Scientific and technological competences: A close bond leading to technological diversification?

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Current

- Associate Professor, Industrial Engineering Department, University of Concepción, Chile
- Director, Center of Innovation Systems Studies (CIS2)
- Member of the Board, Chile's Innovation Network (RICh)
- Co-founder and research associate of the Center of Technological Manufacturing Extension (CETMA)
- Director, Master of Technological Innovation and Entrepreneurship, University of Concepción, Chile

Past

- Chair of the Industrial Engineering Department, University of Concepción, Chile
- Director, Engineering 2030 Project, University of Concepción
- Co-founder of the University of Concepción's Biotechnology Center

My *research* focuses on innovation and entrepreneurship ecosystems, scientific, technological and economic complexity, and science, technology, innovation and entrepreneurship policy. I have done research in different countries: Chile, Costa Rica, Mexico, Uruguay, United States, South Africa, and Mozambique.

- PhD in Public Policy, Georgia Institute of Technology (Georgia Tech), United States
- M. Sc. in Public Policy, Georgia Institute of Technology (Georgia Tech), United States
- Industrial Engineer, University of Concepción, Chile

OUTLINE

1. Introduction
2. Theoretical Framework
3. Methodology
4. Results and Analysis
5. Conclusions

¿How scientific endogenous capacities contribute to shape technological endogenous capacities?

- Diversification has been addressed by focusing on reviewing and visually representing how products are related to each other by means of statistical co-occurrence and how such relationships have evolved over time (Hidalgo et al, 2007).

- And under the assumption that when a country is globally relevant manufacturing two products, those two products respond to common scientific and technological capacities.

- The study of diversification has been extended beyond the issue of exports and country-level distribution, including reviewing spatial and temporal dynamics of the diversification of scientific and technological capacities (Frenken et al. 2007, Frenken and Saviotti, 2008, Neffke et al. 2011, Colombelli et al., 2012, Essletzbichler, 2015).

- Petralia et al (2017) conclude that countries diversify to technologies related to their current profile of competences and that such effect is stronger at earlier stages of development.

182
countries

1988-2015

WEB OF SCIENCE™

252
categories

23.770.813
Publications

uspto UNITED STATES PATENT AND TRADEMARK OFFICE

654
classes

4.289.760
Patents

Knowledge Diversity Index (KDI)

Ranking	Change 1994	Country	KDI	KDI Sciences	KDI Social Sciences	KDI Arts and Humanities
1	=	UNITED KINGDOM	1,0000	1,0000	1,0000	1,0000
2	+5	UNITED STATES	1,0000	1,0000	1,0000	1,0000
3	+9	NETHERLANDS	0,9921	0,9921	1,0000	1,0000
4	+25	SPAIN	0,9921	0,9921	1,0000	1,0000
5	+25	TURKEY	0,9802	0,9802	1,0000	0,9592
6	+21	DENMARK	0,9683	0,9683	0,9774	1,0000
7	-5	FRANCE	0,9643	0,9643	0,9548	1,0000
8	+25	INDIA	0,9603	0,9603	1,0000	0,9592
9	+4	NEW ZELAND	0,9603	0,9603	0,9887	0,9796
10	-5	BRAZIL	0,9048	0,9048	0,8983	0,9796
14	+4	IRELANDA	0,5317	0,5317	0,4633	0,8163
17	-2	ISRAEL	0,4881	0,4881	0,3955	0,8367
23	-5	FINLAND	0,4444	0,4444	0,4294	0,6122
35	**+33**	**CHILE**	**0,3770**	**0,3770**	**0,3503**	**0,4694**
45	-23	SINGAPORE	0,3571	0,3571	0,3616	0,4694
53	+2	SOUTH KOREA	0,3413	0,3413	0,4407	0,1224

Technology Diversity Index (TDI)

