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Artificial Intelligence and Robotics Innovation:
A sectoral and geographic mapping

Dániel Vértesy
with Vincent Van Roy & Giacomo Damioli

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AI, what will it mean?

Helpful robots
washing and caring
for an aging population...
...or...

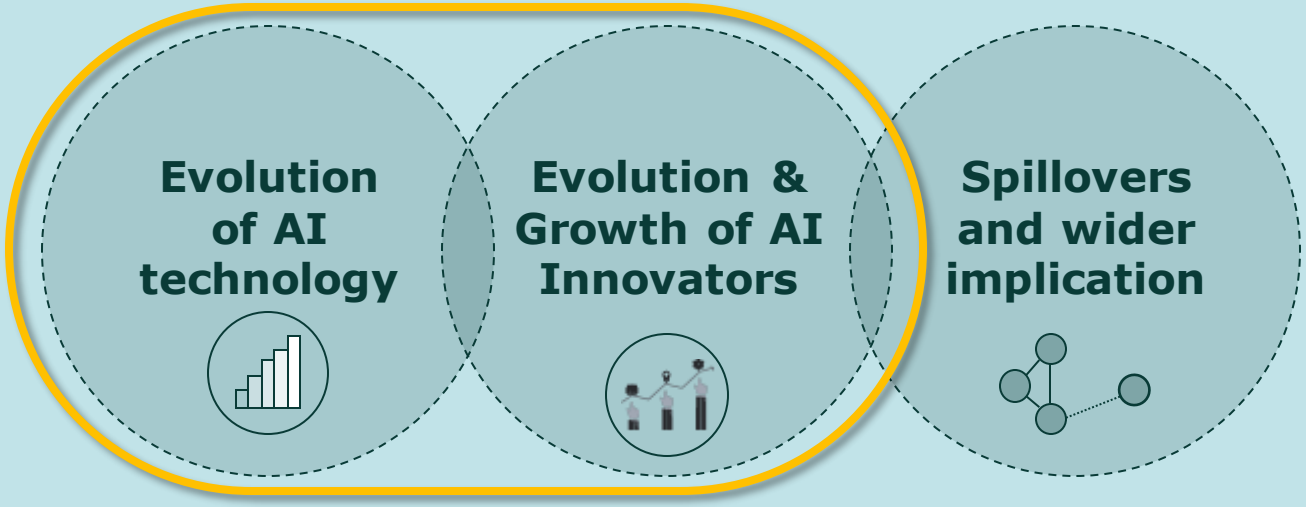
Pink-eyed terminators
sent back from the future
to cull the human race?

What will synthetic biology stand for:
restoring our livers and our eyes with
miracle regeneration of the tissues,
like some fantastic hangover cure?

Or will it bring terrifying
limbless chickens
to our tables?

Motivations

- The emergence and diffusion of AI, a general-purpose technology, with the potential to fundamentally transform the economy
- Uncertainties prevail about scale and speed of its labor market effects (e.g. Acemoglu and Restrepo 2017, 2019; Agrawal et al. 2018; Arntz et al. 2017; Autor 2015; Autor and Salomons 2018; Chiacchio et al. 2018; Dauth et al. 2017; Frey and Osborne 2017; Graetz and Michaels 2018)
- Scale and global distribution, industrial organization is still unknown – evidence starts to emerge (i.e., EC 2018; WIPO, 2019)



The study’s aim

Map the innovative and economic performance of AI inventors [find & describe]

- Map across time, space, technologies and industries [Evolution? Discontinuities?]
- Measuring performance (employment, turnover)

Measure the direct economic impact of AI inventions on inventor (innovator) firms

- “supply-side” perspective (focus on AI technological development, not its uptake)

Methodology:
Identification of AI inventors & measure performance

Cross-cutting issues:
Capturing a *Schumpeterian Moment*:
- Technology and industry life cycle; nature of competition
- Race for technological leadership

The link between Innovation & Employment:
- What are the growth and employment dynamics in AI inventor companies?

Identification and Measurement
- A patent-based approach (unit of observation: patent family)
  - IPR / economic intentions to exploit
  - Signaling effect of firms' capabilities [i.e., assume patenting goes with other IP protection]
  - Limitations: many algorithms not patented (protected by secrecy)
- To complement / verify: we also analyze Venture Capital funding to AI innovators

Data & Methods (1) Identify AI patents

We identify AI patents following a **keyword-based approach, aided by machine learning**

- Alternatives:
  - select IPC classes
  - Combination of the 2 approaches

Study	Identification Approach	Details
Keisner et al. 2015	Combined	Pre-selected set of IPC and CPC codes complemented with keywords (robot, robotics, and robotic) search in patents' title and abstract; Applied to robotics only
De Prato et al. 2018 EC 2018a	Keyword	Applied to patents as well as to business registers, scientific and trade publications and industrial associations records
OECD 2017	Select IPC classes	Selected IPC classes are a subset of those selected by Inaba and Squicciarini (2017) to identify ICT patents; Applied to ICT
WIPO 2019	Combined	Both keywords and IPC classes selection are based on the Association for Computing Machinery Computing Classification Scheme; Keywords also used to map publications
Fujii & Managi 2018	Select IPC classes	IPC classes listed in the Appendix of the study
Cockburn et al. 2019	Combined	Keywords search in the title of patents falling in pre-selected USPC codes; Keywords listed in the Appendix of the study; Keywords also used to map publications; Applied to specific fields: robotics, learning systems and symbol systems

Data & Methods (1)
Identify AI patents

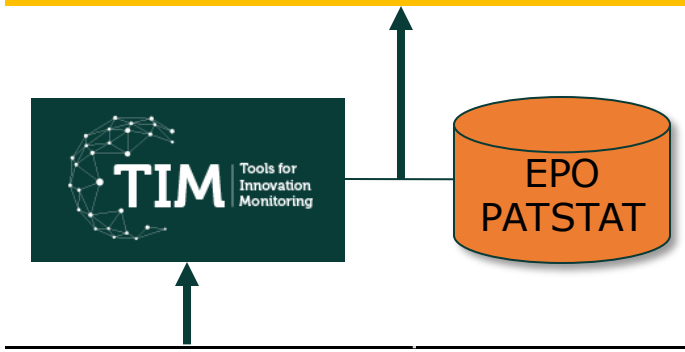
➔ keywords list obtained from De Prato et al (2018) and EC/JRC 2018 combined with text-mining techniques

JRC Tools for Innovation Monitor (TIM)

- for **patent families**: priority year, patent office of application, granted (yes/no), IPC classes
- for **applicants**: name, country, organization type

