The Innovative Input Mix

Assessing the importance of R&D and ICT investments for firm performance in manufacturing and services

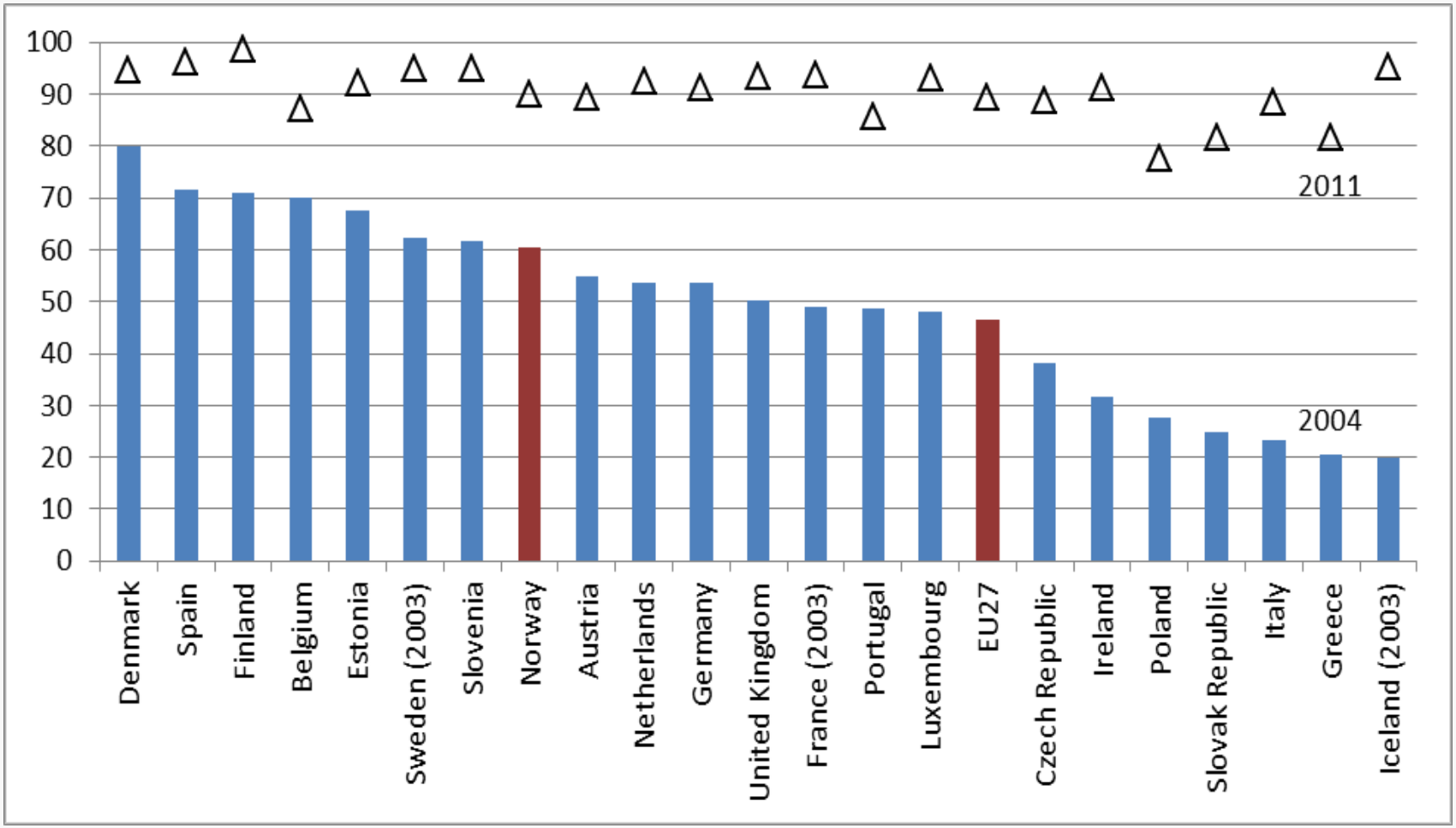
Marina Rybalka

Statistics Norway, Research Department

Motivation

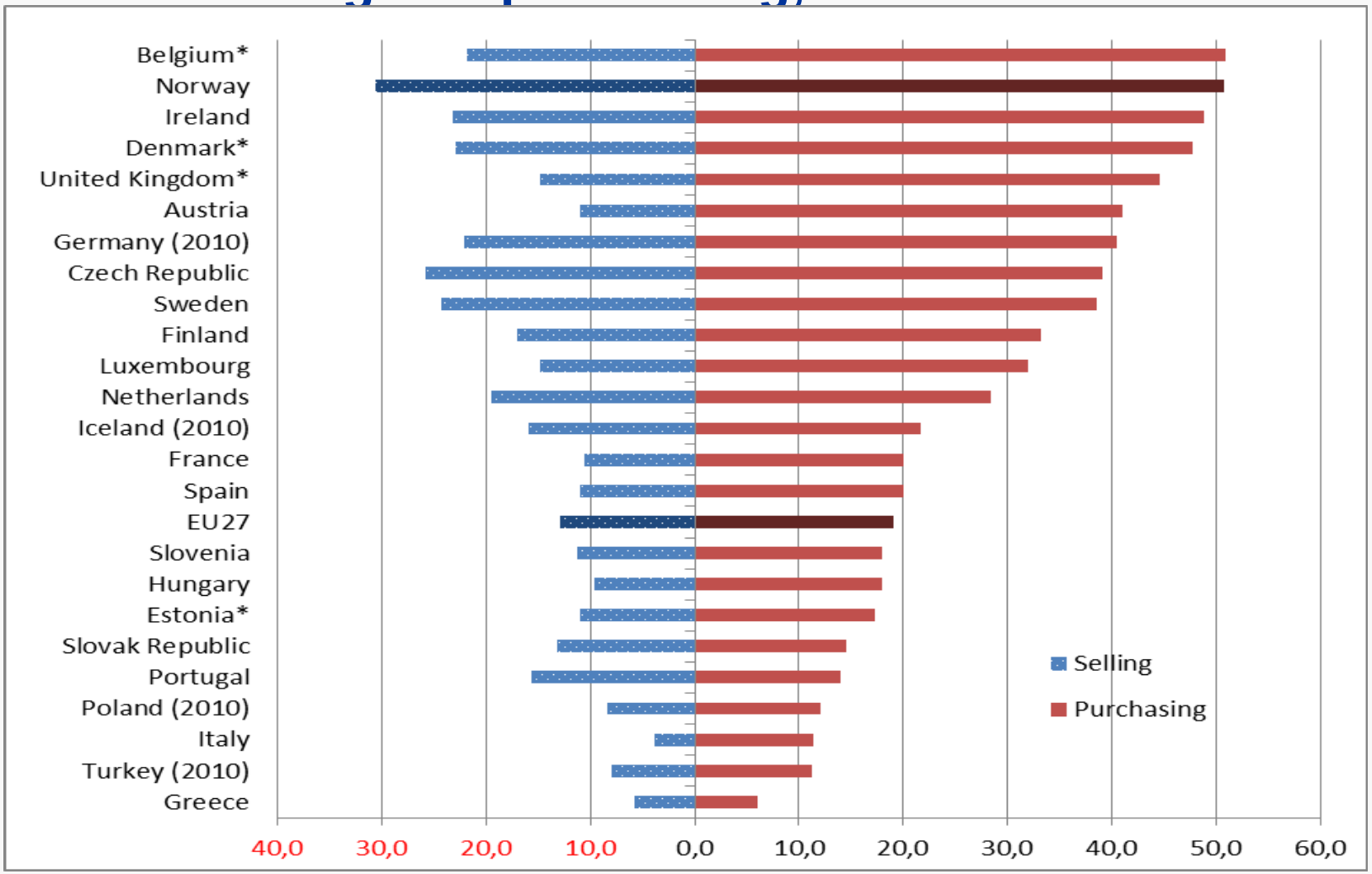
- Increasing integration of Information and Communication Technologies (ICT) in everyday life
- Many studies since 90's on effects of ICT on productivity. **But still few on innovations!**
- Availability of micro data that allow analyzing the effects of ICT at the firm level
- Application for policy decisions
- Norway, as other Scandinavian countries, is among forwards in implementation of ICT technologies.
  - Could intensive ICT-use explain a rapid increase of productivity in Norway despite relatively low R&D investment?

