

Artificial Intelligence, Firm Growth, and Industry Concentration

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Motivation

- Explosion in Artificial Intelligence (AI) investment in recent years
 - From **\$7.6 billion** in 2010 to **\$48 billion** in 2018 in the US + **\$24 billion** targeted by EU, **\$150 billion** by China
 - Most of AI investments are in machine learning (ML), computer vision (CV), and natural language processing (NLP)
- How does AI affect firms and industries?
 - Huge potential to transform production, yet sluggish productivity growth recently
- Potential channels:
 - Productivity growth (Brynjolfsson, Hitt, Kim 2011; Tanaka, Bloom, David, Koga 2019)
 - Market power due to price discrimination (Varian 2018; Mihet and Philippon 2019)
 - Scale advantage (Autor, Dorn, Katz, Patterson, Van Reenen, 2020; Aghion, Bergeaud, Boppart, Klenow, Li 2019; Farboodi, Mihet, Philippon, Veldkamp 2019)

This paper

- Goals:
 - Which firms invest in AI?
 - How do AI investments affect firm and industry growth, employment?
 - Which firms benefit most, and how does AI affect industry concentration?
- Our approach:
 - **Data:** detailed, firm-level information on demand for AI talent (job postings) + hiring of AI talent (resumes) of US public firms
 - **Measure:** data-driven measure of AI-relatedness of each skill and job, without pre-specifying AI-related words
 - **Identification:** instrument AI investments with:
 - a) industry-level AI investments in Europe
 - b) shift-share instrument relying in differences in local exposure to AI

Preview of findings

1. Rapid growth in AI technologies across a wide range of industries
2. Large firms are more likely to invest in AI
3. Firm-level: AI increases sales, employment, market share
 - No effect on productivity or markups
 - Growth is concentrated in ex-ante largest and most productive firms
4. Industry-level: AI increases aggregate sales, employment and industry concentration

Overall, AI leads to the expansion of ex-ante most efficient firms and contributes to the rise of “superstar” firms

How is AI Different from Previous Technologies?

- AI system is a “*Machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations or decisions influencing real or virtual environments*”
- **Artificial Intelligence:** (e.g. machine learning)
 - Perform high-skilled, nonroutine tasks like prediction, detection, and classification
 - Key inputs: data, computing power, AI-skilled workers
- **Robots:** (e.g. car manufacturing robots)
 - Perform low-skilled manual, repetitive tasks
 - Key input: physical capital (robots)
- **IT/Software:** (e.g. bookkeeping software, ATM)
 - Perform medium-skilled routine and codifiable tasks
 - Key inputs: physical capital (computers), software

Data

- Job postings: Burning Glass Technologies
 - 180 million job postings
 - Comprehensive coverage of online job openings in 2007 and 2010–2018
 - Detailed taxonomy of required skills
- Employment profiles (resumes): Cognism, aggregator of public profile information
 - 145 million full profiles; global coverage
 - Job histories, skills, education, publications, patents, awards, references
 - Captures actual hiring, not just demand

How to Identify AI-related Jobs in 100+ Million Job Postings?

Example of clearly AI-related job:

- Job title
 - Machine Learning Engineer
- Required Skills
 - Machine Learning, Artificial Intelligence, Computer Vision, Deep Learning, Python, C++, Research, Teamwork / Collaboration

How to Identify AI-related Jobs in 100+ Million Job Postings?

Example of clearly **not** AI-related job:

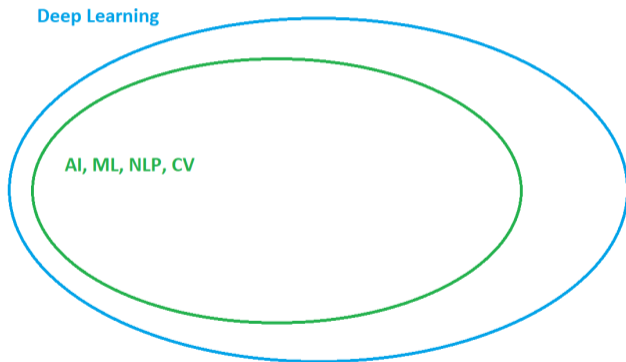
- Job title
 - Parking Attendant
- Required Skills
 - Teamwork / Collaboration, Communication Skills, Detail-Oriented, Scheduling, Heavy Lifting, Physical Abilities, Safety Codes, Snow Removal, Guest Services

How to Identify AI-related Jobs in 100+ Million Job Postings?