155,000 pat. families over 2000-2016

155,000 patent families (2000-2016), worldwide



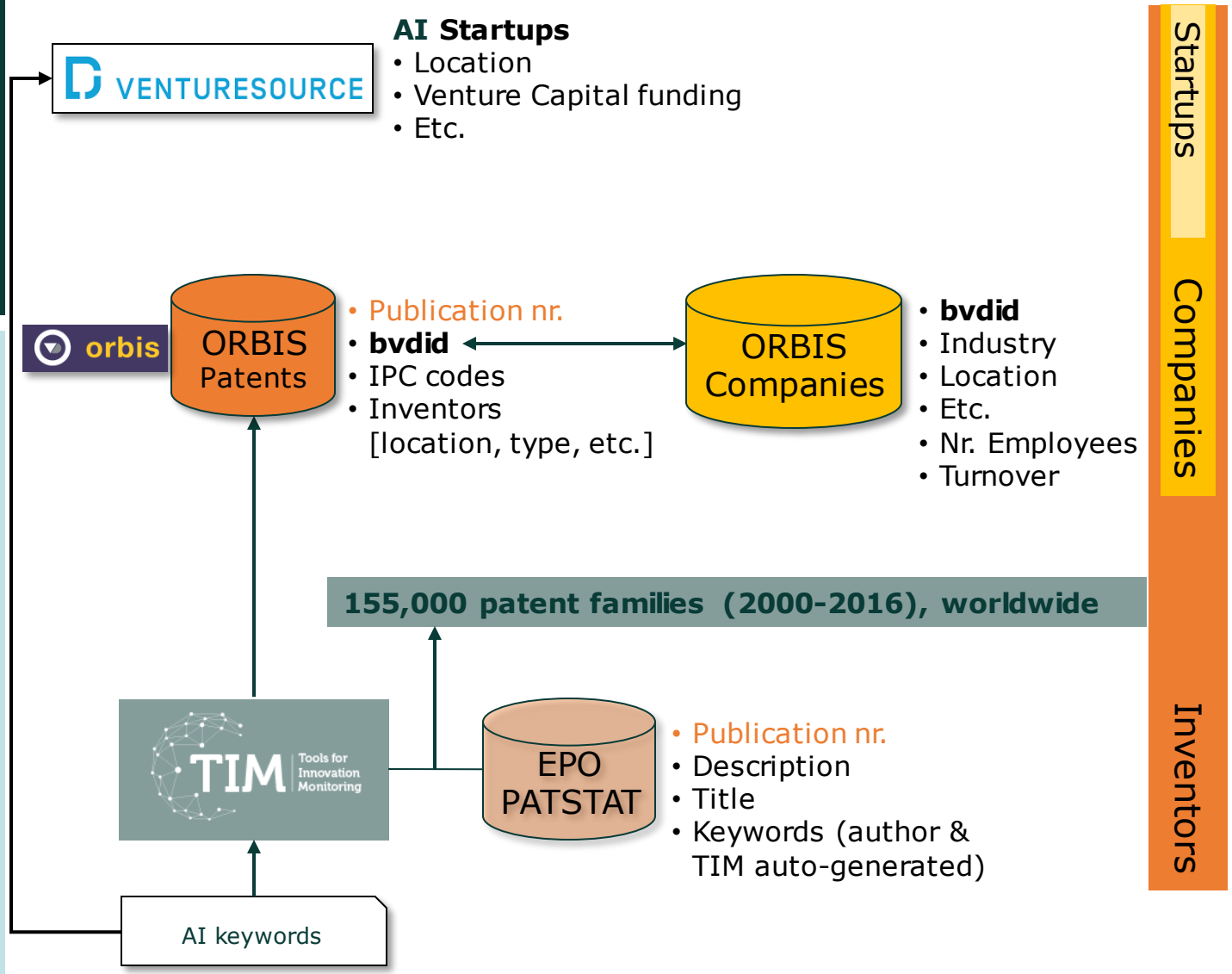
Keywords related to artificial intelligence

Artificial intelligence	Face recognition	Random Forest
Artificial intelligent	Facial recognition	Reinforcement learning
Artificial reality	Gesture recognition	Robotics
Augmented realities	Holographic display	Self driv
Augmented reality	Humanoid robot	Sentiment analysis
Automatic classification	Internet of things	Smart glasses
Autonomous car	Knowledge Representation	Speech Recognition
Autonomous vehicle	Machine intelligence	Statistical Learning
Bayesian modelling	Machine learn	Supervised learning
Big data	Machine to machine	Transfer Learning
Computational neuroscience	Mixed reality	Unmanned Aerial Vehicle
Computer Vision	Natural Language Processing	Unmanned aircraft system
Data mining	Neural Network	Unsupervised learning
Data science	Neuro-Linguistic Programming	Virtual reality
Decision tree	Object detection	Voice recognition
Deep learn	Predictive modeling	
Evolutionary Computation	Probabilistic modeling	

(+ also controlling for spelling variations, i.e. plurals)

Data & Methods (2)
Identify AI inventors

- Identify the owners of AI patents in ORBIS *Patents* [~97,000 organizations, accounting for 60,000 of patents]
- Collect balance sheet data where available from ORBIS *Companies* [~13,400 companies]
  - Unbalanced coverage in ORBIS (EU better than US and Asia)
- Identify AI Startups in DJ *Venture Source* using same keywords [~3,500 Startups]



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Main contribution of the study

- Descriptive analysis of new micro- (patent & firm-level) evidence on AI inventors and their economic performance

Key findings

1. Evolution of AI: an emerging general purpose technology (GPT)
2. Evidence on global technological leadership change (Japan → US → China)
3. Changing industrial organization (concentration of inventors increasing, concentration of companies decreasing)
4. AI inventions are sources of jobs and growth

