	mean	median	st. dev.
ICT investment	0.304	0	0.460	0.375	0	0.484
R&D investment	0.619	1	0.486	0.270	0	0.444
Organizational innovation	0.414	0	0.492	0.325	0	0.468
log employment	4.665	4.644	1.099	4.611	4.554	1.078
export status	0.812	1	0.391	0.479	0	0.500
age	25.213	27	13.543	20.944	18	13.550
number of observations	6706			10668		

Table 2. Combinations of investment strategies

	manufacturing		services	
	%	*N*	%	*N*
000	23.19	1,555	40.36	4,306
001	6.5	436	9.94	1,060
010	19.7	1,321	5.44	580
011	20.24	1,357	6.79	724
100	6.05	406	15.56	1,660
101	2.33	156	7.15	763
110	9.71	651	6.14	655
111	12.29	824	8.62	920

Combinations {0/1; 0/1; 0/1} of ICT, R&D, and organizational innovation, where 0 = zero investment and 1 = positive investment.

Table 4. Estimation results of the investment equation (based on Simulated Maximum Likelihood)

	Manufacturing (N = 6,706)			Services (N = 10,668)		
	coef	se	p-value	coef	se	p-value
ICT						
log employment	0,036 **	0,016	0,028	-0,026 **	0,012	0,028
export status	0,341 ***	0,048	0,000	0,448 ***	0,026	0,000
age	0,001	0,001	0,554	-0,001	0,001	0,591
R&D						
log employment	0,192 ***	0,014	0,000	0,132 ***	0,009	0,000
export status	0,640 ***	0,034	0,000	0,299 ***	0,019	0,000
age	0,000	0,001	0,938	-0,002 **	0,001	0,010
organizational innovation						
log employment	0,128 ***	0,009	0,000	0,090 ***	0,008	0,000
export status	0,147 ***	0,027	0,000	0,117 ***	0,015	0,000
age	-0,002 *	0,001	0,052	-0,002 ***	0,001	0,001
a						
ICT - R&D	0,262 ***	0,024	0,000	0,329 ***	0,016	0,000
ICT - org inno	0,132 ***	0,018	0,000	0,193 ***	0,015	0,000
R&D - org inno	0,280 ***	0,015	0,000	0,391 ***	0,012	0,000
Log-likelihood	-13030,940			-23.473,66		

Results

- Complementarity between ICT, R&D and organizational innovation in strategy adoptions
- Less strong complementarity between ICT and organizational innovation !
- Firms have a tendency to do all three or none at all: doing all three increases the return to each of them individually.

Intensive margin

$$\ln(VA_{it}) = A_{it} + \alpha_K \ln(K_{it}) + \alpha_L \ln(L_{it}) + \varepsilon_{it}$$

$$TFP_{it} = A_{it} + \varepsilon_{it}$$

$$\Delta \ln TFP_{it} = \beta_{ICT} \Delta \ln(ICT_{it}) + \beta_{RND} \Delta \ln(RND_{it}) + \omega_{it}$$

In general, whatever K

$$\alpha_K \Delta \ln(K_{it}) = \rho \frac{K_{it}}{VA_{it}} \frac{K_{it} - K_{it-1}}{K_{it}} = \rho \frac{\Delta K_{it}}{VA_{it}}$$

$$\Delta K_{it} = I_{it-1} - \delta K_{it-1} = \frac{I_{it-1} - \delta K_{it-1}}{I_{it-1}} I_{it-1} = \left(1 - \frac{\delta K_{it-1}}{I_{it-1}}\right) I_{it-1} \equiv (1 - \gamma_{it}) I_{it-1}$$

Estimating equations

$$\Delta \ln TFP_{it} = \rho_{ICT}\, IICT_{it-1}/VA_{it} + \rho_{RND}\, IRND_{it-1}/VA_{it}$$
$$+\theta(IICT_{it-1}/VA_{it}) \times (IRND_{it-1}/VA_{it}) + \omega_{it}$$

Table A2. Depreciation rates in the National Accounts (2012 figures).