Example of job not obviously AI-related:

- Job title
 - Developer Programs Engineer
- Required Skills
 - TensorFlow, Kubernetes, Cloud Computing, Java, HTML5, Technical Writing / Editing, Teamwork / Collaboration, Writing, Troubleshooting

Some Skills **Have High Overlap** with AI-specific Skills



Some Skills **Do Not Have High Overlap** with AI-specific Skills

Communication

AI, ML, NLP, CV



New Measure of AI Human Capital

- Identify relevant skills: Burning Glass
 - Four core AI skills: Artificial Intelligence, Machine Learning, Natural Language Processing, Computer Vision
 - AI-relatedness score of skill s =
% of jobs requiring skill s that also require at least one core AI skill

Highly related (score>0.7) (N=68)	Less related (0.05<score<0.7) (N=533)	Not related (score<0.05) (N=13,577)
Tensorflow (0.90)	Information retrieval (0.37)	Communication skills (0.003)
Unsupervised learning (0.89)	Logistic regression (0.26)	Microsoft Office (0.001)
Deep learning (0.86)	Speech recognition (0.22)	Lawn mowing (0.000)
Random forests (0.84)	Python (0.12)	

New Measure of AI Human Capital

Burning Glass job postings

A job posting is AI-related if average score of all required skills > 0.1

Example:

Required skills: Machine learning (1), Text mining (0.63), MapReduce (0.29), Apache Hadoop (0.21), Data mining (0.16), Software engineering (0.04), Research (0.01), Communication skills (0.00)

Average score: **0.29**

Cognism online resumes

A job in a resume is AI-related if it contains a highly related skill (score > 0.7) in profile

Examples:

Job title: "Senior **Machine Learning** Developer"

Job description: "develop Chatbots using Python with **scikit learn**, **tensorflow** and **deep learning** models..."

Publications: "A New Cluster-Aware Regularization of **Neural Networks**"

Patents: "Systems and methods for prime design using **machine learning**"

- Match employers to Compustat and calculate % of AI jobs at firm level
- AI measures from two datasets highly correlated and yield consistent results

Our Narrow AI Continuous Measure Does Well!

Example of clearly AI-related job:

- Job title
 - Machine Learning Engineer
- Required Skills
 - Machine Learning, Artificial Intelligence, Computer Vision, Deep Learning, Python, C++, Research, Teamwork / Collaboration
- **AI measure: 0.35**

Our Narrow AI Continuous Measure Does Well!

Example of clearly **not** AI-related job:

- Job title
 - Parking Attendant
- Required Skills
 - Teamwork / Collaboration, Communication Skills, Detail-Oriented, Scheduling, Heavy Lifting, Physical Abilities, Safety Codes, Snow Removal, Guest Services
- **AI measure: 0**

Our Narrow AI Continuous Measure Does Well!

Example of job not obviously AI-related or not AI related:

- Job title
 - Developer Programs Engineer
- Required Skills
 - TensorFlow, Kubernetes, Cloud Computing, Java, HTML5, Technical Writing / Editing, Teamwork / Collaboration, Writing, Troubleshooting
- **AI measure: 0.12**

