Complements or Substitutes? Firm-Level Management of Labor and Technology

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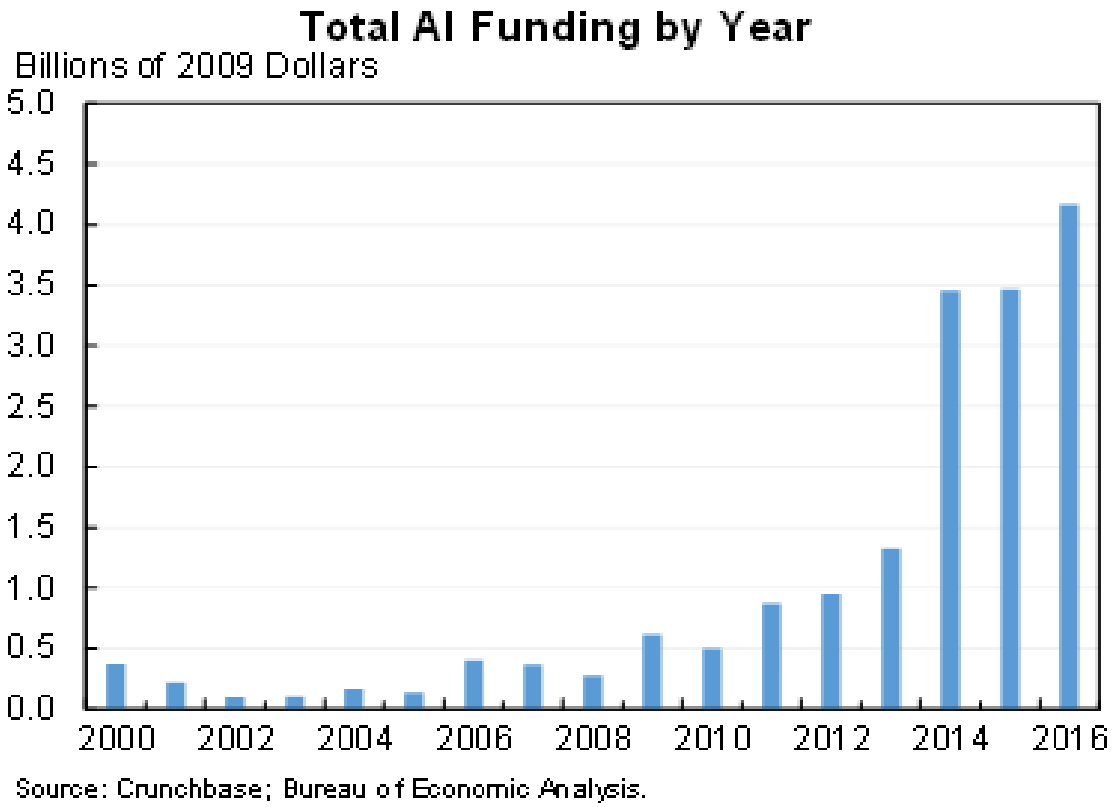
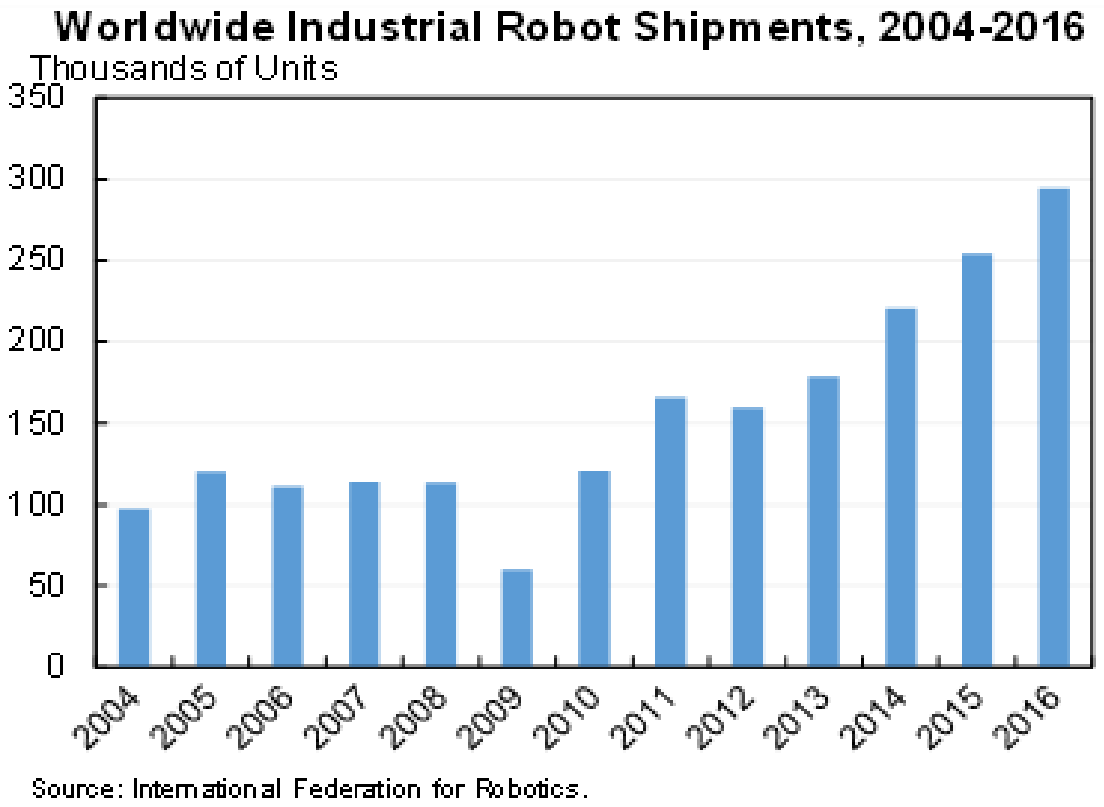
NBER SI 2019, Personnel Econ