Ranking	Dif. 1994	Country	TDI	TDI Human Needs	TDI Operations and Transport	TDI Chemistry and Metallurgy	IDT Textil	IDT Construction	IDT Mechanical Engineering	IDT Physics	IDT Electricity
1	=	UNITED STATES	0,9588	1,0000	0,9649	0,9432	c	0,9677	0,9700	0,9259	1,0000
2	**=**	**JAPAN**	**0,8794**	**0,8690**	**0,8889**	**0,8295**	**0,7500**	**0,9355**	**0,8600**	**0,9259**	**0,9608**
3	=	GERMANY	0,8534	0,8214	0,8480	0,8068	0,7750	0,9355	0,9200	0,8025	0,9412
4	=	FRANCE	0,7420	0,7500	0,6901	0,7727	0,4500	0,7742	0,7700	0,7654	0,9216
5	=	CANADA	0,7252	0,7619	0,6667	0,7841	0,3500	0,9032	0,7800	0,6790	0,8627
6	=	UNITED KINGDOM	0,7130	0,7500	0,6608	0,6818	0,3500	0,8710	0,7800	0,7037	0,9020
7	=	SWITZERLAND	0,6931	0,7262	0,6374	0,7045	0,6000	0,7097	0,6300	0,7284	0,8824
8	+4	SOUTH KOREA	0,6840	0,6071	0,6199	0,6932	0,4000	0,7419	0,7300	0,7531	0,9412
9	+9	CHINA	0,6702	0,6548	0,6082	0,7273	0,3250	0,8065	0,6500	0,7284	0,8824
10	+1	TAIWAN	0,6534	0,6071	0,6257	0,6477	0,3500	0,6129	0,6200	0,7654	0,9412
14	=	ISRAEL	0,4565	0,5714	0,3684	0,4773	0,1250	0,3548	0,3700	0,5802	0,7451
17	-4	FINLAND	0,4504	0,2619	0,4152	0,5682	0,2000	0,6129	0,4000	0,5185	0,6667
21	+8	SINGAPORE	0,3130	0,2500	0,2281	0,3523	0,0250	0,3548	0,2400	0,4815	0,6078
23	-1	IRELAND	0,2687	0,2738	0,1813	0,3182	0,0250	0,2258	0,2000	0,4321	0,4706
28	**+9**	**CHILE**	**0,1878**	**0,2738**	**0,1287**	**0,2273**	**0,0000**	**0,1290**	**0,0900**	**0,2469**	**0,3529**

Product Diversity Index (PDI)

#	Dif. 1994	Country	PDI	PDI Food Products	PDI Beverages and Tobacco	PDI Indelible Raw Materials	PDI Fuel	PDI Vegetable, Animal Oils	PDI Chemical Products	PDI Manufactured Products	PDI Machinery and Transport
1	+4	ITALY	0,3340	0,1949	0,2857	0,1641	0,0769	0,0870	0,2562	0,4449	0,4537
2	-1	GERMANY	0,3158	0,1949	0,3571	0,1172	0,1923	0,1739	0,4545	0,3136	0,4878
3	+10	SPAIN	0,3117	0,4237	0,2857	0,2656	0,1923	0,2174	0,4132	0,3814	0,2195
4	-1	FRANCE	0,3047	0,3559	0,4286	0,2188	0,1538	0,2609	0,3719	0,3475	0,2537
5	+10	CHINA	0,3036	0,0763	0,0000	0,1016	0,1154	0,0435	0,2645	0,4364	0,3512
6	-2	UNITED STATES	0,2895	0,2712	0,0714	0,3047	0,1154	0,2174	0,5041	0,2034	0,3317
7	-1	AUSTRIA	0,2824	0,2458	0,0714	0,1719	0,0769	0,1304	0,2149	0,3347	0,4195
8	-1	NETHERLANDS	0,2824	0,4746	0,5714	0,2656	0,3077	0,5217	0,4711	0,1653	0,1951
9	+2	POLAND	0,2783	0,4407	0,3571	0,1797	0,2308	0,1304	0,1901	0,3644	0,2537
10	-2	BELGIUM	0,2702	0,3729	0,5714	0,2734	0,2692	0,2609	0,5372	0,2331	0,1512
38	-6	FINLAND	0,1609	0,0932	0,1429	0,1250	0,1154	0,0000	0,1818	0,1780	0,2390
40	-15	SOUTH KOREA	0,1498	0,0000	0,0714	0,0625	0,0769	0,0000	0,2810	0,1907	0,2341
63	-32	ISRAEL	0,1113	0,0763	0,0000	0,0859	0,0385	0,0870	0,2810	0,0593	0,1171
65	+2	SINGAPORE	0,1113	0,0508	0,1429	0,0313	0,0769	0,0000	0,2397	0,0424	0,1854
68	-33	IRELAND	0,1012	0,1949	0,3571	0,1172	0,0769	0,0435	0,1818	0,0466	0,0585
69	**-11**	**CHILE**	**0,0982**	**0,2712**	**0,0714**	**0,1641**	**0,0385**	**0,2609**	**0,1074**	**0,0805**	**0,0098**

1994

Cluster	#	Countries		KDI	TDI	PDI
Non-diversified countries	119	**CHILE** Singapore Colombia Serbia	Peru Cameroon Ivory Coast (…)	0,1178	0,0042	0,1219
Middle-diversified countries	5	Poland Portugal South Korea Ireland Finland	Israel China Brazil Argentina (…)	0,4057	0,0723	0,5033
Diversified countries	10	Austria Germany Canada France Italy	**JAPAN** Netherlands Sweden Switzerland United States	0,5291	0,6786	0,7080

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2014

Cluster	#	Countries		KDI	TDI	PDI
Non-diversified countries	120	Tunisia Ivory Coast Nicaragua Panama	Bolivia Cambodia Costa Rica (…)	0,1856	0,0147	0,0745
Middle-diversified countries	52	**CHILE** Colombia Ireland Hungry Mexico	Singapore Norway Portugal South Africa (…)	0,3165	0,0521	0,4609
Diversified countries	23	Austria Belgium Canada China France Germany	**JAPAN** United States Finland Israel South Korea (…)	0,6874	0,5798	0,6696

