The Role of E-skills in Technological Diversification in European Regions

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Appendix: Online supplemental data

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Appendix A: Computation of the technology-adjusted DP (diversification potential)

Our five-step method for computing the diversification potential is based on Santoalha (2019).

<u>Step 1: Computation of expected number of patents for each region i, technology z and year t</u>

$$E(N_{izt}) = N_{it}\ S_{zt} \qquad (1a)$$

such that:

$$N_{it} = \sum_{z=1}^{n} Nizt \qquad (2a)$$

$$S_{zt} = \frac{Nzt}{Nt} = \frac{\sum_{i=1}^{m} Nizt}{\sum_{i=1}^{m}\sum_{z=1}^{n} Nizt} \qquad (3a)$$

where N represents the number of patents; subscripts i, z and t refer to region i, technology z and year t; and m and n are the total number of regions and technologies existing in the sample. $E(N_{izt})$ is the expected number of patents for each region i, technology z and year t; N_{it} represents the total number of patents in region i at time t; and S_{zt} refers to the world (all regions) share of patents for technology z at time t.

<u>Step 2: Computation of expected number of specializations for each region i in year t</u>

$$E(Spec_{it}) = \sum_{z=1}^{n} [\text{E(Nizt) E(SpecRate zt)}]' \qquad (4a)$$

such that:

$$E(SpecRate_{zt}) = \frac{\text{NewSpeczt}}{Nzt} = \frac{\sum_{i=1}^{m} \text{NewSpecizt}}{\sum_{i=1}^{m} \text{Nizt}} \qquad (5a)$$

[E(Nizt) E(SpecRate zt)]' = 1 if E(Nizt) E(SpecRate zt) ≥ 1

(6a)

$[E(N_{izt})\ E(SpecRate_{zt})]' = 0$ if $E(N_{izt})\ E(SpecRate_{zt}) < 1$

where $E(Spec_{it})$ is the expected number of specializations in region i and year t. $E(SpecRate_{zt})$ is the ratio between the number of specializations in technology z at time t, considering all regions included in the sample, and the number of patents in technology z at time t, again taking into account all regions included in the sample of observations. Condition (6a) is added to take into account the fact that the specialization status of a given region in a given technology z ($[E(N_{izt})\ E(SpecRate_{zt})]'$) is a dummy variable that takes the value 1 if a given region i is specialized in z, and 0 otherwise.

<u>Step 3: Computation of number of specializations caused by existing differences between the technological structure of each region and the average technological structure prevailing in all regions</u>

$$Dif_{it} = \sum_{z=1}^{n}[N_{izt}\ E(SpecRate_{zt})]' - E(Spec_{it}) \quad (7a)$$

such that:

$[N_{izt}\ E(SpecRate_{zt})]' = 1$ if $N_{izt}\ E(SpecRate_{zt}) \geq 1$

(8a)

$[N_{izt}\ E(SpecRate_{zt})]' = 0$ if $N_{izt}\ E(SpecRate_{zt}) < 1$

where Dif_{it} represents the number of specializations in region i and year t that are attributed to differences existing between the technological structure of region i at t, and the average technological structure prevailing in all regions in year t.

<u>Step 4: Computation of number of technology-adjusted specializations in each region i in year t</u>

$\text{AdjustedSpec}_{it} = \sum_{z=1}^{n} Spec_{izt} - \text{Dif}_{it}$ (9a)

such that:

$\text{Spec}_{izt} = 1$ if $\text{RCA}_{izt} > 1$

(10a)

$\text{Spec}_{izt} = 0$ if $\text{RCA}_{izt} \leq 1$

where AdjustedSpec_{it} represents the total number of technology-adjusted specializations in region i and year t, and Spec_{izt} is a dummy variable that reflects the specialization status of a given region i in technology z in year t. It takes the value 1 if a given region i has RCA (Revealed Comparative Advantage) greater than 1, and 0 otherwise.