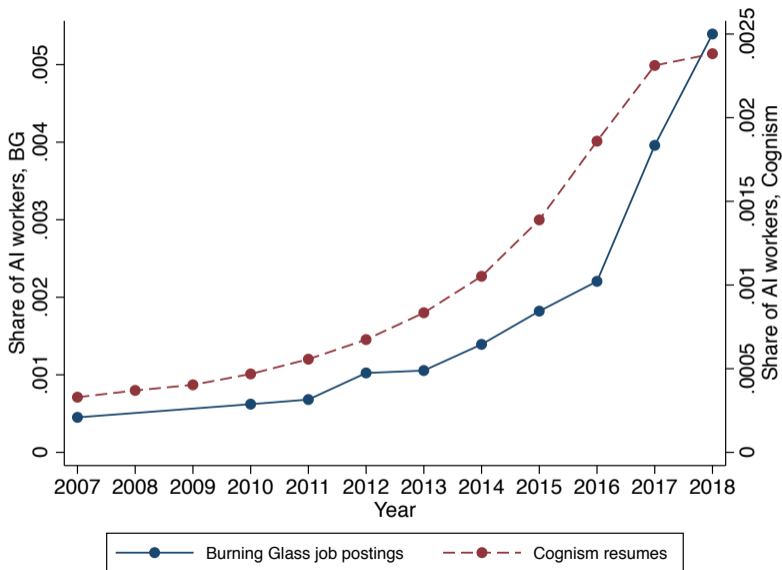
Job Titles with Top Values of Our AI Skill Measure

Cleantitle	Narrow AI Continous Measure
Artificial Intelligence Researcher	0.600
Text And Content Analytics Consultant	0.500
Artificial Intelligence Engineer	0.476
Post-Doctoral Researcher - Natural Language Processing	0.426
Research Staff Member - Semantic Analysis And Integration	0.397
Senior Data Scientist - Machine Learning Engineer	0.367
Ai Consultant	0.365
Artificial Intelligence Technology Manager - Multiple Locations Across The US	0.364
Deep Learning Engineer	0.364
Machine Learning Cloud Consultant	0.358
Ai Senior Analyst	0.354
Data Scientist - Aws Professional Services	0.336
Student Research Collaboration	0.335
Ai Senior Manager	0.330
Machine Learning	0.322
Lead Machine Learning Scientist - Enterprise Products	0.313
Manager - Cognitive Data Scientist Natural Language Processing	0.312
Data Scientist Machine Learning	0.302
Image Analytics Scientist	0.295
Technician Architecture Delivery Senior Analyst Ai	0.294
Data Scientist People Analytics Professional	0.292
Artificial Intelligence Analyst	0.291
Senior Scientist - Image Analytics	0.290
Artificial Intelligence Architect	0.288
Machine Learning Data Engineer	0.285
Natural Language Processing Research Engineer	0.284

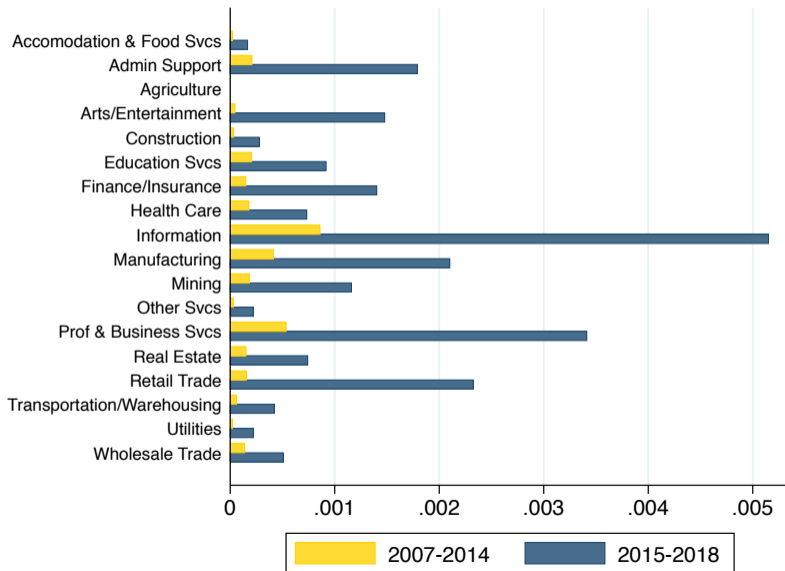
Job Titles with Highest Number of AI-Skilled Job Postings