1. Revealed Comparative Advantage (RCA)

RCA of country *c* for WoS Category *i* in year *t* is measured by the share of WoS Category *i*'s publications among all WoS publications of country *c* relative to WoS Category *i*'s publications share in all global publications.

$$\mathrm{RCA}_{c,t}(i) = \frac{\mathrm{WoS\,category}_{c,t}(i) / \sum_{i} \mathrm{WoS\,category}_{c,t}(i)}{\sum_{c} \mathrm{WoS\,category}_{c,t}(i) / \sum_{c} \sum_{i} \mathrm{WoS\,category}_{c,t}(i)}$$

CIS2 CENTRO DE ESTUDIOS DE SISTEMAS DE INNOVACIÓN

2. Proximity

The conditional probability that *country c* has a comparative advantage in *Patent Class i* in year t given that it has a comparative advantage in *WoS Category j* in year t-lag. The more the conditional probability gets closer to 1, the more both variables are related.

$$\phi_{i,j,t} = \Pr ob\left(RCA\ CPC\ Patent\ Class_{i,t} \,/\, RCA\ WoS\ Category_{j,t-lag} \right)$$

3. Density

Average proximity of a new technology -patent class- j with the scientific portfolio -WoS Category i- of country c.

A high density value means that the country c has scientific areas -WoS categories- surrounding technology j -patent class-.

$$Density_{j,c} = \frac{\sum_i x_i \phi_{ij}}{\sum_i \phi_{ij}}$$

$$x_i = 1 \quad if \;\; RCA_{c,i} > 1$$
$$x_i = 0 \quad otherwise$$

4. Model

$$y_{cjt} = \beta_0 + \beta_1 Density_{cjt-lag} + \beta_2 Density_{cjt-lag} * GDP_{ct} + \sum_c \beta_c T_{cjt}$$

$$+ \sum_c \beta_c T_{cjt} * GDP_{ct} + \alpha_c F_c + \alpha_j F_j + \alpha_t F_t + \varepsilon_{cjt}$$

$$T_{cjt}$$

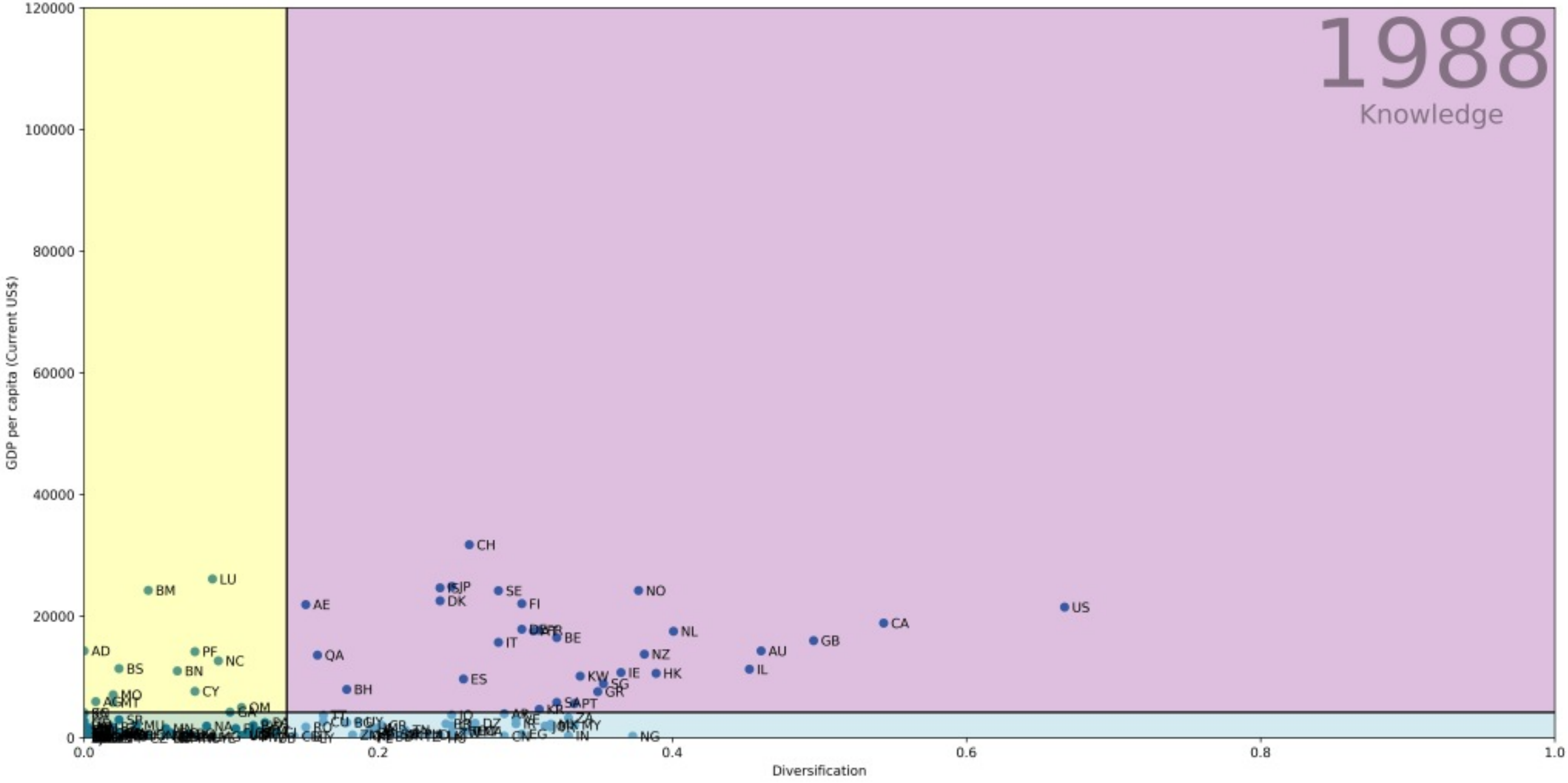
a) Size	*Number of patents per patent class*
b) Complexity	*Index of Technological Complexity*
c) Concentration	*Herfindhal concentration index*