Business use of broadband by enterprises in 2004 and 2011



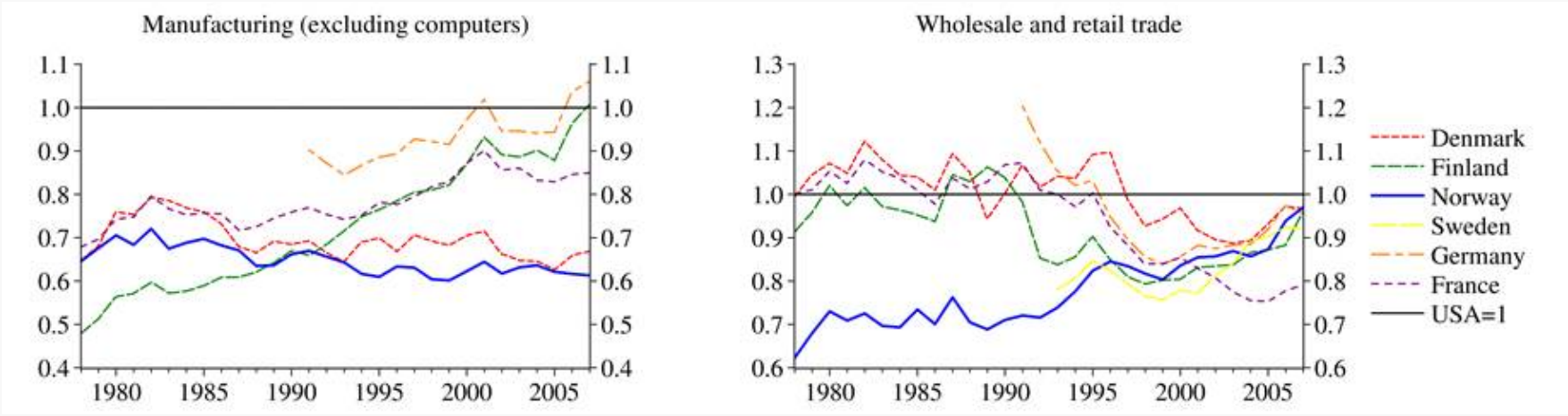
Source: OECD, Key ICT Indicators

Internet selling and purchasing, all industries in 2011



Source: OECD, Key ICT Indicators. * 2010 only for Purchasing

TFP levels in Manufacturing and Wholesale and Retail trade in 1978-2007 (relative to the U.S. industry equivalents)

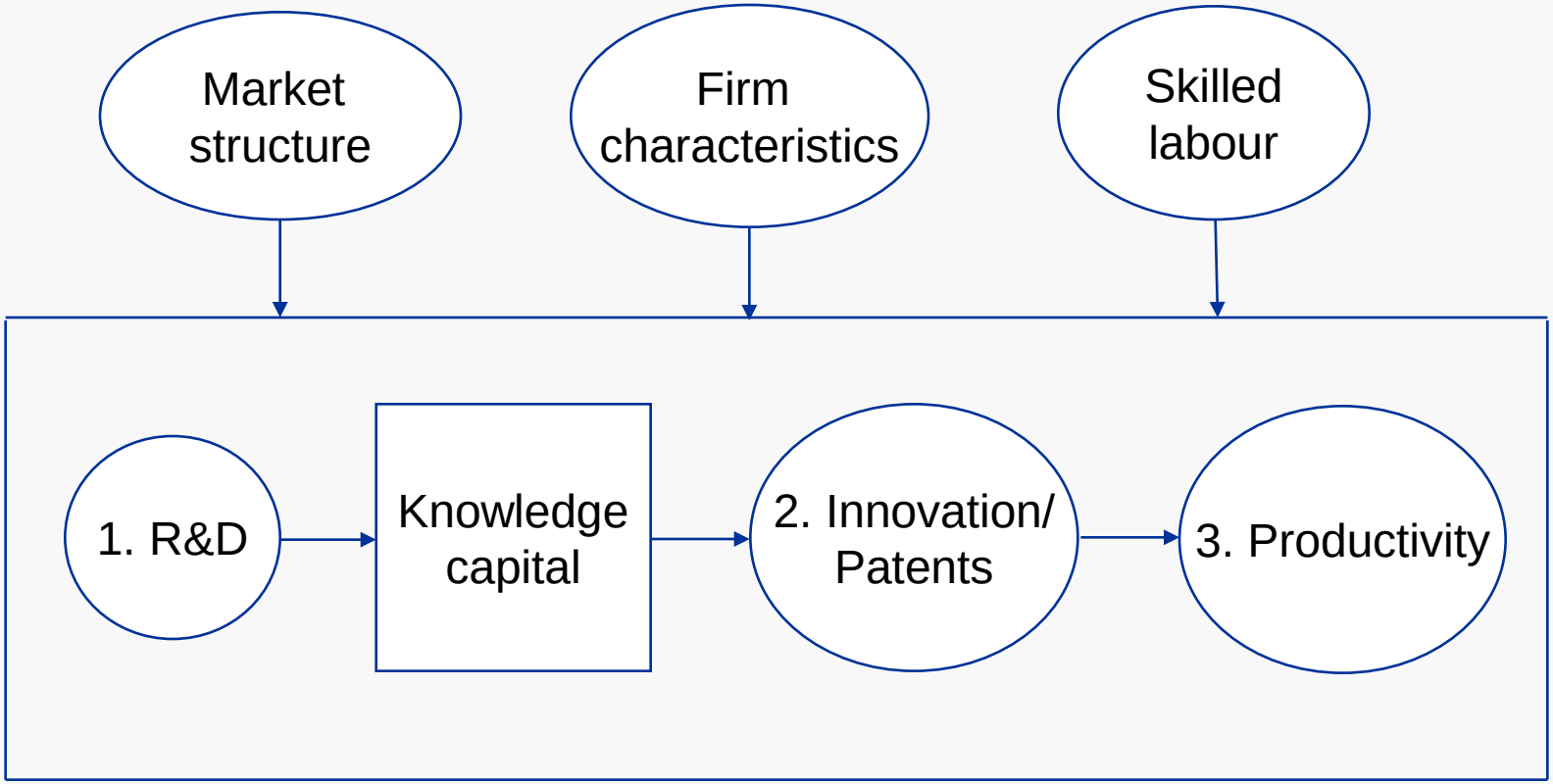


Source: Thomas von Brasch (2015) based on OECD and EU-KLEMS data.