<u>Step 5: Computation of the technology-adjusted diversification potential for each region i in year t</u>

$\text{AdjustedDivPotential}_{it} = n - \text{AdjustedSpec}_{it}$ (11a)

where $\text{AdjustedDivPotential}_{it}$ is the sector-adjusted diversification potential of a given region i in year t.

Appendix B: Computation of the relatedness variable

To capture the extent to which new regional technological specializations at time t+1 are related to the specializations of the region at time t, we compute the degree of proximity (DoP) between pairs of technologies. We follow the formula below, where a and b represent two different technological fields z, and RCA is defined as in (1b):

$$\Omega_{ab} = \min \{P(RCA_a > 1 \mid RCA_b > 1), P(RCA_b > 1 \mid RCA_a > 1)\}, \quad (1b)$$

where $P(RCA_a > 1 \mid RCA_b > 1) = \frac{P(RCAa > 1 \cap RCAb > 1)}{P(RCAb > 1)}$ (2b)

In (2b) Ω_{ab} indicates the DoP between technologies a and b, while the expression $P(RCA_a > 1 \mid RCA_b > 1)$ represents the conditional probability of there being, in the sample, cases where technology a has an RCA>1 given that for technology b RCA>1. For computing Ω_{ab}, one observation represents a pair region-year that is associated with a given technology z RCA. In total, the sample consists of 3097 pairs of regions and years (2000–2013). The DoP between two technological fields is computed based on the frequency of finding the spatial co-occurrence of a specialization (RCA>1) in these fields.

The proximity between each new technological specialization z in region i and its pre-existing technological structure follows Santoalha and Boschma (2019):

$$Proximity_{izt\text{-}t+1} = \frac{\sum_{s=1}^{n} \Omega zsMist}{\sum_{s=1}^{n} Mist} \quad (3b)$$

such that:

$M_{ist} = 1$ if $RCA_{ist} > 1$

(4b)

$M_{ist} = 0$ if $RCA_{ist} \leq 1$

where M_{ist} is a dummy variable that takes the value 1 if region i has a specialization in technology s at time t, and 0 otherwise. $Proximity_{izt-t+1}$, which ranges between 0 and 1, represents the proximity of a given new technological specialization z in region i at time t+1, to time t regional technological structure of specializations. Briefly, (3b) is the average of the DoP between z and the technological specializations s existing in region i at time t. This represents an adaptation of the density index proposed by Hausmann and Klinger (2007).*

Finally, for computing the average relatedness underlying the technological diversification process of region i, between time t and t+1, we propose the following formula:

$$Relatedness_{it-t+1} = \frac{\sum_{z=1}^{xit+1} \text{Proximity izt}-\text{t}+1}{xit+1} \quad (5b)$$

$Relatedness_{it-t+1}$ represents the average of the proximities of all technologies z in which a given region acquires a new specialization at time t+1.

* The use of the density indicator as proposed by Hausmann and Klinger (2007) would imply an almost perfect positive correlation (0.995) between the number of technological specializations of the region at time t and the density indicator itself. The use of (3b) mitigates this problem, as it leads to a negative and moderate correlation between (5b) and the number of technological specializations of the region at time t (-0.343).

Appendix C: E-skill variables

Our main source of information for constructing the e-skill Task Intensity index was the first edition of the European Classification of Skills/Competences, Qualifications and Occupations (ESCO) by the European Commission (2013), freely accessible at https://ec.europa.eu/esco/portal/skill. Information is organized by associating 12,575 work skills for which a textual description is available to 429 jobs at 4-digit level according to the 2008 International Standard Classification of Occupations (ISCO) classification. Occupations are subsequently aggregated to 1-digit level and matched with employment data from the EU Labour Force Survey. To identify e-skills we analysed the textual description contained in the ESCO portal to select work skills explicitly associated with the use of automated processes, by using the terms 'computer' and 'technolog*' as search criteria. Because those terms are broad, we ran specific checks to exclude items that were not associated with automated processes. For instance, following this rationale we discarded items such as 'computer history' or 'cutting technologies'. That yielded 69 e-skill items:

Table C1

idskill	eskills
1	3D body-scanning technologies
2	adapt to changes in technological development plans
3	adapt to new technology used in cars
4	add computer components
5	advise customers on type of computer equipment
6	anticipate change in car technology
7	assess the necessity of new farming technologies
8	automation technology
9	Biotechnology
10	biotechnology in aquaculture
11	building systems monitoring technology
12	call-centre technologies
13	cloud technologies
14	combine business technology with user experience
15	computer engineering
16	computer equipment
17	computer forensics
18	computer programming
19	computer science
20	computer technology
21	computerized feeding systems
22	control objectives for information and related technology
23	coordinate technological activities
24	define technology strategy
25	design computer network
26	develop technological improvement strategies
27	emergent technologies
28	evaluate translation technologies
29	explain characteristics of computer peripheral equipment
30	handle geospatial technologies
31	have computer literacy
32	human-computer interaction
33	keep up-to-date to computer trends
34	lead technology development of an organization
35	learning technologies
36	maintain computer hardware
37	manage computer-based transport operation control systems;
38	maritime transportation technology
39	medical imaging technology
40	medical laboratory technology
41	monitor developments in technology used for design
42	monitor technology trends
43	Nanotechnology

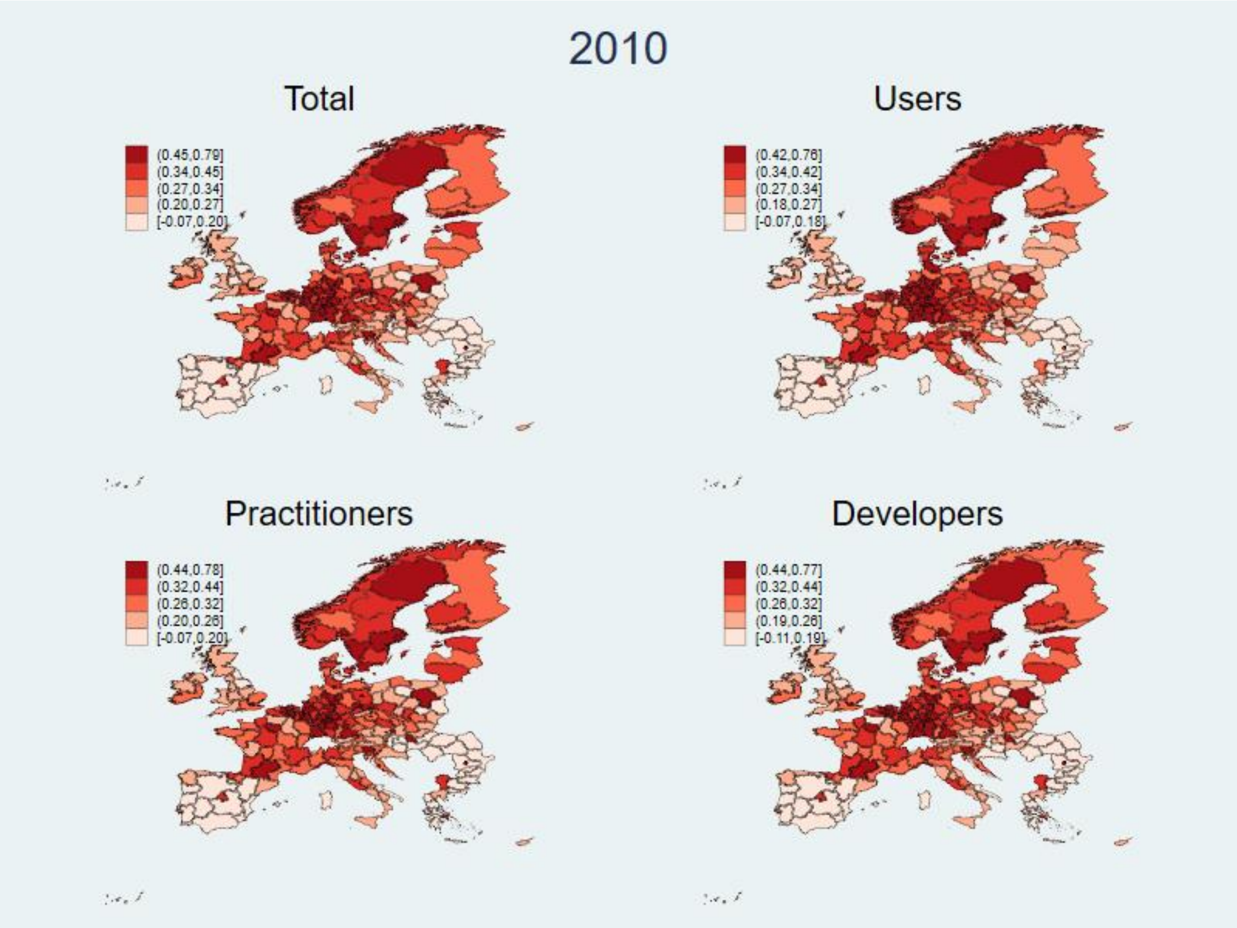
44	operate 3D computer graphics software
45	operate computerized control systems
46	operate on-board computer systems
47	place orders for computer products
48	provide training on technological business developments
49	put uncut recordings into computer
50	renewable energy technologies
51	research remote sensing technologies
52	support service users in using technological aids
53	teach computer science
54	teach medical laboratory technology principles
55	teach transport technology principles
56	tend computer numerical control lathe machine
57	test computer hardware
58	transfer uncut audiovisual material to computer
59	transmission technology
60	use a computer
61	use computer programs to improve patients' skills
62	use computer telephony integration
63	use computer-aided engineering systems
64	use computer-aided translation
65	use computerized maintenance management systems
66	use e-health and mobile health technologies
67	use shorthand computer program
68	use specialized computer models for weather forecasting
69	utilize computer-aided software engineering tools