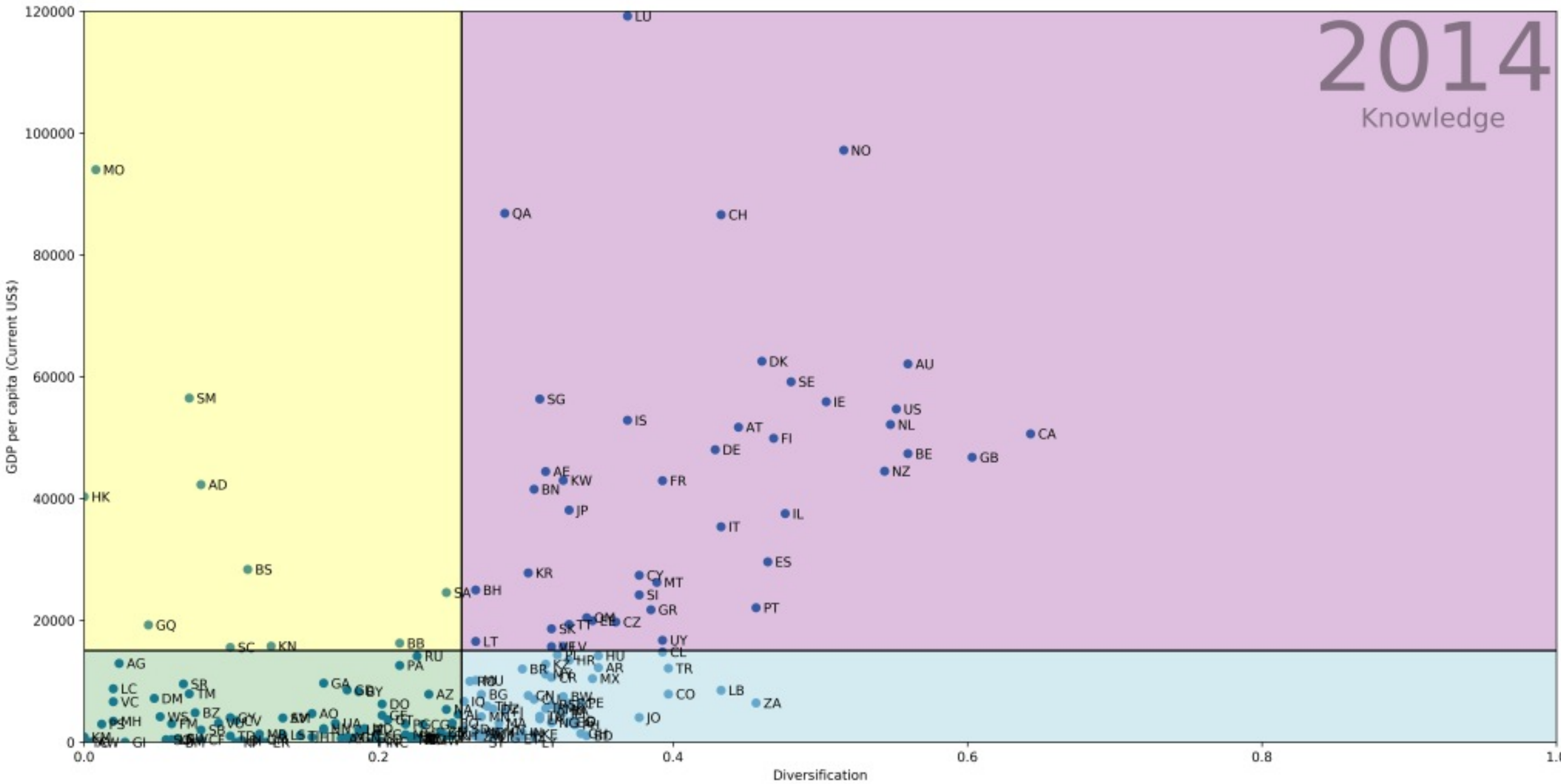
Variable	Mean	SD	Min	Max
Log size	1.447004	1.605533	0	10.2116
Density	0.2654169	0.1669225	0	0.7482795
Complexity ITC	0	1	-2.807627	2.995889
Concentration Herfindhal Index	0.0325956	0.0596688	0.0103499	1