	Type of capital good		
Sectors/branches (SIC 2008)	Total capital stock	Computers	R&D
A Agriculture, forestry and fishing	0.08	0.32	0.18
B Mining and quarrying	0.05	0.38	0.00
10-12 Manufacture of food and beverages	0.08	0.13	0.18
13-15 Man. of textile-, leather products	0.08	0.10	0.18
16-18 Man. wood en paper prod., printing	0.07	0.23	0.18
19 Manufacture of coke and petroleum	0.09	0.21	0.18
20 Manufacture of chemicals	0.06	0.15	0.14
21 Manufacture of pharmaceuticals	0.09	0.15	0.14
22-23 Man. plastics and constructionprod	0.07	0.18	0.18
24-25 Man. of basic metals and -products	0.08	0.23	0.18
26 Manufacture of electronic products	0.17	0.29	0.22
27 Manufacture of electric equipment	0.15	0.23	0.19
28 Manufacture of machinery n.e.c.	0.11	0.13	0.18
29-30 Transport equipment	0.11	0.27	0.18
31-33 Other manufacturing and repair	0.09	0.18	0.18
D Electricity and gas supply	0.06	0.17	0.18
E Water supply and waste management	0.06	0.22	0.18
F Construction	0.10	0.19	0.18
G Wholesale and retail trade	0.13	0.32	0.17
H Transportation and storage	0.07	0.31	0.17
I Accommodation and food serving	0.12	0.32	0.18
58-60 Publishing, movie, radio and TV	0.16	0.26	0.18
61 Telecommunications	0.12	0.31	0.17
62-63 IT- and information services	0.25	0.33	0.18
K Financial institutions	0.09	0.31	0.18
L Renting, buying, selling real estate	0.03	0.32	0.18
69-71 Management, technical consultancy	0.22	0.33	0.18
72 Research and development	0.16	0.31	0.17
73-75 Advertising, design and other	0.18	0.32	0.18
N Renting and other business support	0.19	0.31	0.18
O Public administration and services	0.04	0.32	0.17
P Education	0.10	0.31	0.17
86 Human health activities	0.09	0.31	0.17
87-88 Care and social work	0.07	0.31	0.17
R Culture, sports and recreation	0.15	0.31	0.17
S Other service activities	0.15	0.31	0.19

Estimation

- First step: estimate CD production function
  - by GMM
  - taking depreciation costs as a proxy for capital services and instrumenting labor by labor one-year lagged
  - Industry by industry
- Second step: regress TFP growth on the net investment/output ratios controlling for industry dummies
- Do it separately for firms that have and those that do not have organizational innovation (only in the former case are we constrained to use bi-annual data)

Table 3. Summary statistics for the production function estimation sample

					Investment ratios corrected for depreciation		uncorrected for depreciation	
		value added	depreciation cost	employment	ICT	R&D	ICT	R&D
1700a	Apparel and leather	7.831	5.312	3.916	0.002	-0.009	0.005	0.035
21	Paper	8.655	6.600	4.527	0.001	-0.007	0.005	0.031
22	Publishing and printing	8.174	5.617	4.037	0.002	-0.002	0.009	0.022
24	Chemicals	8.999	6.802	4.461	0.001	0.008	0.005	0.056
25	Rubber, plastics	8.439	6.308	4.367	0.002	0.000	0.005	0.047
26	Construction materials	8.302	6.183	4.186	0.001	0.000	0.003	0.021
27	Basic metal	8.521	5.982	4.295	0.001	-0.005	0.003	0.025
28	Metal	8.001	5.393	4.068	0.001	-0.004	0.005	0.027
29	Machines	8.496	5.579	4.430	0.003	0.002	0.007	0.058
30t32	Equipment	8.037	5.121	3.955	0.001	-0.009	0.006	0.068
33	Medical equipment	8.278	5.271	4.123	0.000	-0.020	0.007	0.089
50	Trade in cars and car repairs	7.734	4.957	3.778	0.001	0.000	0.006	0.004
51	Wholesale	7.763	4.892	3.558	0.002	0.000	0.008	0.016
52	Retail and repairs	7.501	5.165	3.875	0.001	0.000	0.005	0.003
55	Accommodation and catering	7.379	5.175	3.809	0.001	0.000	0.004	0.003
60	Transport on land	7.841	5.699	3.924	0.002	0.000	0.004	0.005
63	Transport services	7.939	5.336	3.862	0.003	0.000	0.008	0.011
72	Computer services	7.704	4.407	3.589	0.004	-0.001	0.015	0.052
74	Other business services	7.779	4.490	3.672	0.002	-0.001	0.010	0.012
90	Environmental services	7.192	5.339	2.973	0.001	-0.008	0.004	0.021
DA	Food and tobacco	8.542	6.492	4.448	0.002	-0.003	0.004	0.034
DN	Other manufacturing	8.464	5.739	4.654	0.002	-0.001	0.005	0.019
F	Construction	7.893	4.670	3.963	0.001	-0.001	0.004	0.004

Value added and depreciation cost in logs and prices of 2005. Employment in logs. Investment ratios based on price levels of 2005.