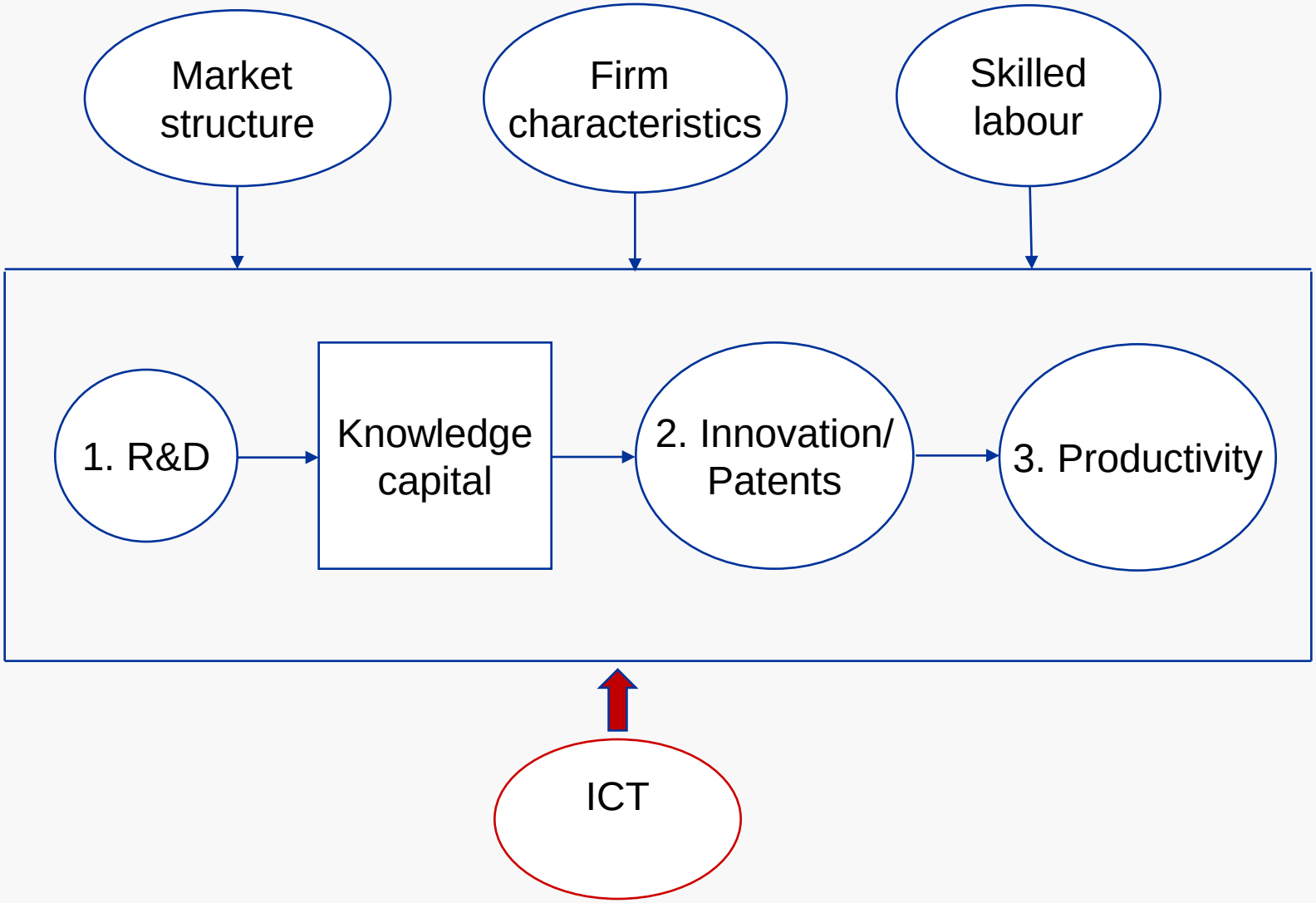
Why do we expect positive effect of ICT on firm performance?

- The possible benefits of ICT use for a firm:
  - savings of inputs
  - general cost reductions
  - greater flexibility of the production process
- The use of ICT can lead to productivity gains
  - directly, through reduced production time
  - indirectly, through improved communication possibilities among employees and reduced co-ordination costs
- Use of ICT may also stimulate the innovation activity
  - leading to higher product and service quality
  - creation of new products and services

A simple CDM model outline



A simple CDM model outline



Most relevant papers

- Hall, B.H., F. Lotti and J. Mairesse (2013)

  Evidence on the Impact of R&D and ICT Investment on Innovation and Productivity in Italian Firms‘

  Economics of Innovation and New Technology, 22(3), 300-328

  - product, process and organisational innovation
  - manufacturing sector
  - links between ICT and both innovation and productivity

- Polder, M., G. van Leeuwen, P. Mohnen and W. Raymond (2009)

  Productivity effects of innovation modes, MPRA Paper No. 18893

  - product, process and organisational innovation
  - manufacturing vs services
  - link between ICT and innovation only

Modeling framework 1: R&D decision

- Model: sample selection model
  - R&D decision: $$rd_{it} = \begin{cases} 1 & \text{if } rd^{*}_{it} = x^{rd}_{it}\alpha_1 + e_{it} > c \\ 0 & \text{else} \end{cases}$$
  - R&D intensity: $$r^{*}_{it} = x^{r}_{it}\alpha_2 + \varepsilon_{it}$$
    - Dependent variable: R&D expenditures per employee (in log)
- Estimation:
  - ML for Heckman selection model

Modeling framework 2: Innovation output

$$INNO_{it}^{*} = \delta_1 \cdot r_{it} + \delta_2 \cdot ict_{it} + x_{it}^{inno}\beta + \eta_{it}$$

- Dependent variables:
  - Probability of any innovation
  - Probability of different types of innovations
    - new product
    - new process
    - new organisation
    - new marketing
  - Number of patent applications
- Model:
  - simple probit model
  - multivariate probit model for system of 4 equations
  - zero inflated negative binomial count data model

Modeling framework 3: Production function

- Model: Cobb-Douglas production function

$$Y_{it} = F(A_{it}, K_{it}, ICTK_{it}, L_{it}) = A_{it} K_{it}^{\gamma_1} ICTK_{it}^{\gamma_2} L_{it}^{\gamma_3}$$

$$\ln(A_{it}) = \pi_0 + \pi_1 INNO_{it}^{*} + \pi_2 FSP_{it} + \zeta_{it}$$

$$L_{it} = N_{l,it} + (1+\theta) N_{h,it} = N_{it}(1+\theta h_{it})$$

$$lp_{it} = \pi_0 + \gamma_1 k_{it} + \gamma_2 ictk_{it} + \gamma_3^{*} l_{it} + \gamma_4 h_{it} + \pi_1 INNO_{it}^{*} + \pi_2 FSP_{it} + \zeta_{it}$$