Lag 1 year

Variable	Mean	SD	Min	Max
Log size	1.452928	1.611823	0	10.2116
Density	0.2618689	0.1668409	0	1
Complexity **ITC**	0	1	-2.60536	2.746945
Concentration **Herfindhal Index**	0.0330901	0.0591179	0.0103499	1

Lag 5 years


1988
Knowledge
GDP per capita (Current US$)
Diversification
CH
LU
BM
NO
US
CA
GB
NL
AU
IL
HK
NZ
IE
SG
GR
KW
ES
BH
QA
AE
SE
FI
DK
IT
BE
AD
BS
BN
PF
NC
CY
NG


2014
Knowledge
GDP per capita (Current US$)
Diversification
0.0
0.2
0.4
0.6
0.8
1.0
0
20000
40000
60000
80000
100000
120000
LU
NO
MO
QA
CH
DK
AU
SE
IE
US
NL
CA
SM
SG
IS
AT
FI
DE
BE
GB
NZ
AE
KW
FR
BN
AD
HK
JP
IL
IT
BS
ES
KR
CY
MT
SA
BH
SI
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PT
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CZ
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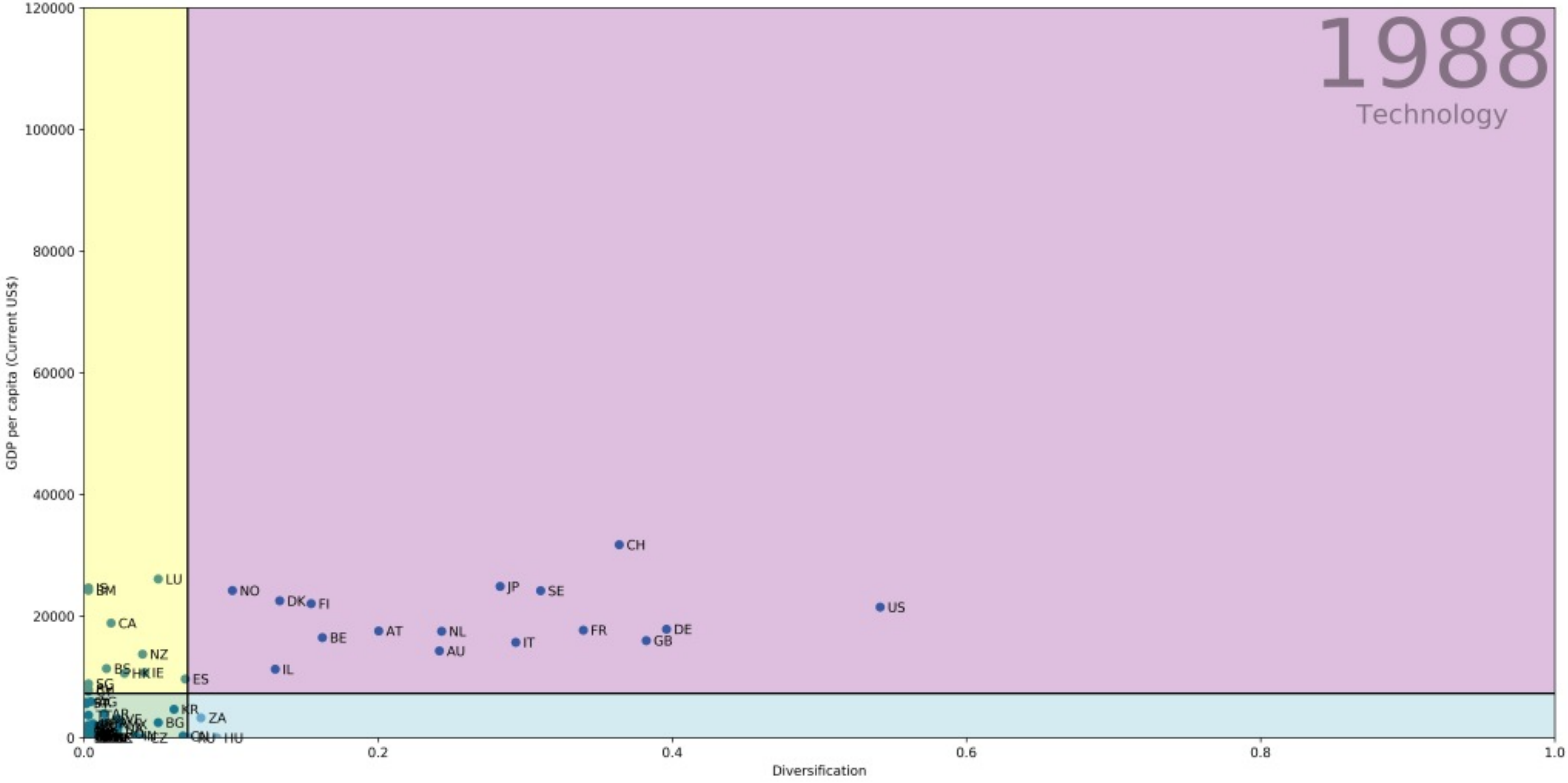
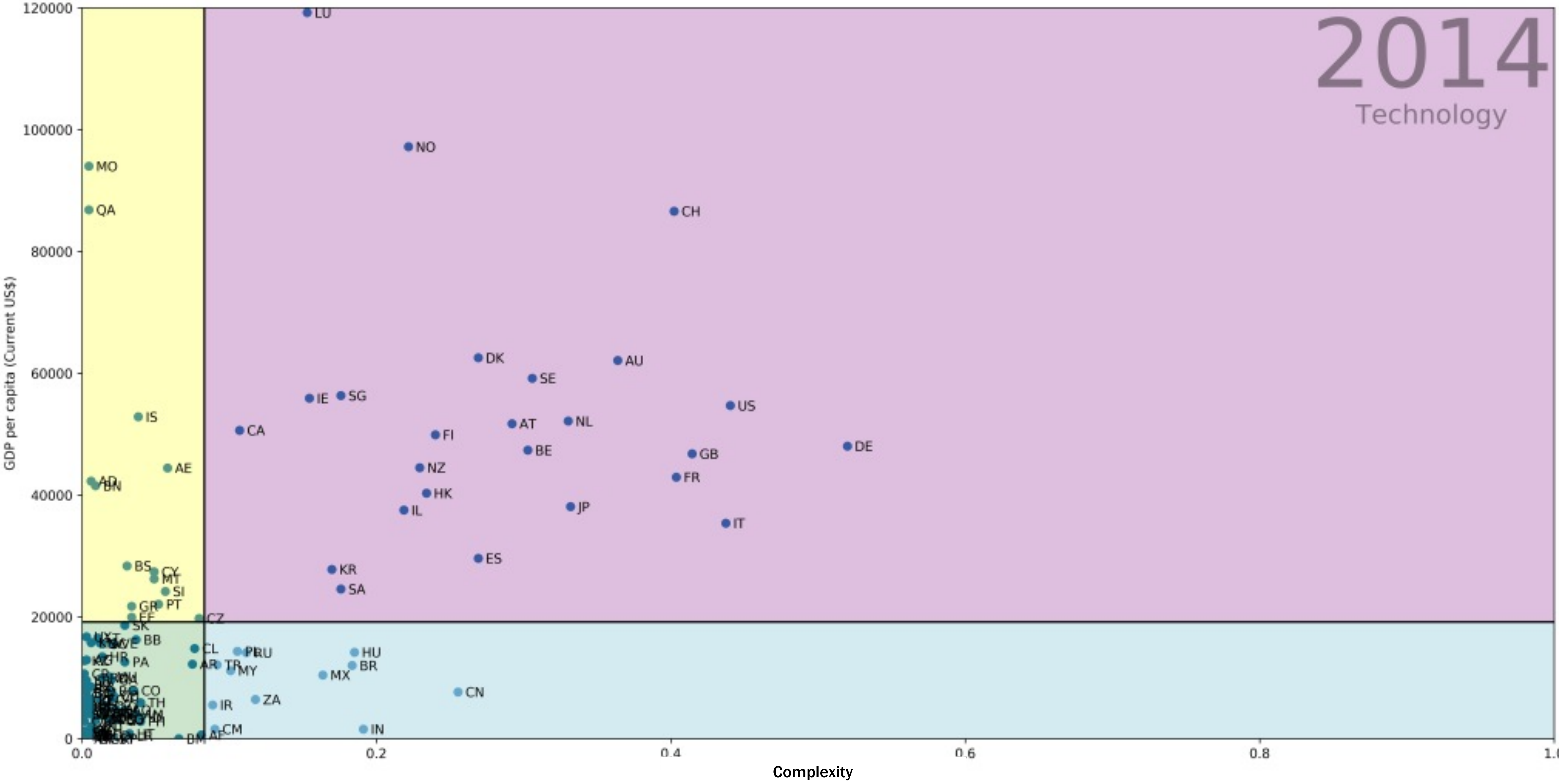
SK
BB
RU
AG
PA
TR
MX
CO
LB
ZA
JO


1988
Technology
GDP per capita (Current US$)
Diversification
120000
100000
80000
60000
40000
20000
0
0.0
0.2
0.4
0.6
0.8
1.0
CH
LU
NO
JP
SE
DK
FI
US
CA
AT
NL
FR
DE
BE
IT
GB
AU
NZ
IL
ES
KR
ZA
BG
HU