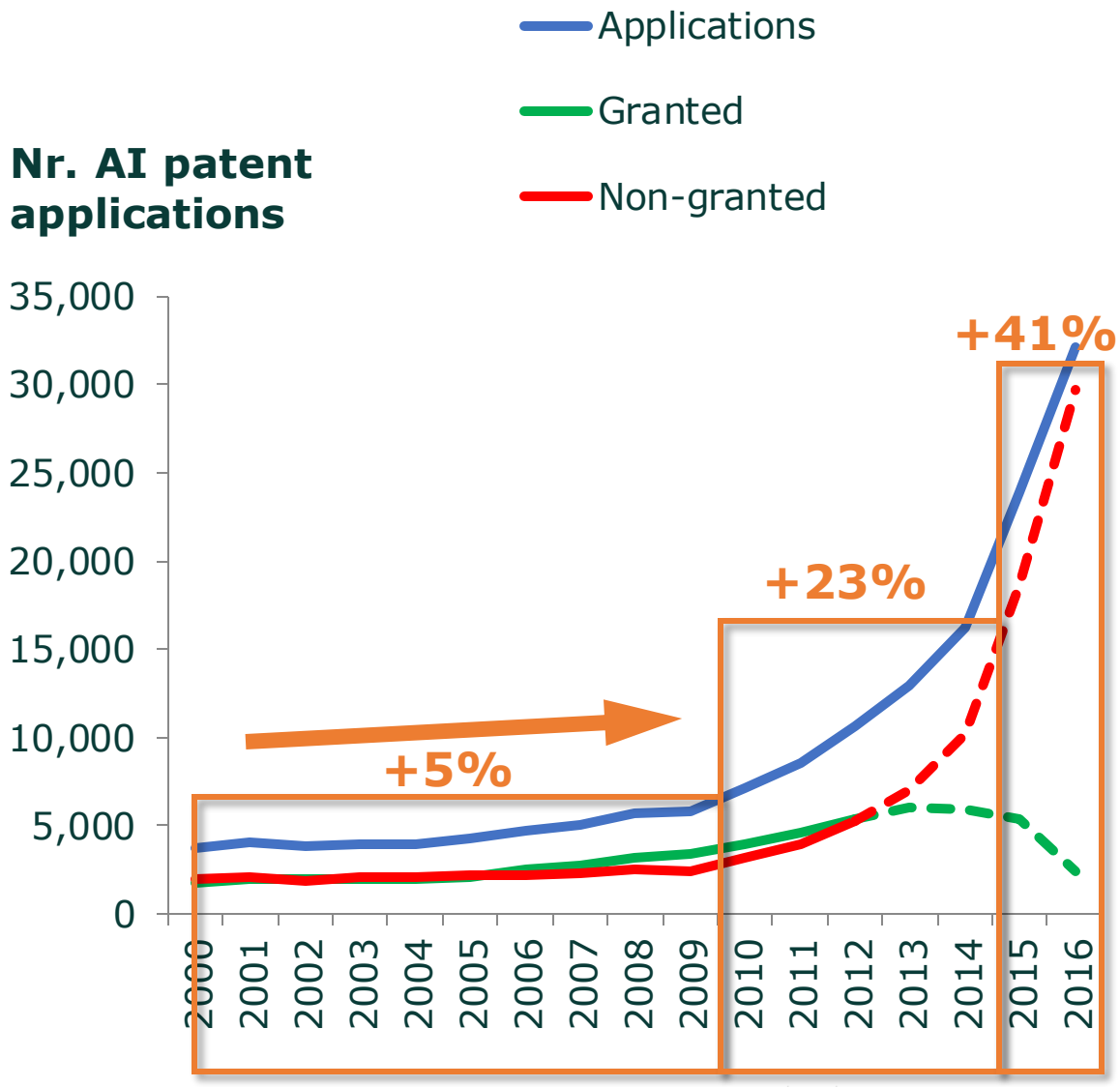
(1) An emerging GPT

Clear patenting trends: upswing of S-curve

3 sub-periods according to rates of growth:

- 2000-09: moderate increase (5% annual average change)
- 2010-14: strong increase (23%)
- 2015-16: booming (41%)

about half (52%) of those filed between 2000 and 2012 have been granted



Source: authors' calculations based on TIM / EPO PATSTAT data

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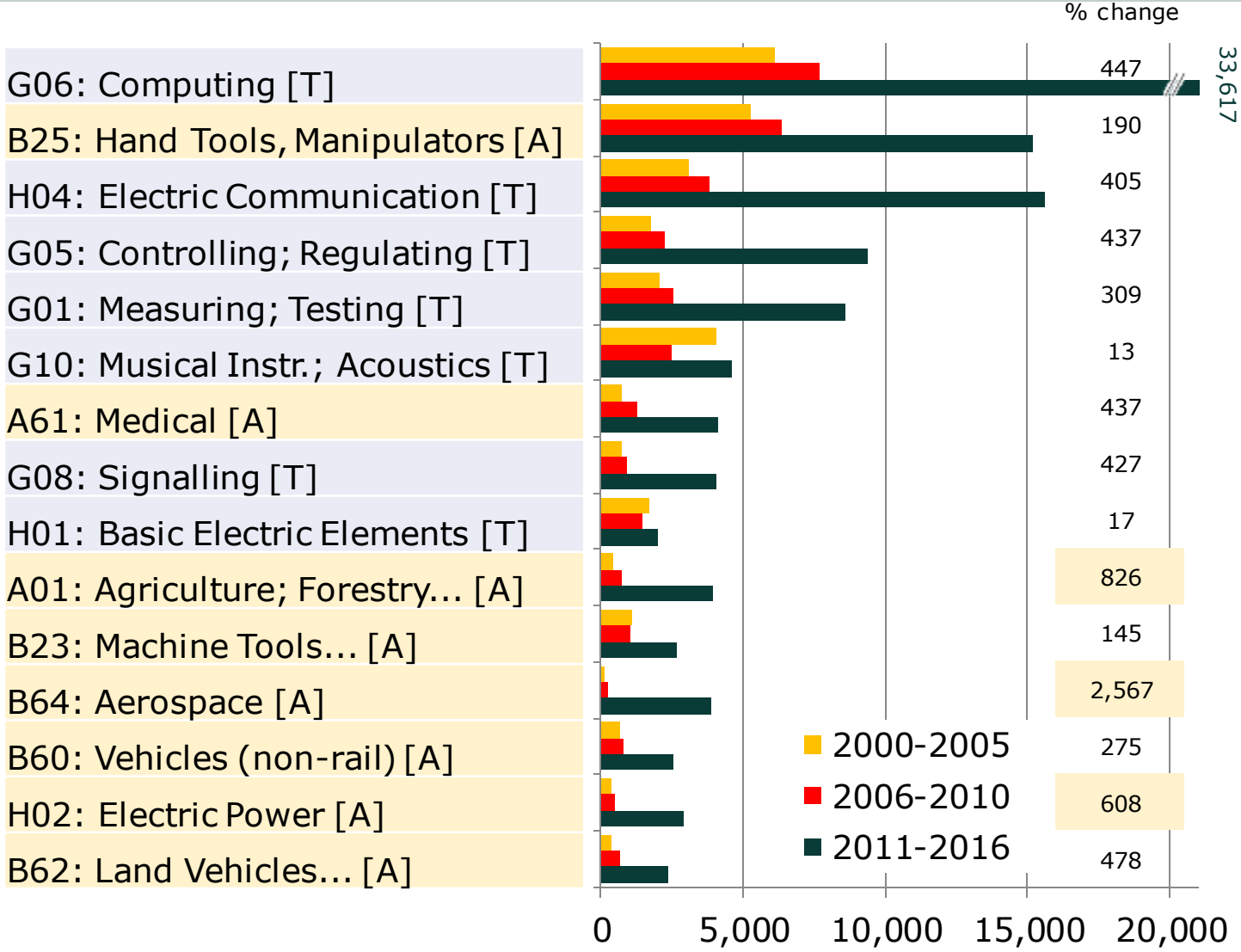
(1) An emerging GPT

- **[T] transversally** applicable technologies
  (i.e., computing, measuring, controlling or signaling, etc.):
  - "Enablers" [2000-05 lead]
- **[A] applied** technologies
  (i.e., related medical, aeronautics, vehicles, sports and games fields)
  - period 1 -> 3: high growth;
  - Further potential (i.e. medicine)

The Top 15 3-digit IPC technology classes with the largest nr. of AI patent applications, 2000-2016