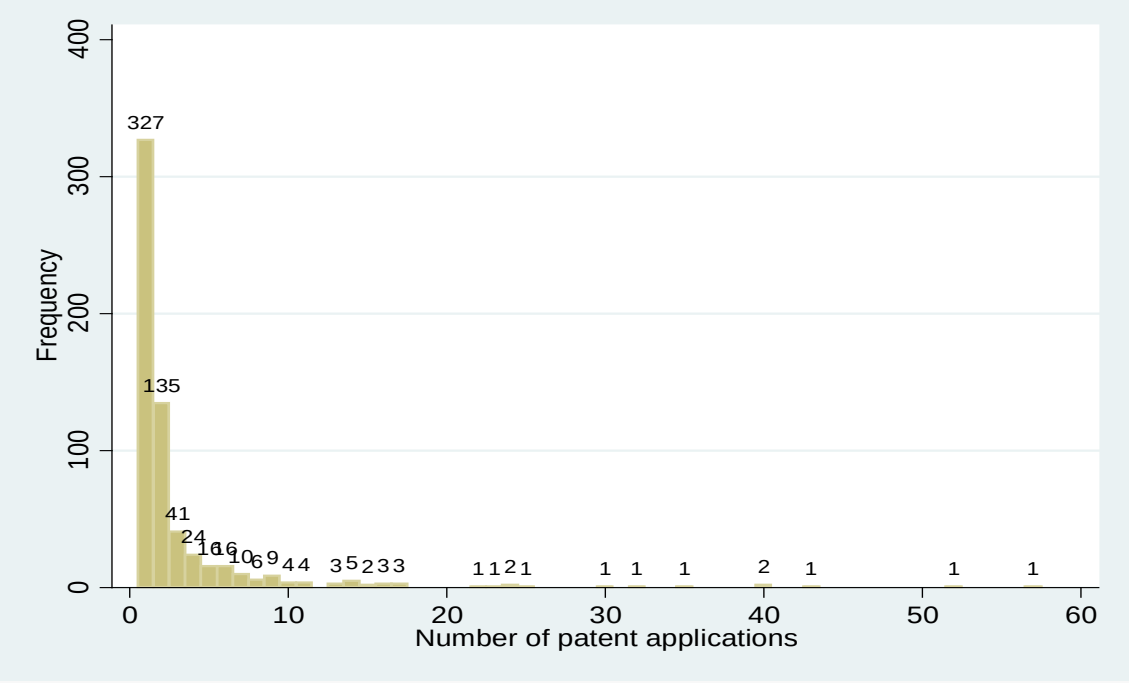
- Dependent variable:
  - Log value added per employee
- Estimation:
  - OLS regression

Data

- Main data: CIS 2004, 2006, 2008 and 2010
  - about 4500-6500 firms in each survey
- Other data 2002-2010:
  - For R&D variables: R&D surveys
  - For patents: Patent database from the Norwegian Patent Office
  - For ICT variables: Investment statistics
  - For human capital: National educational database
    - share of employees with post-secondary education
  - For VA and tangible capital: Accounts statistics
- Level of coverage:
  - all industries: 14533 observations (8554 firms)
  - manufacturing: 6199 observations (3386 firms)
  - services: 6145 observations (3947 firms)

Data: Innovation variables

Variable	Obs	Mean	Std. Dev.	Min	Max
pdt	14533	.2882406	.4529592	0	1
pcs	14533	.2145462	.4105213	0	1
org	14533	.2164040	.4118070	0	1
mkt	14533	.2578958	.4374914	0	1
inno	14533	.4793917	.4995923	0	1
patent	14533	.1009427	.3012632	0	1
sumpat	14533	.2086286	1.600936	0	76



Estimation 1: R&D choice

Dependent variables	(1) Selection R&D^ R&D>0	Log R&D per emp	(2) OLS Log R&D per emp	(3) Selection ICT^ ICT>0	Log ICT per emp	(4) OLS Log ICT per emp
Log employment	0.104	-0.765***	-0.666***	0.518***	0.091*	0.091*
	[0.063]	[0.096]	[0.094]	[0.063]	[0.051]	[0.051]
Log employment squared	0.003	0.036***	0.030***	-0.043***	-0.010	-0.010
	[0.007]	[0.011]	[0.011]	[0.008]	[0.006]	[0.006]
Market location: National	0.331***	0.245***	0.312***	0.081**	0.153***	0.153***
	[0.035]	[0.052]	[0.051]	[0.036]	[0.026]	[0.026]
Market location: European	0.521***	0.461***	0.558***	0.041	0.198***	0.198***
	[0.053]	[0.068]	[0.066]	[0.061]	[0.045]	[0.045]
Market location: World	0.601***	0.702***	0.802***	-0.022	0.312***	0.312***
	[0.062]	[0.075]	[0.072]	[0.073]	[0.052]	[0.052]
Part of a group	-0.046	0.103**	0.101**	-0.077**	0.079***	0.079***
	[0.035]	[0.046]	[0.046]	[0.034]	[0.026]	[0.026]
Hampering factor: high costs	0.280***	-0.053**	-0.011	0.041**	-0.012	-0.012
	[0.018]	[0.023]	[0.022]	[0.020]	[0.013]	[0.013]
Hampering factor: staff	0.136***	0.084***	0.104***	0.028	0.046***	0.046***
	[0.021]	[0.022]	[0.022]	[0.025]	[0.016]	[0.016]
Hampering factor: information	0.111***	-0.023	-0.010	0.035	-0.018	-0.018
	[0.024]	[0.026]	[0.026]	[0.029]	[0.019]	[0.019]
Cooperation in innovation		0.241***	0.252***		0.188***	0.188***
		[0.039]	[0.039]		[0.031]	[0.031]
Received subsidies		0.719***	0.738***		0.137***	0.137***
		[0.041]	[0.041]		[0.032]	[0.032]
Positive investment history	1.732***			0.914***		
	[0.042]			[0.076]		
Chi-square or F-test for age dummies		58.80***	0.51		20.23**	1.90*
Chi-square or F-test for industry dummies		828.21***	20.30***		2419.54***	80.18***
Chi-square or F-test for regional dummies		23.54**	2.43**		53.49***	8.13***
Chi-square or F-test for time dummies		165.66***	2.29*		765.45***	237.19***
Correlation coefficient rho		-0.239***			-0,003	
Chi-square for selection		27.17***			0.01	
R-squared		0.50	0.49		0.29	0.29
Number of obs.(uncensored)		14533(4377)	4377		14533(12982)	12982

Notes: All regressions include a constant, dummies for firm age, industry and location, and time dummies. Reference group: Local/regional market location, year 2004, Wholesale industry (NACE 51), mature firms (16 years old or older) in the capital region (Oslo and Akershus). The standard errors [in brackets] are robust to heteroscedasticity and clustered at the firm level.
^ Estimated by maximum loglikelihood as a Heckman selection model.
*** p<0.01, ** p<0.05, * p<0.1