Cleantitle	# of AI Workers
Data Scientist	3,529
Senior Data Scientist	1,547
Software Engineer	665
Principal Data Scientist	434
Data Engineer	409
Senior Software Engineer	399
Research Scientist	398
Lead Data Scientist	358
Machine Learning Engineer	305
Big Data Engineer	239
Senior Data Engineer	230
Big Data Architect	197
Big Data Consultant	191
Data Analyst	176
Data Scientist, Senior	168
Data Scientist II	153
Hadoop Developer	153
Software Development Engineer	151
Data Science Engineer	147
Big Data Developer	144
Machine Learning Scientist	144

Fast Growth in Share of AI Workers in the Last Decade



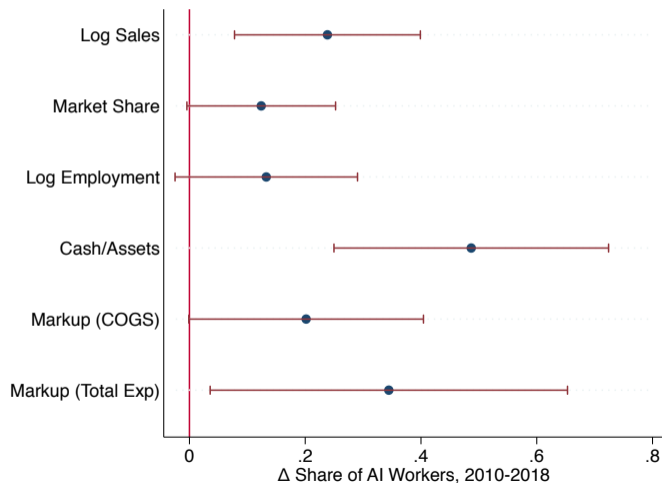
Increase in AI Workers in All Sectors



Which Firms Adopt AI?

- Predict change in AI share from 2010–2018 based on 2010 firm characteristics:

$$\Delta \text{ShareAIWorkers}_i^{2010-2018} = \beta X_i^{2010} + \text{IndustryFE} + \varepsilon_i$$



Effect of AI on Firm Growth

- Long-differences regression:

$$\Delta Y_i^{2010-2018} = \beta \Delta \text{ShareAIWorkers}_i^{2010-2018} + \gamma X_i^{2010} + \text{IndustryFE} + \varepsilon_i$$

	Δ Log Sales		Δ Log Employment		Δ Market Share	
Δ Share AI Workers	0.129*	0.156***	0.134*	0.152**	0.015	0.014*
	(0.071)	(0.057)	(0.079)	(0.062)	(0.012)	(0.008)
Ind FE	Y	Y	Y	Y	Y	Y
Controls	N	Y	N	Y	N	Y

Other IT

By Sector

Burning Glass

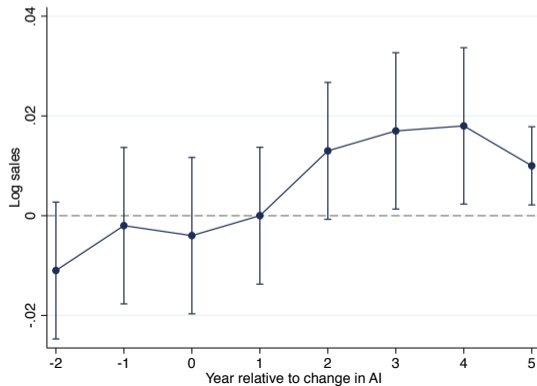
Continuous

Dynamic Effects of AI on Firm Growth: Event Study Design

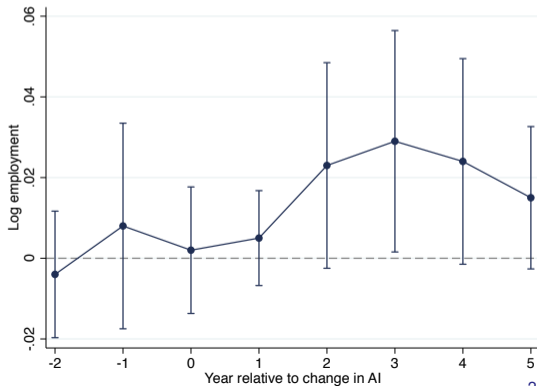
Distributed lead-lag model (Stock and Watson 2015; Aghion, Antonin, Budel, Jaravel 2020):