Table 5. Production function estimation (GMM)

industry	name	capital	p-value	labour	p-value	RTS
1700a	Apparel and leather	0.19	0.000	0.86	0.000	1.05
21	Paper	0.33	0.000	0.71	0.000	1.04
22	Publishing and printing	0.21	0.000	0.81	0.000	1.01
24	Chemicals	0.33	0.000	0.63	0.000	0.96
25	Rubber, plastics	0.32	0.000	0.69	0.000	1.00
26	Construction materials	0.15	0.000	0.88	0.000	1.03
27	Basic metal	0.13	0.000	0.93	0.000	1.06
28	Metal	0.09	0.026	0.96	0.000	1.06
29	Machines	0.12	0.000	0.98	0.000	1.09
30t32	Equipment	0.07	0.059	1.01	0.000	1.08
33	Medical equipment	0.16	0.000	0.84	0.000	1.01
50	Trade in cars and car repairs	0.28	0.000	0.70	0.000	0.98
51	Wholesale	0.27	0.000	0.74	0.000	1.01
52	Retail and repairs	0.38	0.000	0.62	0.000	1.00
60	Transport on land	0.49	0.000	0.55	0.000	1.04
63	Transport services	0.21	0.000	0.72	0.000	0.93
72	Computer services	0.12	0.000	0.85	0.000	0.97
74	Other business services	0.20	0.000	0.93	0.000	1.13
90	Environmental services	0.21	0.000	0.85	0.000	1.06
DA	Food and tobacco	0.35	0.000	0.70	0.000	1.05
DN	Other manufacturing	0.23	0.000	0.73	0.000	0.96
F	Construction	0.10	0.000	0.93	0.000	1.04

Regression of TFP growth on pooled data for positive INV and R&D

	estimate	p-value
INV/VA	0.017	0.951
R&D/VA	0.045	0.386
(INV/VA)*(R&D/VA)	80.86	0.046
intercept	0.031	0.000

Alternative specification

Table 1. Regression of TFP growth on ICT and R&D, Dutch firm data, 2000-2012

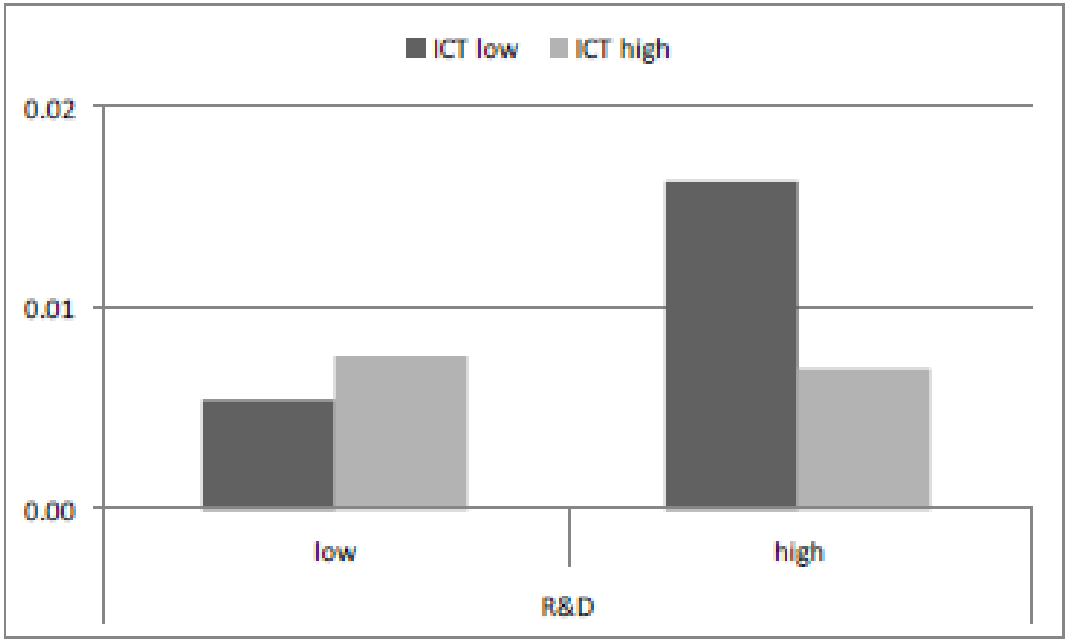
	Coef.	Std. Err.	p-value	
ICT	-0.007	0.008	0.370	
High ICT (dummy)	0.018	0.014	0.185	
ICT*High ICT	0.029	0.012	0.016	*
R&D	0.008	0.005	0.087	*
High R&D (dummy)	0.000	0.012	0.997	
R&D*High R&D	-0.001	0.010	0.933	
ICT*R&D	0.001	0.002	0.795	
High ICT*High R&D (dummy)	-0.019	0.013	0.136	
(ICT*R&D)*(High ICT*high R&D)	0.001	0.001	0.362	
Constant	0.005	0.014	0.737	