2014
Technology
GDP per capita (Current US$)
Complexity
120000
100000
80000
60000
40000
20000
0
0.0
0.2
0.4
0.6
0.8
1.0
LU
NO
MO
QA
CH
DK
AU
SE
SG
IE
US
IS
CA
FI
AT
NL
BE
GB
DE
AE
NZ
FR
HK
IL
JP
IT
ES
KR
SA
BS
CY
MT
SI
PT
GR
CZ
SK
BB
CL
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CO
TH
ZA
IR
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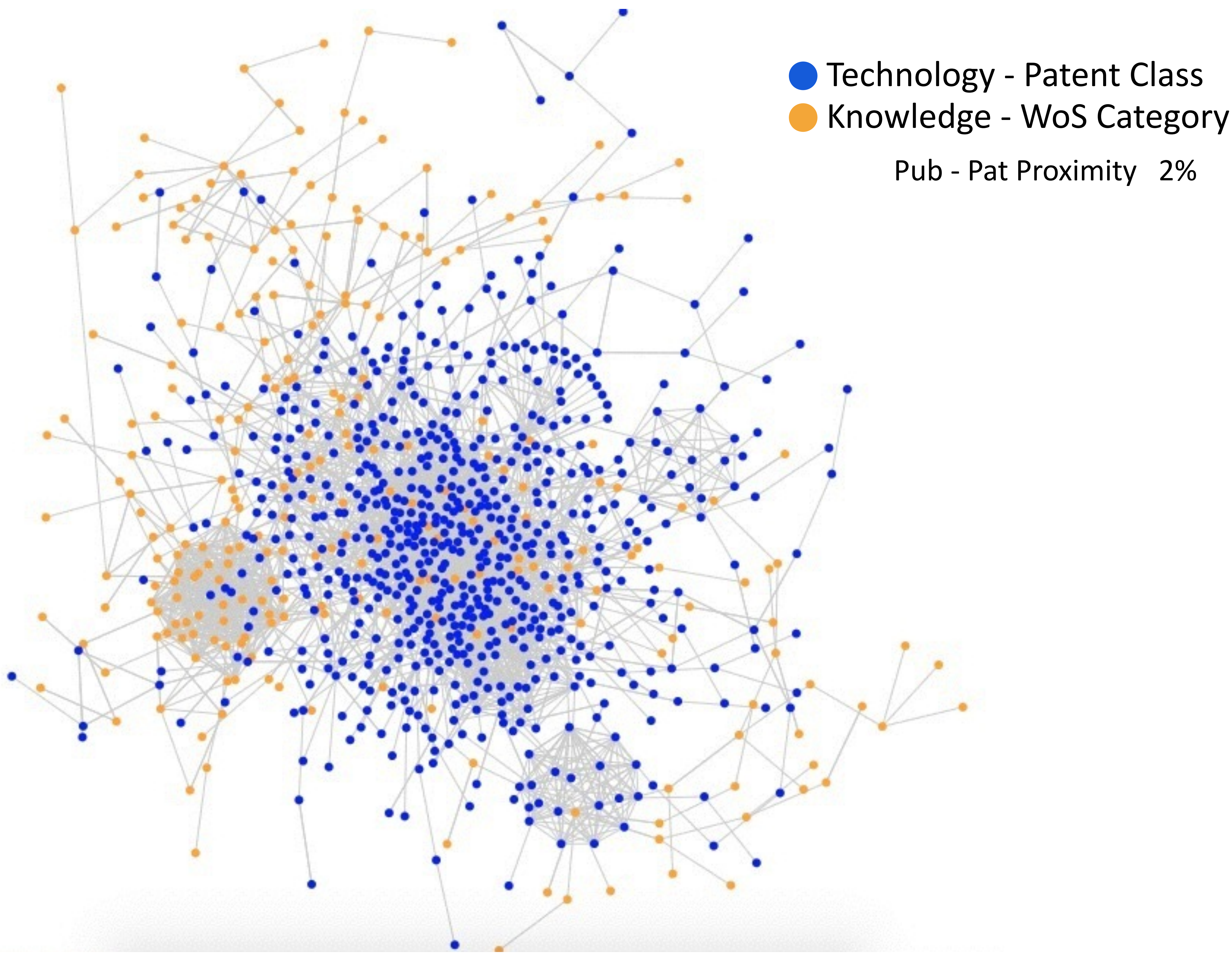
CM
MY
TR
AR