$$Y_{it} = \sum_{k=-2}^5 \delta_k \Delta \text{ShareAIWorkers}_{i,t-k} + \mu_i + \lambda_{st} + \epsilon_{it}$$

Log Sales



Log Employment



Instruments

- Two IV strategies to identify causal effect of AI
- Instrument #1: industry-level AI growth in Europe (Autor, Dorn, Hanson 2013; Acemoglu and Restrepo 2020)
 - Build 5-digit-NAICS-level AI measure from granular European firm-level data
 - Identifying assumption: AI growth in US and Europe driven by similar technological factors that vary across industries
 - First stage F-statistics between 32 and 39 Europe vs. RoW Pretrend Prices
- Instrument #2: Bartik IV based on firms' differences in local exposure to AI
 - Weighed average of US industry-level AI investments, where weights are given by industry employment share at the firm's locations

Effect of AI on Firm Growth, 2010–2018

- Foreign-industry IV:

	Δ Log Sales		Δ Log Employment	
Δ Share AI Workers	0.359*** (0.110)	0.418*** (0.106)	0.313* (0.168)	0.355* (0.190)
Ind FE	Y	Y	Y	Y
Controls	N	Y	N	Y

- Shift-share IV:

	Δ Log Sales		Δ Log Employment	
Δ Share AI Workers	0.343*** (0.087)	0.317*** (0.085)	0.297*** (0.088)	0.260*** (0.100)
Ind FE	Y	Y	Y	Y
Controls	N	Y	N	Y

AI Investments Associated with Expansion at Industry Level

- OLS results:

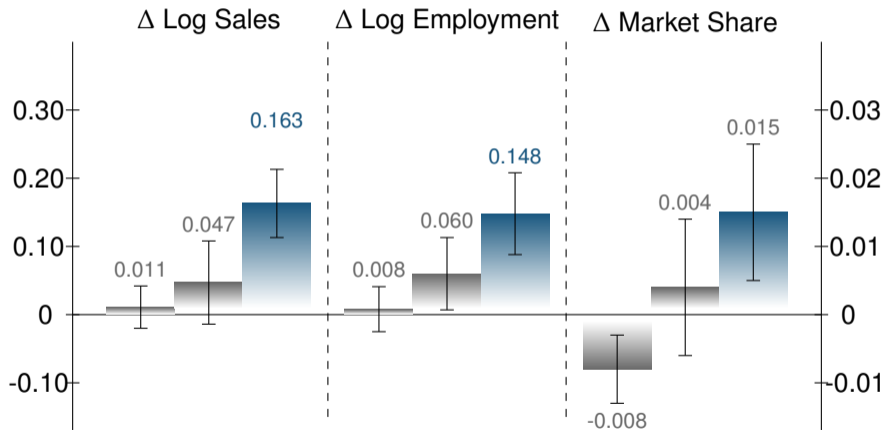
	Δ Log Sales		Δ Log Employment	
Δ Share AI Workers	0.134*** (0.046)	0.150*** (0.035)	0.143** (0.056)	0.167*** (0.047)
Sector FE	Y	Y	Y	Y
Controls	N	Y	N	Y

- IV results (Foreign-industry IV):