Source: authors' calculations based on TIM / EPO PATSTAT data

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(1) An emerging GPT

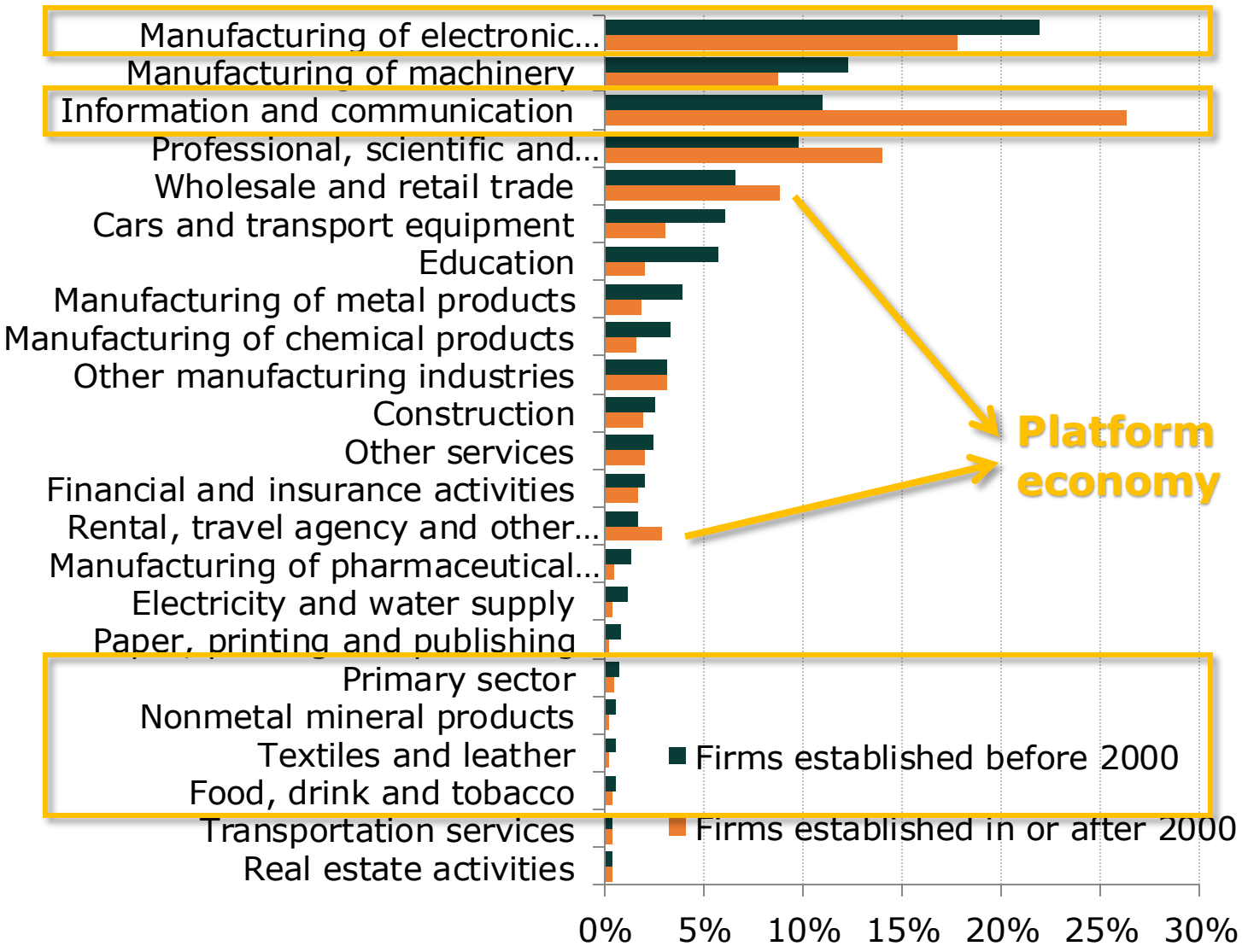
AI applied across the economy

- ICT: top sector among firms est'd since 2000; rising shares
- manufacturing of electronic equipment and machinery: largest industry among firms established before 2000; declining shares

➔ Firms more active in software than hardware or infrastructure;

➔ Primary, agri: still only a few

Sectoral distribution of AI patent applicants, 2000-2016



Source: authors' calculations based on ORBIS data

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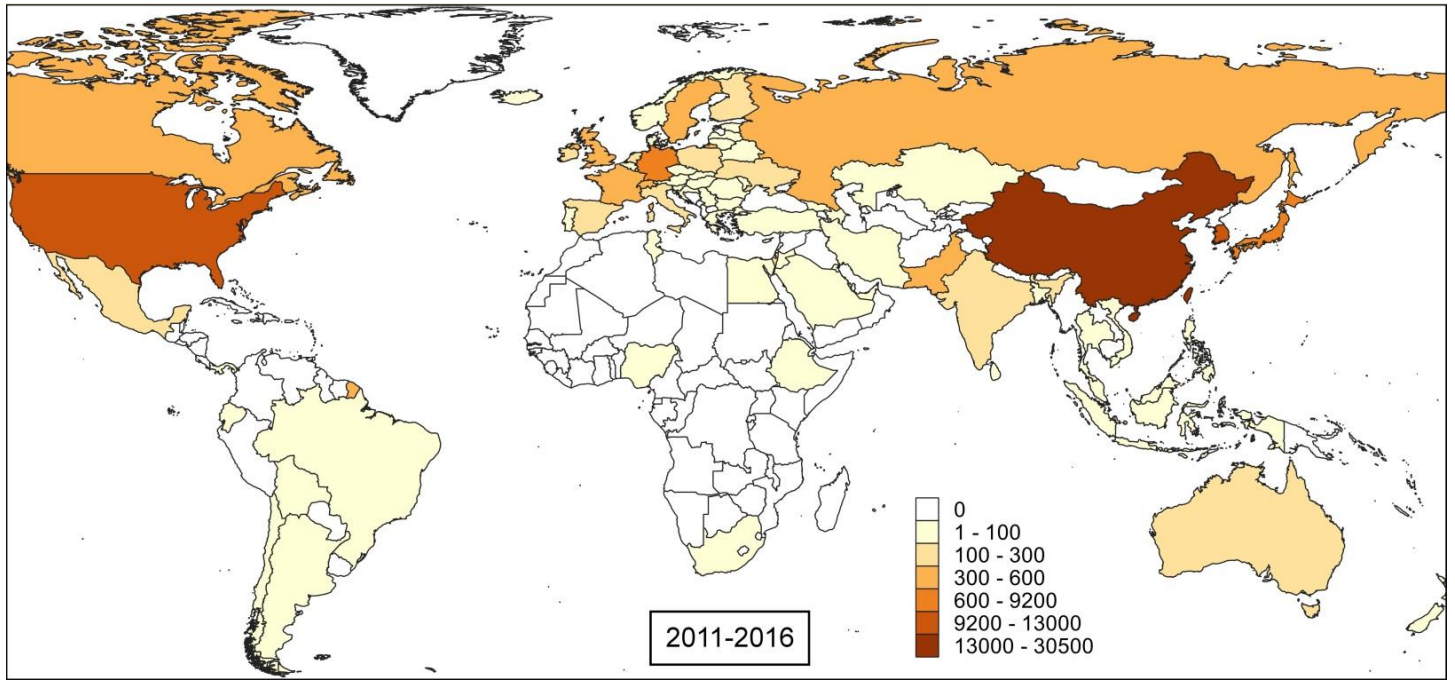
(2) Race for technological leadership