Technology - Patent Class
Knowledge - WoS Category
Pub - Pat Proximity 2%

Lag Pub-Pat 1 year

Variable	Model 1	Model 2	Model 3	Model 4
Log Size	0.2427867*** (0.0009403)	0.2510908*** (0.0009364)	0.2511065*** (0.0009364)	0.2159146*** (0.0018447)
Density	0.0662162** (0.0209807)	0.0506959* (0.0207204)	0.0480168 (0.0207359)	-0.0237724 (0.0254305)
Complexity ITC		0.143486*** (0.0020951)	0.1434182*** (0.0020952)	-0.0211486*** (0.0032191)
Concentration Herfindhal Index			-0.074709*** (0.02271)	-0.052322* (0.0254245)
Log Size * GDP				0.0012431*** (0.0000461)
Density * GDP				0.0039029*** (0.0004119)
ITC * GDP				0.0050182*** (0.0000746)
Herfindahl Index * GDP				-0.0218653*** (0.0019783)
Constant	1.476101*** (0.100224)	1.495417*** (0.0989751)	1.522572*** (0.0993161)	1.785759*** (0.0995398)
Adjusted R-Squared	0.4265	0.4407	0.4407	0.4567
Tech Fixed Effects	Yes	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes

Lag Pub-Pat 2 years

Variable	Model 1	Model 2	Model 3	Model 4
Log Size	0.2443369*** (0.0009502)	0.252342*** (0.0009464)	0.2523472*** (0.0009464)	0.2139412*** (0.001868)
Density	0.3936282*** (0.0225729)	0.3358304*** (0.0223165)	0.3333822*** (0.0223718)	0.3122848*** (0.0271573)
Complexity ITC		0.1426783*** (0.0021462)	0.1426517*** (0.0021463)	-0.0273189*** (0.0033074)
Concentration Herfindhal Index			-0.0362078 (0.0232782)	-0.0500661 (0.026077)
Log Size * GDP				0.0013241*** (0.0000464)
Density * GDP				0.0037668*** (0.0004114)
ITC * GDP				0.0050868*** (0.0000755)
Herfindahl Index * GDP				-0.0159604*** (0.0019945)
Constant	1.479517*** (0.0999836)	1.49645*** (0.0987731)	1.509606*** (0.0993161)	1.714906*** (0.0993674)
Adjusted R-Squared	0.4313	0.4450	0.4450	0.4611
Tech Fixed Effects	Yes	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes

Lag Pub-Pat 3 years

Variable	Model 1	Model 2	Model 3	Model 4
Log Size	0.2468187*** (0.0009981)	0.2545054*** (0.0009934)	0.2545057*** (0.0009934)	0.2150187*** (0.0019987)
Density	0.2424233*** (0.0227234)	0.2382013*** (0.0224476)	0.2371549*** (0.0224631)	0.1983784*** (0.0277189)
Complexity ITC		0.1435475*** (0.0022655)	0.1435257*** (0.0022656)	-0.0319629*** (0.0035297)
Concentration Herfindhal Index			-0.0306398 (0.0244783)	-0.0214439 (0.0276654)
Log Size * GDP				0.0013702*** (0.0000504)
Density * GDP				0.0038978*** (0.0004353)
ITC * GDP				0.0052085*** (0.0000807)
Herfindahl Index * GDP				-0.0250265*** (0.0021996)
Constant	1.328325*** (0.1169714)	1.34263*** (0.1155513)	1.355053*** (0.1159766)	1.615099*** (0.116074)
Adjusted R-Squared	0.4356	0.4492	0.4493	0.4652
Tech Fixed Effects	Yes	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes

Lag Pub-Pat 5 years

Variable	Model 1	Model 2	Model 3	Model 4
Log Size	0.2492438*** (0.0009872)	0.2564894*** (0.0009825)	0.2564886*** (0.0009825)	0.2178442*** (0.0019744)
Density	0.0699324** (0.0232389)	0.057465* (0.0207204)	0.0565711* (0.022984)	-0.0156457 (0.0286463)
Complexity ITC		0.1452386*** (0.0023276)	0.1452185*** (0.0023277)	-0.0264417*** (0.0035853)
Concentration Herfindhal Index			-0.0244052 (0.0246257)	-0.0157044 (0.0275839)
Log Size * GDP				0.0012793*** (0.0000481)
Density * GDP				0.0034603*** (0.0004395)
ITC * GDP				0.0048875*** (0.000078)
Herfindahl Index * GDP				-0.0187085*** (0.0020759)
Constant	1.54164*** (0.12246)	1.571752*** (0.1210201)	1.582776*** (0.1215303)	1.901072*** (0.1226274)
Adjusted R-Squared	0.4433	0.4563	0.4563	0.4711
Tech Fixed Effects	Yes	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes

Conclusions

Most of our models show that for countries to become more globally relevant in developing specific new technologies, their scientific portfolio should be closely “related” to such new technologies. The effect increases as countries move up along the ladder of development.

Size matters. The greatest the size of a technology class, the greater the probability that countries developed such technology. The effect also increases as countries move up along the ladder of development.

Technological concentration results not to be statistically significant thereby that technologies may be developed in few locations does not affect the probability that countries develop new those new technologies.

Technological complexity results to be statistically significant, although with a negative effect. Therefore, when facing more complex technologies, countries have a harder time becoming globally relevant in developing those new-to-the-country technologies.

Still struggling with lags.

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Thank you