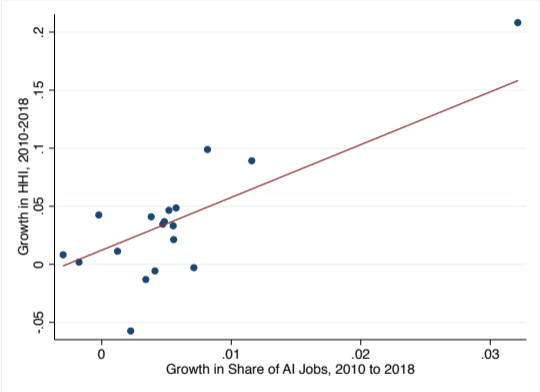
	Δ Log Sales		Δ Log Employment	
Δ Share AI Workers	0.241*** (0.053)	0.289*** (0.053)	0.206* (0.107)	0.246** (0.095)
Sector FE	Y	Y	Y	Y
Controls	N	Y	N	Y

Growth is Concentrated in Big Firms

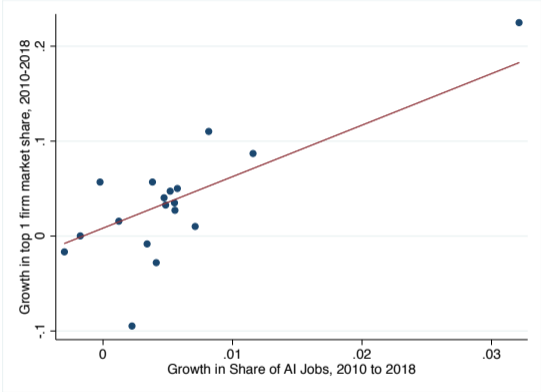
Subsamples: firms ranked (terciles) based on employment as of 2010



AI Investments Lead to Increased Industry Concentration



(a) HHI



(b) Top Firm Market Share

AI Investments Lead to Increased Industry Concentration

	OLS				IV			
	HHI		Top Firm Market Share		HHI		Top Firm Market Share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δ Share AI Workers	0.029*** (0.007)	0.027*** (0.007)	0.035*** (0.008)	0.033*** (0.008)	0.052*** (0.014)	0.041*** (0.015)	0.060*** (0.016)	0.046*** (0.017)
NAICS2 FE	Y	Y	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y	Y	Y

Mechanisms

Mechanisms

1. Productivity growth

	Δ Log Sales Per Worker		Δ Revenue TFP	
Δ Share AI Workers	-0.028 (0.038)	-0.006 (0.035)	-0.015 (0.033)	0.004 (0.035)
Ind FE	Y	Y	Y	Y
Controls	N	Y	N	Y

Mechanisms

1. Productivity growth

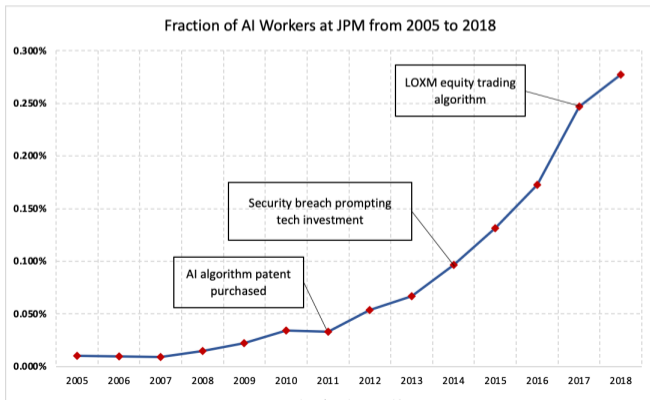
	Δ Log Sales Per Worker		Δ Revenue TFP	
Δ Share AI Workers	-0.028 (0.038)	-0.006 (0.035)	-0.015 (0.033)	0.004 (0.035)
Ind FE	Y	Y	Y	Y
Controls	N	Y	N	Y

2. Market power

	Δ Log Markup (COGS)		Δ Log Markup (Total Exp)		Δ Lerner Index	
Δ Share AI Workers	0.001 (0.016)	0.031 (0.028)	-0.001 (0.006)	0.010 (0.011)	-0.005 (0.003)	0.004 (0.006)
Ind FE	Y	Y	Y	Y	Y	Y
Controls	N	Y	N	Y	N	Y