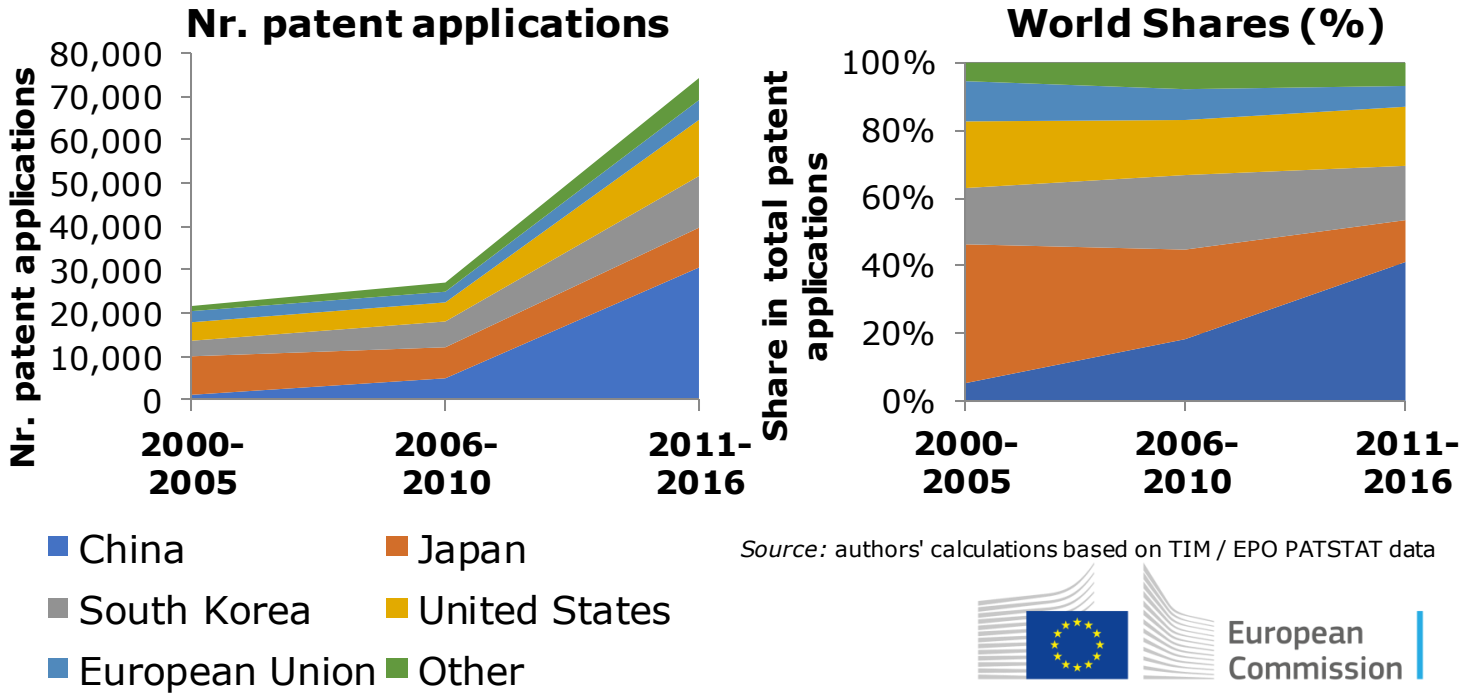
Four global players:

- CN, JP, KR, US – account for more than 85%
- EU28: <8% [half from DE]

Leadership change

1. Japan: First mover in AI
2. China takes over by 2011-2016





Source: authors' calculations based on TIM / EPO PATSTAT data

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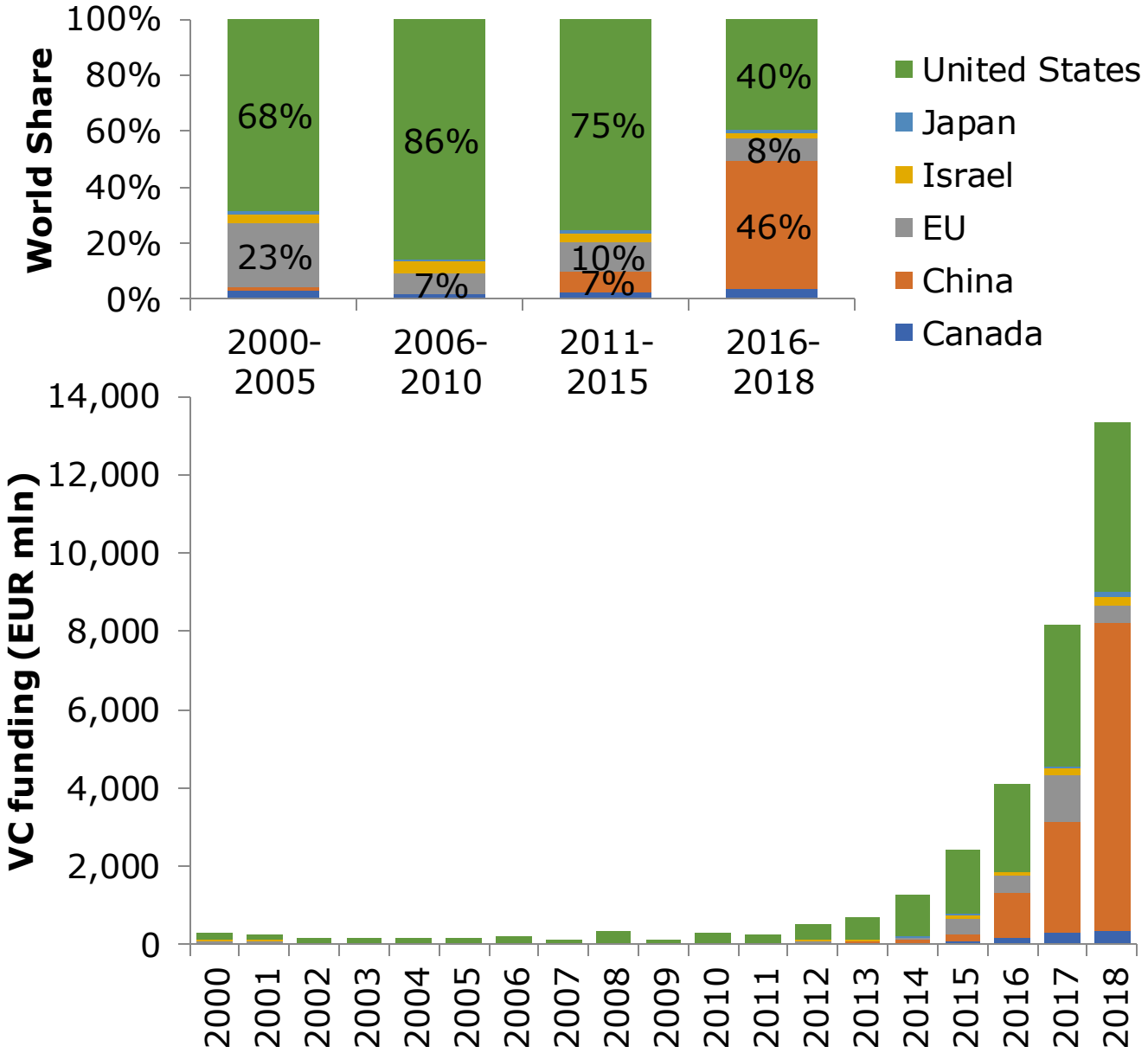
(2) Race for technological leadership

Beyond patents:

AI capabilities attract Venture Capital funding

- US has attracted most funding
- CN caught up since 2016 (novel phenomenon: departure from Univ / PRO dominance)