Estimation 1: ICT choice

Dependent variables	(1) Selection R&D^ R&D>0	Log R&D per emp	(2) OLS Log R&D per emp	(3) Selection ICT^ ICT>0	Log ICT per emp	(4) OLS Log ICT per emp
Log employment	0.104	-0.765***	-0.666***	0.518***	0.091*	0.091*
	[0.063]	[0.096]	[0.094]	[0.063]	[0.051]	[0.051]
Log employment squared	0.003	0.036***	0.030***	-0.043***	-0.010	-0.010
	[0.007]	[0.011]	[0.011]	[0.008]	[0.006]	[0.006]
Market location: National	0.331***	0.245***	0.312***	0.081**	0.153***	0.153***
	[0.035]	[0.052]	[0.051]	[0.036]	[0.026]	[0.026]
Market location: European	0.521***	0.461***	0.558***	0.041	0.198***	0.198***
	[0.053]	[0.068]	[0.066]	[0.061]	[0.045]	[0.045]
Market location: World	0.601***	0.702***	0.802***	-0.022	0.312***	0.312***
	[0.062]	[0.075]	[0.072]	[0.073]	[0.052]	[0.052]
Part of a group	-0.046	0.103**	0.101**	-0.077**	0.079***	0.079***
	[0.035]	[0.046]	[0.046]	[0.034]	[0.026]	[0.026]
Hampering factor: high costs	0.280***	-0.053**	-0.011	0.041**	-0.012	-0.012
	[0.018]	[0.023]	[0.022]	[0.020]	[0.013]	[0.013]
Hampering factor: staff	0.136***	0.084***	0.104***	0.028	0.046***	0.046***
	[0.021]	[0.022]	[0.022]	[0.025]	[0.016]	[0.016]
Hampering factor: information	0.111***	-0.023	-0.010	0.035	-0.018	-0.018
	[0.024]	[0.026]	[0.026]	[0.029]	[0.019]	[0.019]
Cooperation in innovation		0.241***	0.252***		0.188***	0.188***
		[0.039]	[0.039]		[0.031]	[0.031]
Received subsidies		0.719***	0.738***		0.137***	0.137***
		[0.041]	[0.041]		[0.032]	[0.032]
Positive investment history	1.732***			0.914***		
	[0.042]			[0.076]		
Chi-square or F-test for age dummies		58.80***	0.51		20.23**	1.90*
Chi-square or F-test for industry dummies		828.21***	20.30***		2419.54***	80.18***
Chi-square or F-test for regional dummies		23.54**	2.43**		53.49***	8.13***
Chi-square or F-test for time dummies		165.66***	2.29*		765.45***	237.19***
Correlation coefficient rho		-0.239***			-0,003	
Chi-square for selection		27.17***			0.01	
R-squared		0.50	0.49		0.29	0.29
Number of obs.(uncensored)		14533(4377)	4377		14533(12982)	12982

Notes: All regressions include a constant, dummies for firm age, industry and location, and time dummies. Reference group: Local/regional market location, year 2004, Wholesale industry (NACE 51), mature firms (16 years old or older) in the capital region (Oslo and Akershus). The standard errors [in brackets] are robust to heteroscedasticity and clustered at the firm level.
^ Estimated by maximum loglikelihood as a Heckman selection model.
*** p<0.01, ** p<0.05, * p<0.1

Estimation 2: Innovation output

Dependent variables:	Four types of innovation^												Any innovation ~		
	Product			Process			Organisational			Marketing					
	Coeff.		S.e.	Coeff.		S.e.	Coeff.		S.e.	Coeff.		S.e.	Coeff.		S.e.
All firms (14533 observations, 8854 firms)															
Log R&D intensity (predicted)	0,895	***	0,043	0,541	***	0,041	0,246	***	0,039	0,387	***	0,038	0,836	***	0,043
Share of high skilled	0,694	***	0,084	0,036		0,082	0,245	***	0,082	0,277	***	0,076	0,500	***	0,076
Log ICT intensity	0,054	***	0,012	0,042	***	0,012	0,044	***	0,011	0,022	**	0,011	0,046	***	0,010
No ICT investment(d)	-0,107	**	0,054	-0,123	**	0,053	-0,057		0,053	-0,110	**	0,048	-0,125	***	0,044
Non-zero observations	4189			3118			3145			3748			6967		
Chi-squared for all rho=0	3504,38	***													
Manufacturing firms (6199 observations, 3386 firms)															
Log R&D intensity (predicted)	0,800	***	0,061	0,598	***	0,059	0,165	***	0,057	0,360	***	0,054	0,803	***	0,063
Share of high skilled	0,814	***	0,150	-0,038		0,154	0,389	***	0,149	0,453	***	0,138	0,780	***	0,143
Log ICT intensity	0,089	***	0,019	0,043	**	0,018	0,048	***	0,019	0,053	***	0,018	0,074	***	0,018
No ICT investment(d)	-0,068		0,074	-0,286	***	0,075	-0,169	**	0,081	-0,050		0,070	-0,165	**	0,066
Non-zero observations	2217			1590			1467			1848			3412		
Chi-squared for all rho=0	1382,10	***													
Firms in Services (6145 observations, 3947 firms)															
Log R&D intensity (predicted)	0,953	***	0,063	0,457	***	0,060	0,316	***	0,058	0,378	***	0,058	0,812	***	0,062
Share of high skilled	0,592	***	0,104	0,083		0,102	0,221	**	0,108	0,169	*	0,097	0,385	***	0,096
Log ICT intensity	0,035	**	0,017	0,042	**	0,016	0,037	**	0,016	-0,001		0,015	0,026	*	0,015
No ICT investment(d)	-0,153	*	0,091	0,061		0,085	0,043		0,088	-0,190	**	0,077	-0,118		0,073
Non-zero observations	1827			1327			1330			1677			2997		
Chi-squared for independence (all rho=0)	1749.67	***													

Note: All regressions include a constant, firm age and location, and time dummies. The standard errors are robust to heteroscedasticity and clustered at the firm level.

^ Estimated by maximum loglikelighood as quadrivariate probit model; ~ Estimated by maximum loglikelighood as simple probit model