Table C2. Task intensity index, by occupation and type of e-skills

	ISCO Code	Total	Developer	Practitioner	User
1	Managers	-0.4169	-0.2937	-0.3055	-0.7005
2	Professionals	2.2013	2.3447	2.3302	1.5502
3	Technicians and associate professionals	1.1840	0.9235	0.9695	1.7122
4	Clerical Support Workers	-0.4296	-0.5941	-0.5541	0.0269
5	Services and Sales Workers	-0.5122	-0.5099	-0.4461	-0.5644
6	Skilled Agricultural, Forestry and Fishery Workers	-0.3410	-0.5941	-0.4619	0.2041
7	Craft and Related Trades Workers	-0.3603	-0.2642	-0.3651	-0.4235
8	Plant and Machine Operators And Assemblers	-0.6024	-0.4181	-0.5419	-0.8512
9	Elementary Occupations	-0.7229	-0.5941	-0.6251	-0.9538

Appendix D: Additional empirical results

Figure D1: Distribution of e-skills across European regions



Source: authors' computations

Table D1. Descriptive statistics

Variables	N	mean	max	min	std dev
N new specializations	2445	12.20	33	1	5.90
Diversification	2445	0.13	0.39	0.008	0.07
Eskills intensity - Total (std)	2445	0.28	0.79	-0.20	0.15
Eskills intensity - Users (std)	2445	0.28	0.76	-0.17	0.14
Eskills intensity - Practitioners (std)	2445	0.27	0.78	-0.21	0.15
Eskills intensity - Developers (std)	2445	0.26	0.77	-0.23	0.15
GDP per capita	2445	22457	68400	4000	8746
R&D	2445	1.38	8.37	0.06	1.15
Share female workers	2445	0.44	0.53	0.28	0.04
Share elderly population	2445	0.17	0.27	0.10	0.03
Relatedness	2445	0.26	0.48	0.05	0.03

Table D2. Correlation matrix.