Source: authors' calculations based on Venture Source data

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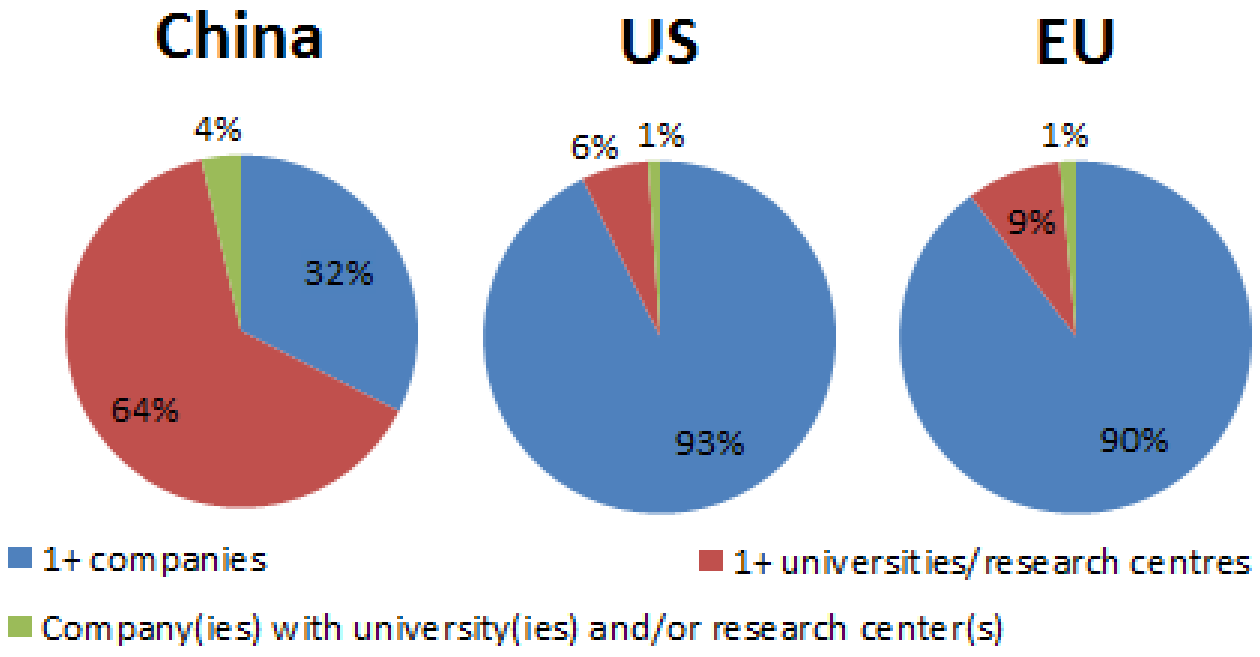
The Chinese model of AI development

- Explicit strategy; link to national security
- Quantity of applications → quality follows
- Dominance of Universities & [public] research organizations are the leading patenters
  ⇔ US, JP, KR, EU: corporate inventors
- Still to be seen: patent quality; VC-backed startups



Source: authors' calculations based on TIM / EPO PATSTAT data

The leading AI patent applicant organizations

Applicant organization name	Country	2000-16		2000-05		2006-10		2011-16	
		Rank	Patent families	Rank	Patent families	Rank	Patent families	Rank	Patent families
China University of Mining & Tech.	CN	2	2,219	159	14	42	90	1	2,115
Tencent Technology	CN	4	1,721	343	6	57	70	2	1,645
Samsung	KR	1	2,990	1	724	1	872	3	1,394
Chinese Academy of Sciences	CN	5	1,629	38	66	14	216	4	1,347
Seiko-Epson	JP	7	1,551	20	152	11	245	5	1,154
State Grid	CN	11	1,125	4894	0	861	3	6	1,122
IBM	US	3	1,731	5	436	16	207	7	1,088
Semiconductor Manufacturing Int'l Co.	CN	9	1,204	106	21	30	118	8	1,065
LG	KR	6	1,625	3	529	4	418	9	678
Collaborative Innovation Center of Chemical Science and Engineering	CN	25	656	916	2	206	17	10	637
Source Photonics	US	29	622	916	2	479	6	11	614
Google Inc.	US	27	639	251	8	71	55	12	576
Canon Inc.	JP	14	1,016	11	250	15	211	13	555
Toyota Motor	JP	8	1,494	9	304	2	651	14	539
Microsoft	US	12	1,031	15	208	6	300	15	523
Tsinghua University	CN	20	729	45	56	20	171	16	502
Elect & Telecom Research Institute	KR	15	916	28	103	5	316	17	497
Zhejiang University	CN	28	634	174	13	25	138	18	483
Harbin Institute of Technology	CN	32	584	343	6	36	105	19	473
Beihang University	CN	26	641	295	7	21	164	20	470
Led One	CN	34	489	408	5	242	14	20	470

Source: authors' calculations based on JRC TIM/EPO PATSTAT

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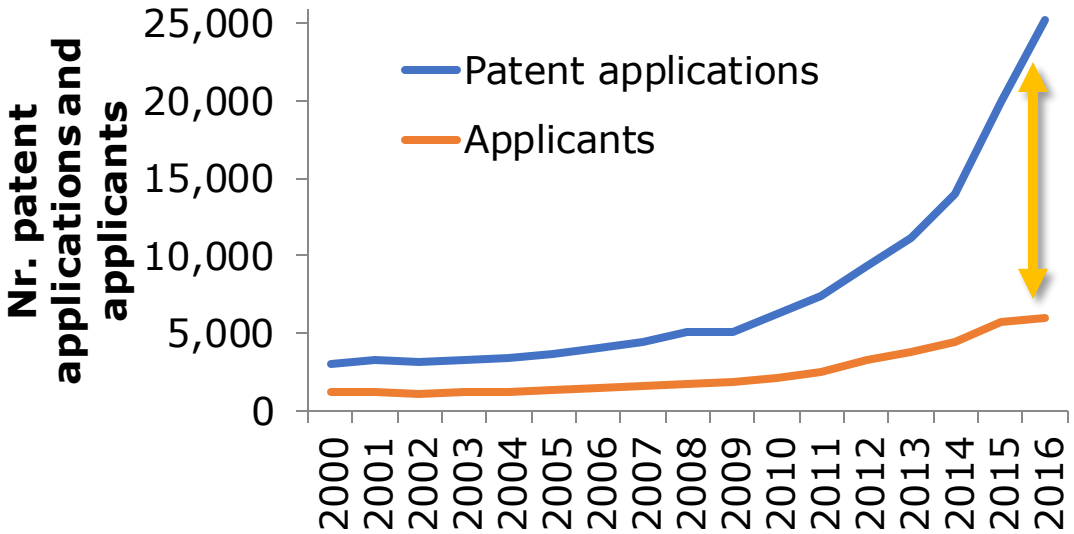
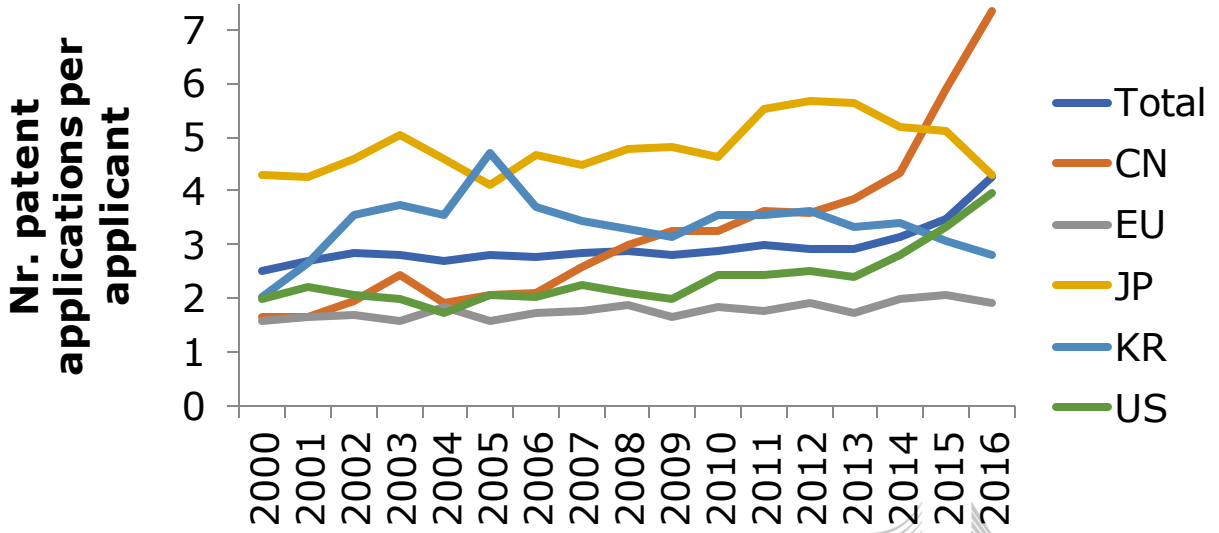
(3) AI's industrial organization
Growing tech. concentration

- AI inventors: the growth of the number of patent applications is faster than the growth of applicants
  => growing concentration
  - Economies of scale? [data as key resource]
  - CN, US: main drivers

However...