*** p<0.01, ** p<0.05, * p<0.1

Estimation 2: Innovation output

	Four types of innovation^												Any innovation ~		
Dependent variables:	Product			Process			Organisational			Marketing					
	Coeff.		S.e.	Coeff.		S.e.	Coeff.		S.e.	Coeff.		S.e.	Coeff.		S.e.
All firms (14533 observations, 8854 firms)															
Log R&D intensity (predicted)	0,895	***	0,043	0,541	***	0,041	0,246	***	0,039	0,387	***	0,038	0,836	***	0,043
Share of high skilled	0,694	***	0,084	0,036		0,082	0,245	***	0,082	0,277	***	0,076	0,500	***	0,076
Log ICT intensity	0,054	***	0,012	0,042	***	0,012	0,044	***	0,011	0,022	**	0,011	0,046	***	0,010
No ICT investment(d)	-0,107	**	0,054	-0,123	**	0,053	-0,057		0,053	-0,110	**	0,048	-0,125	***	0,044
Non-zero observations	4189			3118			3145			3748			6967		
Chi-squared for all rho=0	3504,38	***													
Manufacturing firms (6199 observations, 3386 firms)															
Log R&D intensity (predicted)	0,800	***	0,061	0,598	***	0,059	0,165	***	0,057	0,360	***	0,054	0,803	***	0,063
Share of high skilled	0,814	***	0,150	-0,038		0,154	0,389	***	0,149	0,453	***	0,138	0,780	***	0,143
Log ICT intensity	0,089	***	0,019	0,043	**	0,018	0,048	***	0,019	0,053	***	0,018	0,074	***	0,018
No ICT investment(d)	0,068		0,074	-0,286	***	0,075	-0,169	**	0,081	-0,050		0,070	-0,165	**	0,066
Non-zero observations	2217			1590			1467			1848			3412		
Chi-squared for all rho=0	1382,10	***													
Firms in Services (6145 observations, 3947 firms)															
Log R&D intensity (predicted)	0,953	***	0,063	0,457	***	0,060	0,316	***	0,058	0,378	***	0,058	0,812	***	0,062
Share of high skilled	0,592	***	0,104	0,083		0,102	0,221	**	0,108	0,169	*	0,097	0,385	***	0,096
Log ICT intensity	0,035	**	0,017	0,042	**	0,016	0,037	**	0,016	-0,001		0,015	0,026	*	0,015
No ICT investment(d)	-0,153	*	0,091	0,061		0,085	0,043		0,088	-0,190	**	0,077	-0,118		0,073
Non-zero observations	1827			1327			1330			1677			2997		
Chi-squared for independence (all rho=0)	1749.67	***													

Note: All regressions include a constant, firm age and location, and time dummies. The standard errors are robust to heteroscedasticity and clustered at the firm level.

^ Estimated by maximum loglikelighood as quadrivariate probit model; ~ Estimated by maximum loglikelighood as simple probit model

*** p<0.01, ** p<0.05, * p<0.1

Estimation 2: Innovation output

	Four types of innovation^														
Dependent variables:	Product			Process			Organisational			Marketing			Any innovation ~		
	Coeff.		S.e.	Coeff.		S.e.	Coeff.		S.e.	Coeff.		S.e.	Coeff.		S.e.
All firms (14533 observations, 8854 firms)															
Log R&D intensity (predicted)	0,895	***	0,043	0,541	***	0,041	0,246	***	0,039	0,387	***	0,038	0,836	***	0,043
Share of high skilled	0,694	***	0,084	0,036		0,082	0,245	***	0,082	0,277	***	0,076	0,500	***	0,076
Log ICT intensity	0,054	***	0,012	0,042	***	0,012	0,044	***	0,011	0,022	**	0,011	0,046	***	0,010
No ICT investment(d)	-0,107	**	0,054	-0,123	**	0,053	-0,057		0,053	-0,110	**	0,048	-0,125	***	0,044
Non-zero observations	4189			3118			3145			3748			6967		
Chi-squared for all rho=0	3504,38	***													
Manufacturing firms (6199 observations, 3386 firms)															
Log R&D intensity (predicted)	0,800	***	0,061	0,598	***	0,059	0,165	***	0,057	0,360	***	0,054	0,803	***	0,063
Share of high skilled	0,814	***	0,150	-0,038		0,154	0,389	***	0,149	0,453	***	0,138	0,780	***	0,143
Log ICT intensity	0,089	***	0,019	0,043	**	0,018	0,048	***	0,019	0,053	***	0,018	0,074	***	0,018
No ICT investment(d)	-0,068		0,074	-0,286	***	0,075	-0,169	**	0,081	-0,050		0,070	-0,165	**	0,066
Non-zero observations	2217			1590			1467			1848			3412		
Chi-squared for all rho=0	1382,10	***													
Firms in Services (6145 observations, 3947 firms)															
Log R&D intensity (predicted)	0,953	***	0,063	0,457	***	0,060	0,316	***	0,058	0,378	***	0,058	0,812	***	0,062
Share of high skilled	0,592	***	0,104	0,083		0,102	0,221	**	0,108	0,169	*	0,097	0,385	***	0,096
Log ICT intensity	0,035	**	0,017	0,042	**	0,016	0,037	**	0,016	-0,001		0,015	0,026	*	0,015
No ICT investment(d)	-0,153	*	0,091	0,061		0,085	0,043		0,088	-0,190	**	0,077	-0,118		0,073
Non-zero observations	1827			1327			1330			1677			2997		
Chi-squared for independence (all rho=0)	1749.67	***													

Note: All regressions include a constant, firm age and location, and time dummies. The standard errors are robust to heteroscedasticity and clustered at the firm level.

^ Estimated by maximum loglikelighood as quadrivariate probit model; ~ Estimated by maximum loglikelighood as simple probit model

*** p<0.01, ** p<0.05, * p<0.1

Estimation results for the number of patents

Sample:	All firms		Manufacturing		Services	
Log R&D intensity (predicted)	0.898***	[0.093]	0.419***	[0.120]	1.500***	[0.142]
Share of high skilled	1.656***	[0.219]	2.190***	[0.310]	1.159***	[0.307]
Log ICT intensity	0.086***	[0.030]	0.104***	[0.037]	0.077*	[0.046]
Zero ICT investment	0.408***	[0.158]	0.282	[0.174]	0.446*	[0.264]
Log employment	1.145***	[0.153]	0.663***	[0.238]	1.983***	[0.251]
Log employment squared	-0.031**	[0.016]	0.010	[0.022]	-0.108***	[0.026]
Cooperation: National	0.039	[0.088]	0.152	[0.104]	-0.074	[0.158]
Cooperation: Scandinavia	0.041	[0.101]	-0.018	[0.120]	0.158	[0.191]
Cooperation: EU	0.241**	[0.104]	0.275**	[0.126]	0.187	[0.187]
Cooperation: World	0.176	[0.113]	0.217	[0.142]	-0.051	[0.207]
Purchased R&D	0.369***	[0.080]	0.339***	[0.097]	0.405***	[0.137]
Inflation (any innovation)	-35.659***	[2.977]	-5.598***	[1.912]	-53.474***	[3.156]
Log likelihood	-4724.486		-2694.006		-1726.743	
Alpha for NB vs Poisson specification	1.24		0.89		1.67	
Vuong test for zero inflated specification	8.38***		5.36***		5.09***	
Number of observations (non-zero)	14533(1467)		6392 (900)		6145(503)	

Note: All regressions include a constant, firm age, industry and location, and time dummies. Reference group: Local/regional market location, year 2004, Manufacture of food products and beverages (NACE15) for Manufacturing firms or Wholesale (NACE51) for firms in Services, mature firms (16 years old or older)) in the capital region (Oslo and Akershus). The standard errors are robust to heteroscedasticity and clustered at the firm level.
Estimated by pseudo maximum loglikelihood as a zero inflated negative binomial (NB) count data model.
*** p<0.01, ** p<0.05, * p<0.1