Mechanisms

- Case study: JP Morgan
 - Largest bank in US with consumer banking, commercial banking, investment banking and asset management arms
 - New financial products & investment products (e.g. Algo Central, LOXM, and DeepX)
 - Serve customers through AI-powered virtual assistants



Mechanisms

3. Scale advantage: AI allows ex-ante large and efficient firms to expand

- AI and big data can induce economies of scale and reinforce winner-take-all effects (Farboodi, Mihet, Philippon, Veldkamp 2019)
- Aghion, Bergeaud, Boppart, Klenow, Li (2019): technology use leads to falling costs of spanning multiple markets \Rightarrow most efficient firms expand into new markets

	Δ Log # of Counties		Δ Log # of Product Managers	
Δ Share AI Workers	0.067*** (0.020)	0.078*** (0.024)	0.165*** (0.046)	0.134*** (0.067)
Ind FE	Y	Y	Y	Y
Controls	N	Y	N	Y

Conclusion

- AI leads to higher firm growth
 - AI allows firms to grow even larger, capturing more market share
 - No significant impact on productivity and markups
- Industry-level shift towards ex-ante larger firms
 - The impact of AI is most pronounced among the largest, most productive firms
 - AI investments are associated with higher industry concentration
- Our results highlight the role of technology in shaping industry concentration and reinforcing winner-take-most dynamics

Contribution

- Impact of Artificial Intelligence and Big Data

(e.g., Mihet and Philippon, 2017; Agrawal, Gans, Goldfarb, 2019; Webb 2020; Acemoglu, Autor, Hazell, Restrepo, 2020; Grennan and Michaely, 2019; Rock 2019; Alderucci, Branstetter, Hovy, Runge, Zolas, 2020; Seamans and Raj, 2018; Brynjolfsson, Rock, Syverson, 2018 & 2019; Brynjolfsson, Hitt, Kim 2011; Abis and Veldkamp 2020; Farboodi, Mihet, Philippon, Veldkamp 2019)

Our paper offers a new measure of AI and provides one of the first systematic evidence of the impact of AI on firms and industries

- Causes and Consequences of Increasing Concentration

(e.g., Gutiérrez and Philippon, 2017; De Loecker, Eeckhout, Unger 2020; Covarrubias, Gutiérrez, Philippon 2019; Barkai 2020; Bessen 2017; Autor, Dorn, Katz, Patterson, Van Reenen 2020; Aghion, Bergeaud, Boppart, Klenow, Li, 2019; Pellegrino 2020; Meghana, Demirguc-Kunt, Maksimovic, 2019)

Our results point to new technologies as a contributor of rising concentration

Appendix

Controlling for Other IT and Robotics

	Δ Log Sales	Δ Log Employment	Δ Market Share
Δ Share AI Workers	0.155*** (0.044)	0.139*** (0.053)	0.014 (0.009)
Δ Share Other IT Workers	0.120** (0.057)	0.074 (0.053)	0.014 (0.009)
Δ Share Robotics Workers	-0.031 (0.022)	-0.035** (0.018)	-0.004 (0.005)
NAICS2 FE	Y	Y	Y
Controls	Y	Y	Y

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Burning Glass Share of AI Workers

	Δ Log Sales		Δ Log Employment		Δ Market Share	
Δ Share AI Workers	0.133*** (0.050)	0.121*** (0.038)	0.148** (0.066)	0.100* (0.052)	0.013 (0.009)	0.015* (0.008)
NAICS2 FE	Y	Y	Y	Y	Y	Y
Controls	N	Y	N	Y	N	Y

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Continuous AI Measure

	Δ Log Sales		Δ Log Employment		Δ Market Share	
Δ Share AI Workers	0.135*** (0.050)	0.125*** (0.040)	0.151** (0.066)	0.103* (0.054)	0.012 (0.009)	0.014* (0.008)
NAICS2 FE	Y	Y	Y	Y	Y	Y
Controls	N	Y	N	Y	N	Y