Source: authors' calculations based on TIM / EPO PATSTAT data

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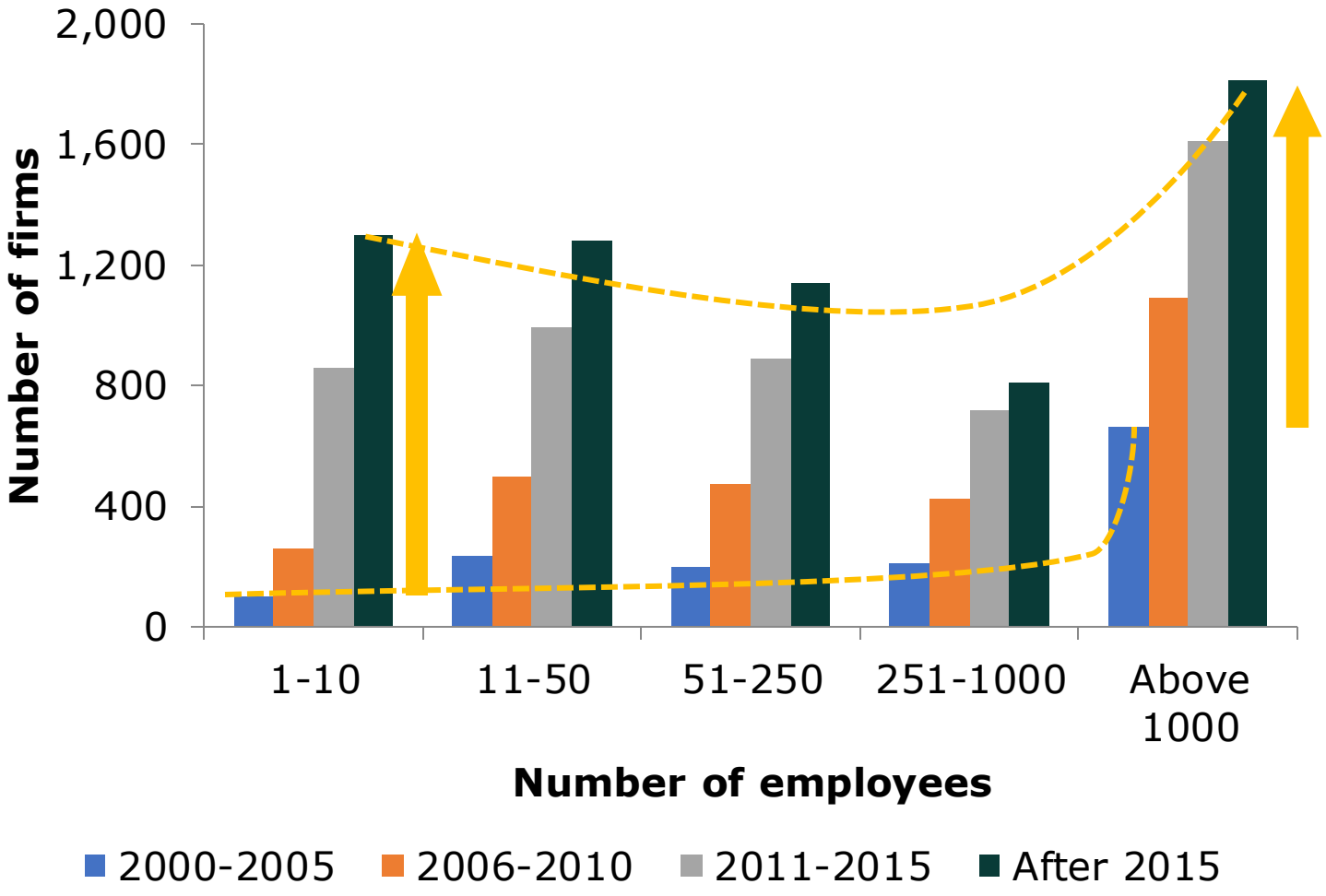
(3) AI's industrial organization:
SMEs entering the world of giants

AI business demography:

1. Initial AI inventors: large firms
2. Over time, distribution changed from '**J-**' to '**U-shaped**' pattern
(similar for turnover classes)
   - Most AI inventors have remain large firms (1000< employees)
   - Growing share of Micro & SMEs

➔ more competition / new challengers to incumbents?

➔ Industry life cycle: indicates an emerging, not a mature industry



Source: authors' calculations based on ORBIS data [all firms]

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(4) AI inventors are sources of jobs & growth

[Focusing on EU, where data is more complete:]

AI patent applicants show strong average annual **growth rates:**

- Almost 10% turnover gr.;
- 2.5% employment gr.
- Services lead (ICT, prof. S&T), but high-tech mfg. also strong

Growth rates of AI patent applicants by sector in the EU, 2000-2016

Sectors	Percentage growth		
	Employment	Turnover	Labour productivity
Manufacturing of electronic equipment	2.9	9.0	5.4
Information and communication	5.3	15.6	8.7
Professional, sci. & tech activities	3.7	13.2	8.7
Manufacturing of machinery	3.6	9.4	6.6
Wholesale and retail trade	1.6	4.7	6.5
Cars and transport equipment	1.7	9.6	6.2
Education	2.4	6.2	7.2
All sectors	2.5	9.8	6.9

Source: authors' calculations based on ORBIS data

(4) AI inventors are sources of jobs & growth

AI patent applicant firms **grow faster than industry** average in terms of Turnover & Employment

- Positive gap
- Gap increases over time

[EU firms]

Sector	Employment growth					
	2000-2005		2006-2010		After 2010	
	AI	Industry	AI	Industry	AI	Industry
Manufacturing of electronic eqpt.	0.1	-2.0	2.0	-2.0	3.6	-0.5
Information and communication	2.1	1.3	4.8	1.1	5.9	1.8
Professional, sci. & tech. activities	3.7	2.7	2.8	2.3	4.0	2.1
Manufacturing of machinery	-1.1	-1.3	2.0	-1.2	4.3	1.1
Wholesale and retail trade	-4.9	0.9	0.7	0.5	2.8	0.0
Cars and transport equipment	-0.6	-1.1	0.9	-2.0	2.3	2.0
Education	-4.7	1.1	5.1	1.1	1.7	0.5
All sectors	0.2	> -0.1	2.1	> -0.4	3.8	> 0.1