Regression of TFP growth for positive INV and R&D by industry

- In 6 out of 23 industries positive and significant interaction terms, one industry has a negative significant interaction term

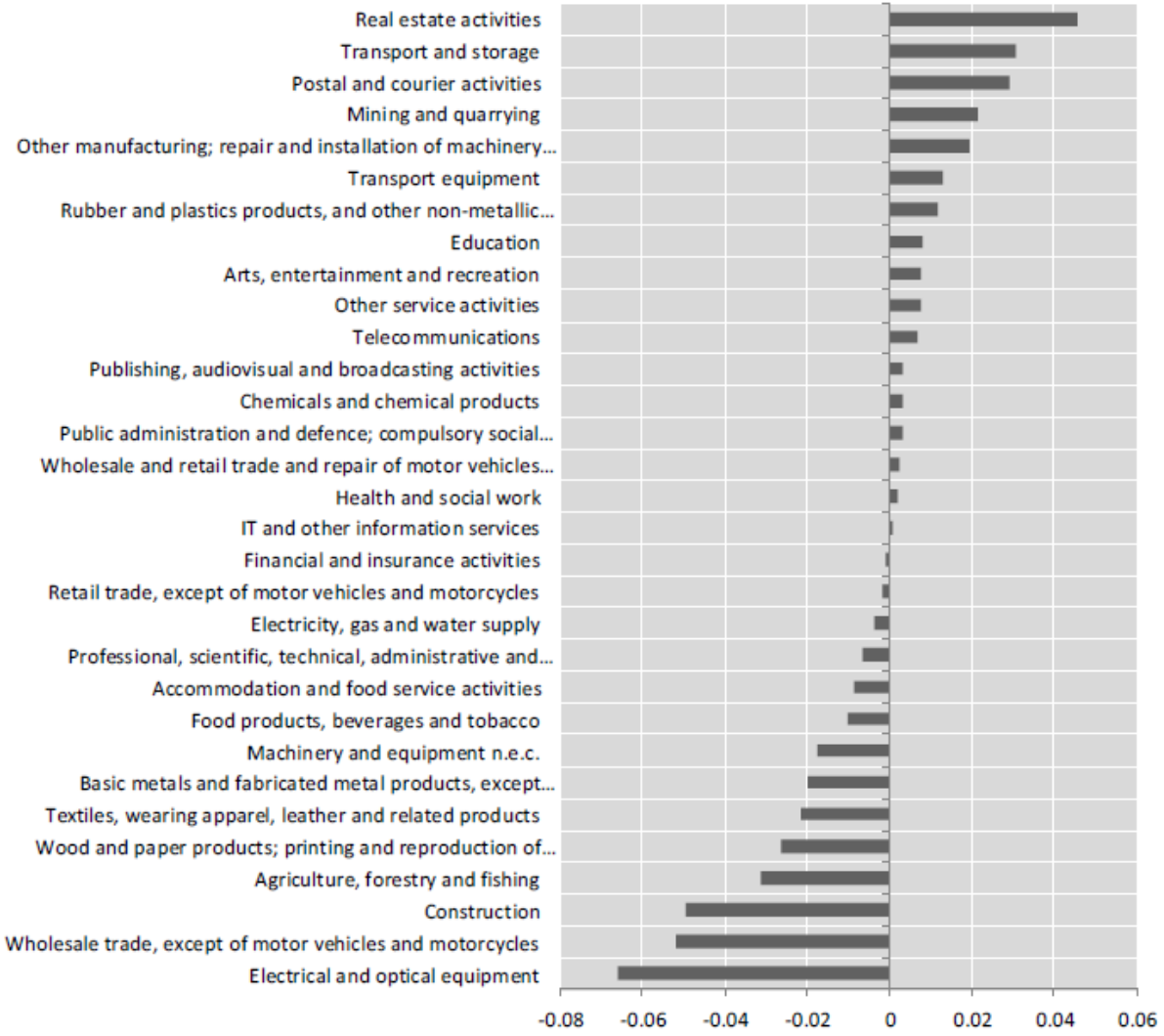
Evidence from pooled meso data

- 2016 release of EU-KLEMS for 9 countries, 32 manufacturing and services sectors, 1995-2014



Evidence at the meso level

Figure 6. Complementarity across industry



Conclusions

- There is a clear complementarity between ICT, R&D and organizational innovation at the adoption stage
- Complementarity is less clear cut at the outcome stage in terms of productivity
- There is quite some variability between industries

Next steps

- Include software ICT (data available from 2012)
- Consider different types of organizational innovations
- Industry-specific measure of ICT dummy
- Estimate R&D and ICT elasticities instead of marginal productivities
- Try to integrate the binary and continuous analyses