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Effects by Sector

	Manufacturing		Wholesale & Retail		Finance		Other	
	Sales	Employment	Sales	Employment	Sales	Employment	Sales	Employment
Δ Share AI Workers	0.114** (0.050)	0.110** (0.055)	0.237** (0.101)	0.262* (0.135)	0.217* (0.122)	0.235* (0.129)	0.203** (0.098)	0.175 (0.112)
NAICS2 FE	Y	Y	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y	Y	Y

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(Lack of) Pre-trend: Foreign Industry IV

	Δ Log Sales, 2000–2008	Δ Log Employment, 2000–2008
Δ Share AI Workers	-0.246 (0.443)	-0.199 (0.399)
NAICS2 FE	Y	Y
Controls	Y	Y

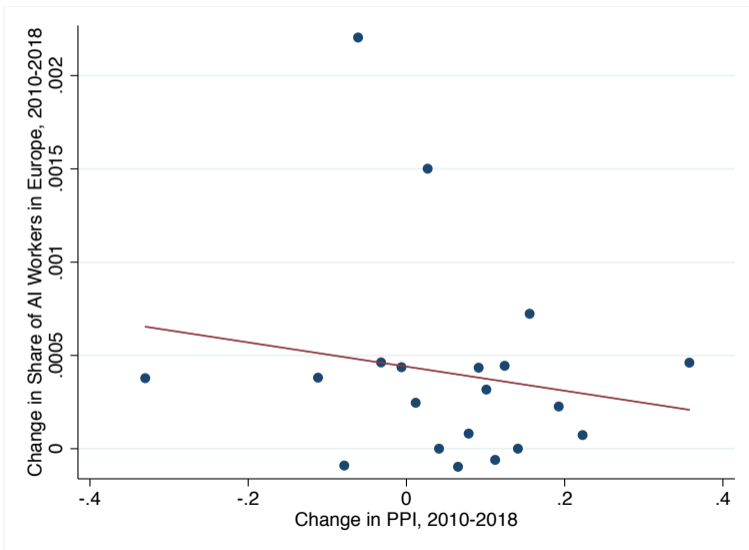
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(Lack of) Pre-trend: Shift-Share IV

	Δ Log Sales, 2000–2008	Δ Log Employment, 2000–2008	Δ Market Share, 2000–2008
Δ Share AI Workers	0.031 (0.182)	0.095 (0.153)	0.004 (0.023)
NAICS2 FE	Y	Y	Y
Controls	Y	Y	Y

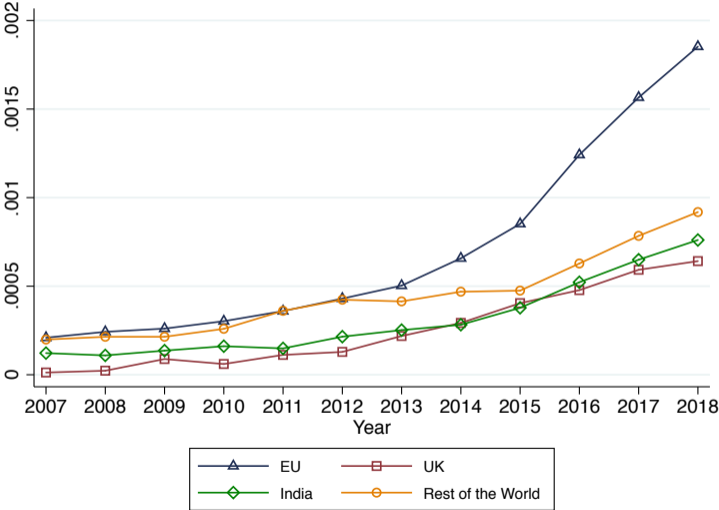
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European Industry-level AI Investments and US Price Changes



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AI Investments in Foreign Countries



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