Estimation results for the number of patents

Sample:	All firms		Manufacturing		Services	
Log R&D intensity (predicted)	0.898***	[0.093]	0.419***	[0.120]	1.500***	[0.142]
Share of high skilled	1.656***	[0.219]	2.190***	[0.310]	1.159***	[0.307]
Log ICT intensity	0.086***	[0.030]	0.104***	[0.037]	0.077*	[0.046]
Zero ICT investment	0.408***	[0.158]	0.282	[0.174]	0.446*	[0.264]
Log employment	1.145***	[0.153]	0.663***	[0.238]	1.983***	[0.251]
Log employment squared	-0.031**	[0.016]	0.010	[0.022]	-0.108***	[0.026]
Cooperation: National	0.039	[0.088]	0.152	[0.104]	-0.074	[0.158]
Cooperation: Scandinavia	0.041	[0.101]	-0.018	[0.120]	0.158	[0.191]
Cooperation: EU	0.241**	[0.104]	0.275**	[0.126]	0.187	[0.187]
Cooperation: World	0.176	[0.113]	0.217	[0.142]	-0.051	[0.207]
Purchased R&D	0.369***	[0.080]	0.339***	[0.097]	0.405***	[0.137]
Inflation (any innovation)	-35.659***	[2.977]	-5.598***	[1.912]	-53.474***	[3.156]
Log likelihood	-4724.486		-2694.006		-1726.743	
Alpha for NB vs Poisson specification	1.24		0.89		1.67	
Vuong test for zero inflated specification	8.38***		5.36***		5.09***	
Number of observations (non-zero)	14533(1467)		6392 (900)		6145(503)	

Note: All regressions include a constant, firm age, industry and location, and time dummies. Reference group: Local/regional market location, year 2004, Manufacture of food products and beverages (NACE15) for Manufacturing firms or Wholesale (NACE51) for firms in Services, mature firms (16 years old or older)) in the capital region (Oslo and Akershus). The standard errors are robust to heteroscedasticity and clustered at the firm level.
Estimated by pseudo maximum loglikelihood as a zero inflated negative binomial (NB) count data model.
*** p<0.01, ** p<0.05, * p<0.1

Conclusions for innovation output analysis

- ICT investment intensity is associated with all types of innovation
  - However, it is relatively less important compared to R&D investment intensity and skills of workforce
- The result for ICT is strongest for the product innovation in manufacturing and for the process innovation in services
- Not having any ICT investment is strongly negative
  - for process and organisational innovation in manufacturing
  - for product and marketing innovation in services
- Given that the firm innovates, ICT investment intensity is also associated with higher number of patent applications in manufacturing
  - with skills being relatively more important for patenting in manufacturing
  - with R&D being relatively more important for the patenting in services
- Both cooperation in innovation and purchase of R&D services from external providers are positively related to innovating and patenting

Estimation 3: Productivity

Dependent variable: Log VA per employee									
Sample:	All firms			Manufacturing			Services		
Innovation variable: Any innovation									
Probability of any innovation (predicted)	0.086***	0.052***	0.012*	0.081***	0.043***	0.012*	0.078***	0.045***	-0.015
	[0.007]	[0.007]	[0.007]	[0.007]	[0.007]	[0.007]	[0.012]	[0.012]	[0.012]
Log ICT capital intensity		0.107***	0.092***		0.117***	0.102***		0.110***	0.096***
		[0.005]	[0.005]		[0.006]	[0.006]		[0.007]	[0.007]
Share of high skilled			0.472***			0.491***			0.520***
			[0.031]			[0.045]			[0.035]
Log non-ICT capital intensity	0.097***	0.076***	0.086***	0.095***	0.078***	0.087***	0.097***	0.070***	0.081***
	[0.004]	[0.004]	[0.004]	[0.005]	[0.005]	[0.005]	[0.005]	[0.005]	[0.005]
R-squared	0.24	0.28	0.30	0.29	0.34	0.36	0.16	0.21	0.24
Innovation variable: Patent applications per employee									
Number of patents per empl. (predicted)	0.331***	0.240***	-0.053	0.801***	0.606***	0.220**	0.240***	0.201***	-0.033
	[0.059]	[0.057]	[0.056]	[0.098]	[0.093]	[0.096]	[0.066]	[0.064]	[0.063]
Log ICT capital per employee		0.112***	0.093***		0.122***	0.104***		0.113***	0.095***
		[0.005]	[0.005]		[0.006]	[0.006]		[0.007]	[0.007]
Share of high skilled			0.496***			0.475***			0.510***
			[0.031]			[0.045]			[0.034]
Log non-ICT capital per employee	0.101***	0.077***	0.086***	0.101***	0.081***	0.087***	0.098***	0.070***	0.081***
	[0.004]	[0.004]	[0.004]	[0.005]	[0.005]	[0.005]	[0.005]	[0.005]	[0.005]
R-squared	0.23	0.27	0.30	0.28	0.34	0.36	0.16	0.21	0.24
Number of observations	14427			6162			6086		
Note: Regressions also include a constant, age, industry, location and time dummies.									
The standard errors (in brackets) are robust to heteroscedasticity and clustered at the firm level.									
*** p<0.01, ** p<0.05, * p<0.1									

Estimation 3: Productivity

Predicted propensities from the quadrivariate probit knowledge production function (by industry)

	All firms		Manufacturing		Services	
Combinations*	Observed frequencies**	Predicted Mean	Observed frequencies**	Predicted Mean	Observed frequencies**	Predicted Mean
QP1111	0.0527	0.0593	0.0644	0.0725	0.0548	0.0599
QP1110	0.0202	0.0217	0.0268	0.0273	0.0171	0.0204
QP1101	0.0411	0.0384	0.0513	0.0463	0.0433	0.0442
QP1011	0.0246	0.0242	0.0318	0.0304	0.0241	0.0251
QP0111	0.0103	0.0107	0.0113	0.0110	0.0112	0.0116
QP0011	0.0266	0.0224	0.0231	0.0197	0.0303	0.0254
QP0101	0.0089	0.0088	0.0102	0.0113	0.0098	0.0094
QP0110	0.0189	0.0149	0.0197	0.0163	0.0176	0.0133
QP1001	0.0441	0.0418	0.0552	0.0540	0.0470	0.0430
QP1010	0.0150	0.0120	0.0186	0.0167	0.0158	0.0118
QP1100	0.0338	0.0309	0.0365	0.0356	0.0386	0.0332
QP0001	0.0495	0.0616	0.0510	0.0625	0.0524	0.0660
QP0010	0.0482	0.0607	0.0411	0.0530	0.0456	0.0600
QP0100	0.0287	0.0383	0.0365	0.0454	0.0236	0.0355
QP1000	0.0568	0.0692	0.0732	0.0844	0.0566	0.0739
QP0000	0.5206	0.5156	0.4496	0.4451	0.5123	0.5034
Number of obs.		14333		6199		6145
Number of draws		120		80		80

*QP refers to the combinations of the Quadrivariate Probit model for four innovation types: product, process, organisational and marketing innovation.
** In per cent