	N new specializ.	Diversification	Eskills - Total (std)	Eskills - Users (std)	Eskills - Practitioners (std)	Eskills - Developers (std)	GDP per capita	R&D	Share female workers	Share elderly population	Relatedness
N new specializ.	1										
Diversification	0.953 ***	1									
Eskills - Total (std)	0.268 ***	0.321 ***	1								
Eskills - Users (std)	0.247 ***	0.302 ***	0.964 ***	1							
Eskills - Practitioners (std)	0.268 ***	0.321 ***	0.997 ***	0.941 ***	1						
Eskills - Developers (std)	0.273 ***	0.323 ***	0.994 ***	0.931 ***	0.999 ***	1					
GDP per capita	0.308 ***	0.380 ***	0.656 ***	0.625 ***	0.659 ***	0.650 ***	1				
R&D	0.260 ***	0.319 ***	0.599 ***	0.573 ***	0.601 ***	0.593 ***	0.499 ***	1			
Share female workers	0.109 ***	0.132 ***	0.289 ***	0.313 ***	0.281 ***	0.271 ***	0.040 *	0.276 ***	1		
Share elderly population	0.159 ***	0.169 ***	0.085 ***	0.124 ***	0.072 ***	0.070 ***	0.177 ***	0.115 ***	-0.084 ***	1	
Relatedness	-0.192 ***	-0.278 ***	-0.379 ***	-0.359 ***	-0.380 ***	-0.377 ***	-0.309 ***	-0.375 ***	-0.177 ***	0.042 **	1

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

Table D3. Tests of hypotheses 2 and 3. Marginal effects of e-skills.
Model specifications including interactions of e-skills with GDP per capita and relatedness. Fixed effects panel estimations (panel composed of different sub-periods).

		3-year sub-periods		4-year sub-periods		5-year sub-periods		GDP per capita level	Relatedness level
Specification ix	E-skills - Total	7.11	***	6.31	**	8.80	*	GDP pc = min	Relatedness = min
		5.82	***	4.73	**	6.63	*	GDP pc = Q1	
		5.34	***	4.10	**	5.79		GDP pc = Q2	
		4.82	***	3.51	**	4.96		GDP pc = Q3	
		0.91		-1.04		-1.83		GDP pc = max	
	E-skills - Total	3.62	***	4.08	***	5.57	**	GDP pc = min	Relatedness = Q2
		2.40	***	3.08	***	3.19	*	GDP pc = Q1	
		1.94	**	2.68	**	2.28		GDP pc = Q2	
		1.45	*	2.30	**	1.36		GDP pc = Q3	
		-2.27		-0.59		-6.07	**	GDP pc = max	
	E-skills - Total	-2.03		-1.79		2.72		GDP pc = min	Relatedness = max
		-3.16		-1.28		0.17		GDP pc = Q1	
		-3.58	*	-1.08		-0.82		GDP pc = Q2	
		-4.03	**	-0.89		-1.80	*	GDP pc = Q3	
		-7.44		0.59		-9.79	***	GDP pc = max	
Specification x	E-skills - Users	6.48	***	6.03	*	13.58	*	GDP pc = min	Relatedness = min
		5.03	***	4.63	**	9.07	**	GDP pc = Q1	
		4.48	***	4.08	**	7.34		GDP pc = Q2	
		3.90	**	3.56	*	5.61		GDP pc = Q3	
		-0.51		-0.47		-8.46		GDP pc = max	
	E-skills - Users	3.45	***	4.17	***	5.50	**	GDP pc = min	Relatedness = Q2
		2.10	***	3.05	**	3.69		GDP pc = Q1	
		1.60	**	2.61	**	2.99		GDP pc = Q2	
		1.06		2.19	*	2.29		GDP pc = Q3	
		-3.02	*	-1.02		-3.36		GDP pc = max	
	E-skills - Users	-1.47		-0.74		-1.61		GDP pc = min	Relatedness = max
		-2.64		-1.11		-1.05		GDP pc = Q1	
		-3.08		-1.26		-0.84		GDP pc = Q2	
		-3.55	*	-1.40		-0.62		GDP pc = Q3	
		-7.11		-2.47		1.13		GDP pc = max	
Specification xi	E-skills - Practitioners	7.25	***	6.31	**	7.59	*	GDP pc = min	Relatedness = min
		6.05	***	4.68	**	5.88	*	GDP pc = Q1	
		5.60	***	4.03	**	5.22		GDP pc = Q2	
		5.12	***	3.43	**	4.56		GDP pc = Q3	
		1.47		-1.28		-0.77		GDP pc = max	