Sector	Turnover growth					
	2000-2005		2006-2010		After 2010	
	AI	Industry	AI	Industry	AI	Industry
Manufacturing of electronic eqpt.	10.1	-0.3	8.0	0.7	9.2	0.4
Information and communication	24.2	4.6	8.3	2.3	16.8	3.2
Professional, sci. & tech. activities	7.5	4.7	12.9	3.2	13.9	3.7
Manufacturing of machinery	5.9	2.9	6.7	2.3	10.7	4.0
Wholesale and retail trade	-0.9	3.9	5.8	2.0	4.9	2.5
Cars and transport equipment	7.1	3.3	7.2	1.8	11.1	5.9
Education	0.9	4.7	18.5	3.3	3.1	2.3
All sectors	8.7	> 3.4	8.2	> 2.2	10.6	> 2.4

Note: AI refers to identified AI patent applicants with known balance sheet data in ORBIS

Source: authors' calculations based on ORBIS (Sample) and Eurostat National Accounts (Industry) data

(4) AI inventors are sources of jobs & growth

Patents' growth premium:

firms with at least one granted patent…

- perform significantly better in terms of employment growth
- perform significantly better in terms of turnover growth if SME

(Causality may work in two ways)

AI patenting firms	Percentage growth	
	Employment	Turnover
Total sample		
Only non-granted patent applications	2.9	9.6
At least one granted patent	3.6*	9.5
SMEs		
Only non-granted patent applications	3.3	14.5
At least one granted patent	4.6*	15.9*

Source: authors' calculations based on ORBIS data [European firms]

Conclusions: what does it all mean for the EU?

1. Take stock with reality: technological leadership in East Asia and North America!
   - China emerging as leader, first-mover advantages [*not just patents, VC too!*]
   - EU: overall, a slow mover in AI, but with strong technological capabilities to build on
   - AI techs: still in its infancy
2. Find & create windows of opportunity
   - Tech complexity: Needs a smart combination of first-mover & fast-follower advantages!
   - Strong growth potential in applied fields: help AI's diffusion in low-tech/service sectors
   - Peculiar dynamics of "industry": entry both of new, small firms AND fast growth of tech giants [Schumpeter Mk I AND II competition!]
3. Beware of proprietary /transversal/ technologies
   - Key underlying techs owned by non-EU inventors = potential barrier to EU innovators
   - EU's strategy = more openness in general; with data: share & protect...

Disclaimer: reflects the views of the authors, not the official EU position...

Thanks

Questions?

You can find me at **daniel.vertesy@ec.europa.eu**

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Next steps

- Further description: internationalization, M&A of AI inventors
- Investigate patents' growth premium
- Investigate employment dynamics of AI inventors

Sectors	AI firms	
	Numbers	Percentage
Manufacturing of electronic equipment	2,274	19.5
Information and communication	2,172	18.6
Professional, scientific and technical activities	1,385	11.9
Manufacturing of machinery	1212	10.4
Wholesale and retail trade	905	7.8
Cars and transport equipment	527	4.5
Education	509	4.4
Other manufacturing industries	363	3.1
Manufacturing of metal products	336	2.9
Other services	293	2.5
Manufacturing of chemical products	287	2.5
Rental, travel agency and other business support activities	271	2.3
Construction	262	2.3
Financial and insurance activities	218	1.9
Manufacturing of pharmaceutical products	109	0.9
Electricity and water supply	94	0.8
Primary sector	83	0.7
Paper, printing and publishing	70	0.6
Food, drink and tobacco	56	0.5
Real estate activities	54	0.5
Textiles and leather	53	0.5
Nonmetal mineral products	53	0.5
Transportation services	51	0.4
Accommodation and food service	25	0.2
Total	11,662	100.0

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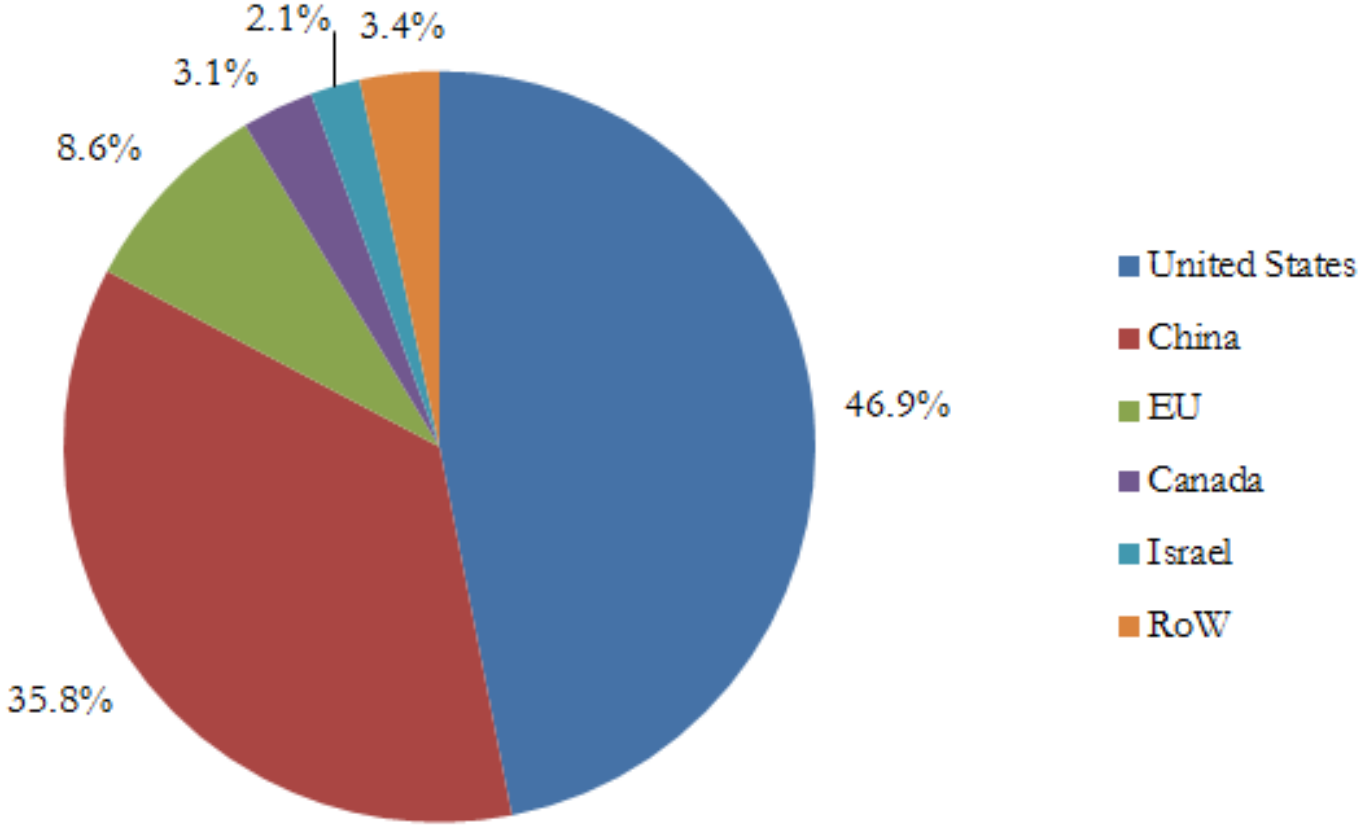
Start-ups and venture capital in AI

Similar keywords/text mining techniques used to identify AI players in (the company description of) Venture Source data

➔ 3,459 AI startups in Venture Source

… broadly speaking, similar patterns as those observed in patents …

Figure 9 Distribution of total VC funding across selected regions



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