Estimation 3: Productivity

Innovation variable: Four types of innovation						
Log value added per employee	All firms		Manufacturing		Services	
QP1111 (predicted)	0.441**	[0.175]	0.096	[0.230]	0.375	[0.230]
QP1110 (predicted)	0.907	[0.674]	0.694	[0.727]	1.368	[0.950]
QP1101 (predicted)	-1.162***	[0.312]	-0.472	[0.417]	-0.868**	[0.364]
QP1011 (predicted)	-0.296	[0.674]	0.974	[0.909]	-0.387	[0.802]
QP0111 (predicted)	-1.569	[1.276]	-3.164**	[1.350]	-2.487	[1.848]
QP0011 (predicted)	1.126	[0.888]	0.961	[1.139]	2.035*	[1.107]
QP0101 (predicted)	1.449	[1.716]	3.059	[1.867]	-0.104	[2.107]
QP0110 (predicted)	0.100	[0.871]	1.500	[1.044]	-0.410	[1.349]
QP1001 (predicted)	1.713***	[0.472]	1.294**	[0.545]	0.974	[0.667]
QP1010 (predicted)	-0.663	[1.089]	-3.232**	[1.456]	1.485	[1.542]
QP1100 (predicted)	-1.178**	[0.504]	-1.323**	[0.663]	-0.589	[0.587]
QP0001 (predicted)	-0.706	[0.475]	-0.647	[0.567]	-0.891	[0.563]
QP0010 (predicted)	0.237	[0.299]	-0.455	[0.531]	0.685*	[0.396]
QP0100 (predicted)	1.218*	[0.644]	-0.641	[0.583]	4.855***	[0.909]
QP1000 (predicted)	0.503*	[0.278]	0.753***	[0.291]	-0.167	[0.417]
Log ICT capital intensity	0.090***	[0.005]	0.100***	[0.006]	0.088***	[0.007]
Share of high skilled	0.411***	[0.042]	0.355***	[0.065]	0.535***	[0.041]
Log capital intensity	0.085***	[0.004]	0.086***	[0.005]	0.080***	[0.005]
Log employment	0.075**	[0.034]	0.088**	[0.039]	0.034	[0.050]
Log employment squared	-0.006*	[0.003]	-0.002	[0.004]	-0.007	[0.005]
R-squared	0.30		0.36		0.25	
Number of observations	14427		6162		6086	
Note: Regression also includes a constant, age, industry, location and time dummies.						
The standard errors (in brackets) are robust to heteroscedasticity and clustered at the firm level.						
*** p<0.01, ** p<0.05, * p<0.1						

Estimation 3: Productivity

Innovation variable: Four types of innovation						
Log value added per employee	All firms		Manufacturing		Services	
QP1111 (predicted)	0.441**	[0.175]	0.096	[0.230]	0.375	[0.230]
QP1110 (predicted)	0.907	[0.674]	0.694	[0.727]	1.368	[0.950]
QP1101 (predicted)	-1.162***	[0.312]	-0.472	[0.417]	-0.868**	[0.364]
QP1011 (predicted)	-0.296	[0.674]	0.974	[0.909]	-0.387	[0.802]
QP0111 (predicted)	-1.569	[1.276]	-3.164**	[1.350]	-2.487	[1.848]
QP0011 (predicted)	1.126	[0.888]	0.961	[1.139]	2.035*	[1.107]
QP0101 (predicted)	1.449	[1.716]	3.059	[1.867]	-0.104	[2.107]
QP0110 (predicted)	0.100	[0.871]	1.500	[1.044]	-0.410	[1.349]
QP1001 (predicted)	1.713***	[0.472]	1.294**	[0.545]	0.974	[0.667]
QP1010 (predicted)	-0.663	[1.089]	-3.232**	[1.456]	1.485	[1.542]
QP1100 (predicted)	-1.178**	[0.504]	-1.323**	[0.663]	-0.589	[0.587]
QP0001 (predicted)	-0.706	[0.475]	-0.647	[0.567]	-0.891	[0.563]
QP0010 (predicted)	0.237	[0.299]	-0.455	[0.531]	0.685*	[0.396]
QP0100 (predicted)	1.218*	[0.644]	-0.641	[0.583]	4.855***	[0.909]
QP1000 (predicted)	0.503*	[0.278]	0.753***	[0.291]	-0.167	[0.417]
Log ICT capital intensity	0.090***	[0.005]	0.100***	[0.006]	0.088***	[0.007]
Share of high skilled	0.411***	[0.042]	0.355***	[0.065]	0.535***	[0.041]
Log capital intensity	0.085***	[0.004]	0.086***	[0.005]	0.080***	[0.005]
Log employment	0.075**	[0.034]	0.088**	[0.039]	0.034	[0.050]
Log employment squared	-0.006*	[0.003]	-0.002	[0.004]	-0.007	[0.005]
R-squared	0.30		0.36		0.25	
Number of observations	14427		6162		6086	
Note: Regression also includes a constant, age, industry, location and time dummies.						
The standard errors (in brackets) are robust to heteroscedasticity and clustered at the firm level.						
*** p<0.01, ** p<0.05, * p<0.1						

Estimation 3: Productivity

Innovation variable: Three types of innovation						
Log value added per employee	All firms		Manufacturing		Services	
TP111	0.454***	[0.106]	0.313**	[0.130]	0.245*	[0.137]
TP110	-1.075***	[0.164]	-0.559***	[0.189]	-0.671***	[0.209]
TP101	0.011	[0.305]	-0.269	[0.326]	0.835**	[0.363]
TP011	0.049	[0.438]	-0.274	[0.455]	0.300	[0.589]
TP001	0.164	[0.234]	-0.021	[0.319]	0.340	[0.283]
TP010	-0.238	[0.422]	-0.291	[0.394]	2.061***	[0.518]
TP100	1.186***	[0.194]	0.826***	[0.206]	0.277	[0.232]
Log ICT capital intensity	0.091***	[0.005]	0.101***	[0.006]	0.092***	[0.007]
Share of high skilled	0.357***	[0.040]	0.376***	[0.062]	0.521***	[0.041]
Log capital intensity	0.084***	[0.004]	0.086***	[0.005]	0.080***	[0.005]
Log employment	0.069**	[0.033]	0.081**	[0.038]	0.054	[0.048]
Log employment squared	-0.005	[0.003]	-0.002	[0.004]	-0.007	[0.005]
Observations	14427		6162		6086	
R-squared	0.30		0.36		0.24	
Robust standard errors in brackets						
*** p<0.01, ** p<0.05, * p<0.1						

Conclusions for productivity analysis

- ICT use has positive effect on the firm productivity independent on model specification
  - the effect is slightly higher in manufacturing industry than in services
- Importance of innovation for productivity
  - of product innovation in manufacturing
  - of process and organisational innovation in services
  - no any strong evidence for importance of marketing innovation (only in combination with product innovation in manufacturing)
- Accounting for the heterogeneity in the quality of labour is important for not overstating the productivity effects of innovation and ICT
- All inputs (innovation, ICT and human capital) are important for the productivity in manufacturing
  - ICT and human capital are relatively more important for the productivity in service industries

Main conclusions

- R&D and ICT are both strongly associated with innovation and productivity
  - with R&D being more important for innovation, and ICT being more important for productivity
  - important for the explanation of the «Norwegian productivity puzzle»
- There are considerable differences between firms in manufacturing and services
  - with respect to innovation and productivity effects of ICT, R&D and human capital
- Accounting for the ICT capital and heterogeneity in the quality of labour reduces substantially the innovation impact on productivity