Specification xi	E-skills - Practitioners	3.65	***	3.99	***	5.57	***	GDP pc = min	Relatedness = Q2
		2.44	***	3.01	***	3.01	*	GDP pc = Q1	
		2.00	***	2.62	**	2.03		GDP pc = Q2	
		1.51	*	2.26	**	1.04		GDP pc = Q3	
		-2.14		-0.55		-6.94	**	GDP pc = max	
	E-skills - Practitioners	-2.20		-2.15		3.79		GDP pc = min	Relatedness = max
		-3.41	*	-1.39		0.49		GDP pc = Q1	
		-3.86	**	-1.09		-0.78		GDP pc = Q2	
		-4.34	**	-0.81		-2.05		GDP pc = Q3	
		-8.01		1.37		-12.37		GDP pc = max	
Specification xii	E-skills - Developers	7.14	***	6.39	**	6.90	*	GDP pc = min	Relatedness = min
		5.98	***	4.74	**	5.58	*	GDP pc = Q1	
		5.54	***	4.08	**	5.07		GDP pc = Q2	
		5.07	***	3.46	**	4.56		GDP pc = Q3	
		1.54		-1.31		0.44		GDP pc = max	
	E-skills - Developers	3.73	***	4.03	***	5.58	***	GDP pc = min	Relatedness = Q2
		2.52	***	3.05	***	2.90	**	GDP pc = Q1	
		2.07	***	2.66	**	1.87		GDP pc = Q2	
		1.59	**	2.30	**	0.84		GDP pc = Q3	
		-2.07		-0.53		-7.51	***	GDP pc = max	
	E-skills - Developers	-1.81		-2.19		4.42		GDP pc = min	Relatedness = max
		-3.08	*	-1.39		0.55		GDP pc = Q1	
		-3.56	*	-1.07		-0.94		GDP pc = Q2	
		-4.07	**	-0.77		-2.43		GDP pc = Q3	
		-7.93		1.55		-14.51		GDP pc = max	

* p<0.1, ** p<0.05, *** p<0.01
3-year sub-periods: 2002–2004; 2005–2007; 2008–2010; 2011–2013
4-year sub-periods: 2002–2005; 2006–2009; 2010–2013
5-year sub-periods: 2003–2007; 2008–2012

Table D4. Tests of hypotheses 2 and 3. Marginal effects of e-skills.
Model specifications including interactions of e-skills with GDP per capita and relatedness. Model controlling for industry structure. Fixed effects and GMM estimations (annual data).

		FE		Difference GMM		GDP per capita level	Relatedness level
Specification ix	E-skills - Total	6.67	***	11.94	***	GDP pc = min	Relatedness = min
		4.87	***	5.81	***	GDP pc = Q1	
		4.19	***	3.58	*	GDP pc = Q2	
		3.53	***	1.30		GDP pc = Q3	
		-2.29		-18.18	**	GDP pc = max	
	E-skills - Total	2.01	***	5.40	**	GDP pc = min	Relatedness = Q2
		1.66	***	3.80	**	GDP pc = Q1	
		1.54	***	3.21	*	GDP pc = Q2	
		1.41	**	2.62	*	GDP pc = Q3	
		0.31		-2.48		GDP pc = max	
	E-skills - Total	-2.98		-4.10		GDP pc = min	Relatedness = max
		-1.75		0.87		GDP pc = Q1	
		-1.30		2.69		GDP pc = Q2	
		-0.85		4.54		GDP pc = Q3	
		3.08		20.36		GDP pc = max	
Specification x	E-skills - Users	5.91	*	8.36	**	GDP pc = min	Relatedness = min
		4.16	**	4.99	*	GDP pc = Q1	
		3.51	**	3.76		GDP pc = Q2	
		2.86	**	2.50		GDP pc = Q3	
		-2.79		-8.24		GDP pc = max	
	E-skills - Users	2.09	**	3.94	*	GDP pc = min	Relatedness = Q2
		1.78	***	2.87	*	GDP pc = Q1	
		1.66	***	2.48		GDP pc = Q2	
		1.54	***	2.08		GDP pc = Q3	
		0.54		-1.33		GDP pc = max	
	E-skills - Users	-1.99		-2.50		GDP pc = min	Relatedness = max
		-0.76		-0.22		GDP pc = Q1	
		-0.31		0.61		GDP pc = Q2	
		0.14		1.46		GDP pc = Q3	
		4.09		8.72		GDP pc = max	
Specification xi	E-skills - Practitioners	6.80	***	12.96	***	GDP pc = min	Relatedness = min
		5.03	***	6.08	***	GDP pc = Q1	
		4.38	***	3.58	*	GDP pc = Q2	
		3.72	***	1.02		GDP pc = Q3	
		-1.97		-20.84	**	GDP pc = max	

Specification xi	E-skills - Practitioners	2.01	***	5.87	**	GDP pc = min	Relatedness = Q2
		1.63	***	4.14	**	GDP pc = Q1	
		1.49	***	3.51	**	GDP pc = Q2	
		1.36	**	2.86	*	GDP pc = Q3	
		0.15		-2.65		GDP pc = max	
	E-skills - Practitioners	-3.11		-4.45		GDP pc = min	Relatedness = max
		-2.00	*	1.30		GDP pc = Q1	
		-1.58		3.40		GDP pc = Q2	
		-1.17		5.54		GDP pc = Q3	
		2.41		23.82		GDP pc = max	
Specification xii	E-skills - Developers	6.51	***	13.38	***	GDP pc = min	Relatedness = min
		4.85	***	6.30	***	GDP pc = Q1	
		4.23	***	3.72	*	GDP pc = Q2	
		3.62	***	1.09		GDP pc = Q3	
		-1.73		-21.39	**	GDP pc = max	
	E-skills - Developers	1.97	**	5.77	**	GDP pc = min	Relatedness = Q2
		1.62	***	4.10	**	GDP pc = Q1	
		1.49	***	3.49	**	GDP pc = Q2	
		1.36	**	2.87	*	GDP pc = Q3	
		0.23		-2.45		GDP pc = max	
	E-skills - Developers	-2.89		-5.28		GDP pc = min	Relatedness = max
		-1.84	*	0.90		GDP pc = Q1	
		-1.45		3.15		GDP pc = Q2	
		-1.06		5.46		GDP pc = Q3	
		2.32		25.11	*	GDP pc = max	

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

Table D5. RESET misspecification test (Ramsey regression equation specification error test). Fixed effects panel estimations (annual data)

Model Specification		p-value of the Ramsey RESET test
Only e-skills	i	0.01
	ii	0.05
	iii	0.00
	iv	0.00
e-skills + control variables	v	0.04
	vi	0.02
	vii	0.07
	viii	0.06
e-skills + controls + interaction variables	ix	0.44
	x	0.26
	xi	0.31
	xii	0.18

Note: Ramsey Regression Equation Specification Error Test (RESET) includes in each model specification. as regressors. the squared, cubic and quadratic fitted values, and tests if their coefficients are statistically different from 0. The null hypothesis is that there is no misspecification / the model is well specified (i.e. the coefficients of the three regressors are equal 0).