“Insider econometrics”

Rapid commercialization of AI and robots



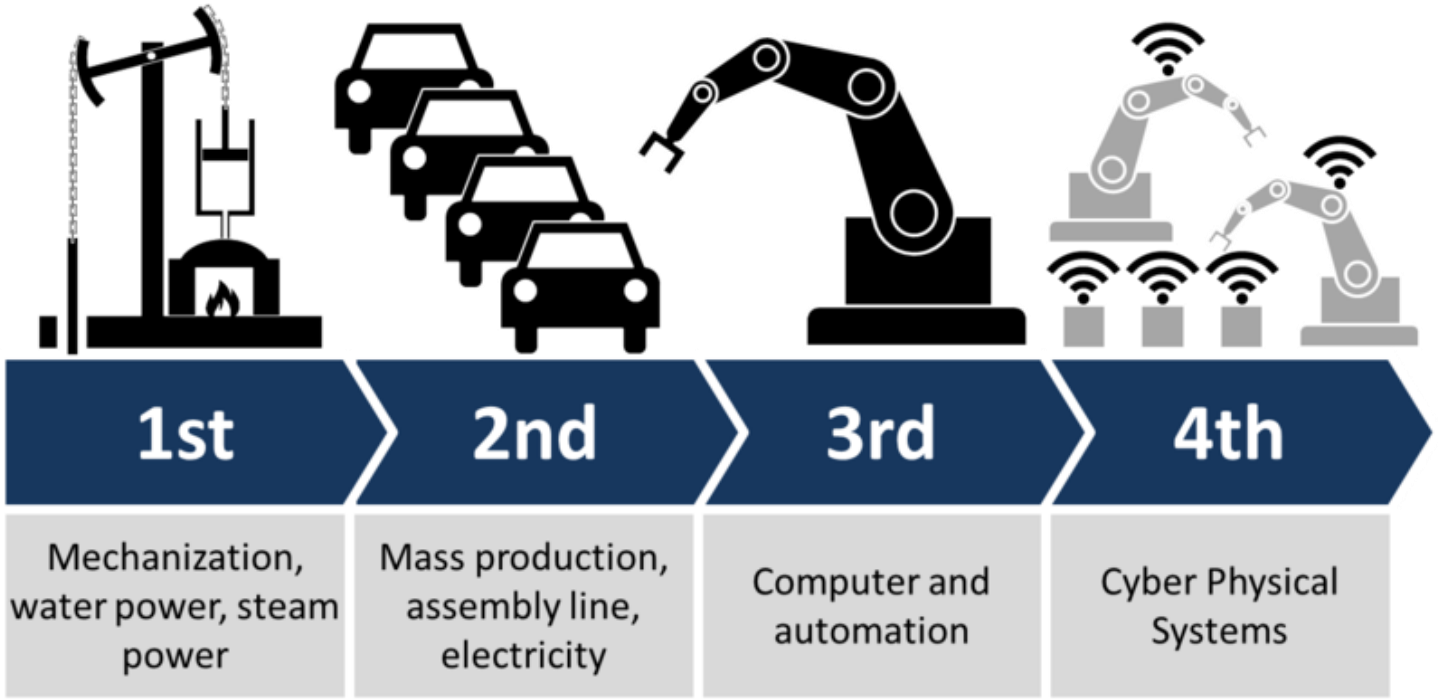


Furman and Seamans, 2019

AI and robots in manufacturing: Industry 4.0

The Industry 4.0 Vision:

- Continuous collection and analysis of manufacturing data in real-time
- Allows managers (both at middle and upper levels) to remotely monitor operations and alter as needed
- More dramatically: machines that "think" – that can configure themselves and adapt to changes within the manufacturing process itself



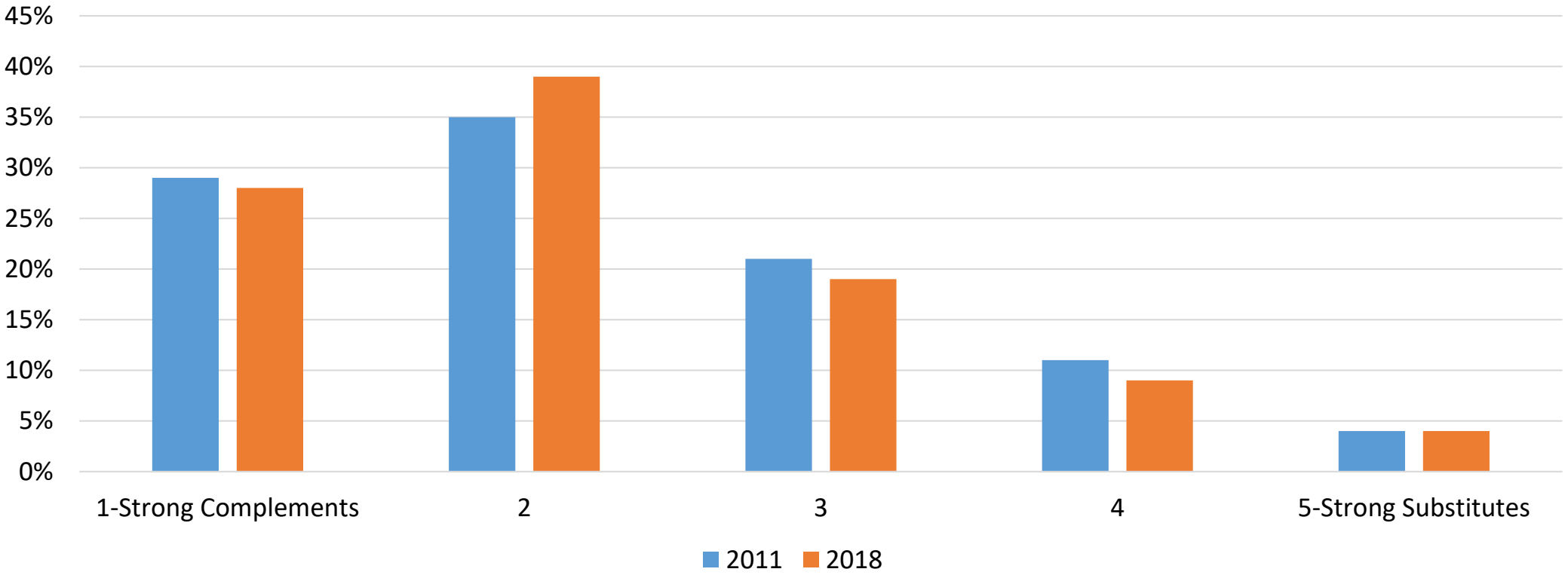
Christoph Roser at AllAboutLean.com

Can data be separated from context?

- Key assumption of Industry 4.0 (and much of the automation literature):
  - Data can be separated from its operational context
- "recent developments in ML and MR [Machine Learning and Mobile Robotics], building upon big data, allow for pattern recognition, and thus enable computer capital to rapidly substitute for labour across a wide range of non-routine tasks. … **[W]e argue that it is largely already technologically possible to automate almost any task, provided that sufficient amounts of data are gathered for pattern recognition."** *- Frey and Osborne 2013*

- This assumption → if firms can collect and interpret data far from where it was generated, then new technology substitutes for shop-floor workers' skills

But, many firms see complementarities between workers and technology



Responses to question: "We have found that use of Information Technology (IT) reduces the need for shop-floor workers to have analytical skill." (1-Strong Disagree; 5-Strong Agree)

Our study

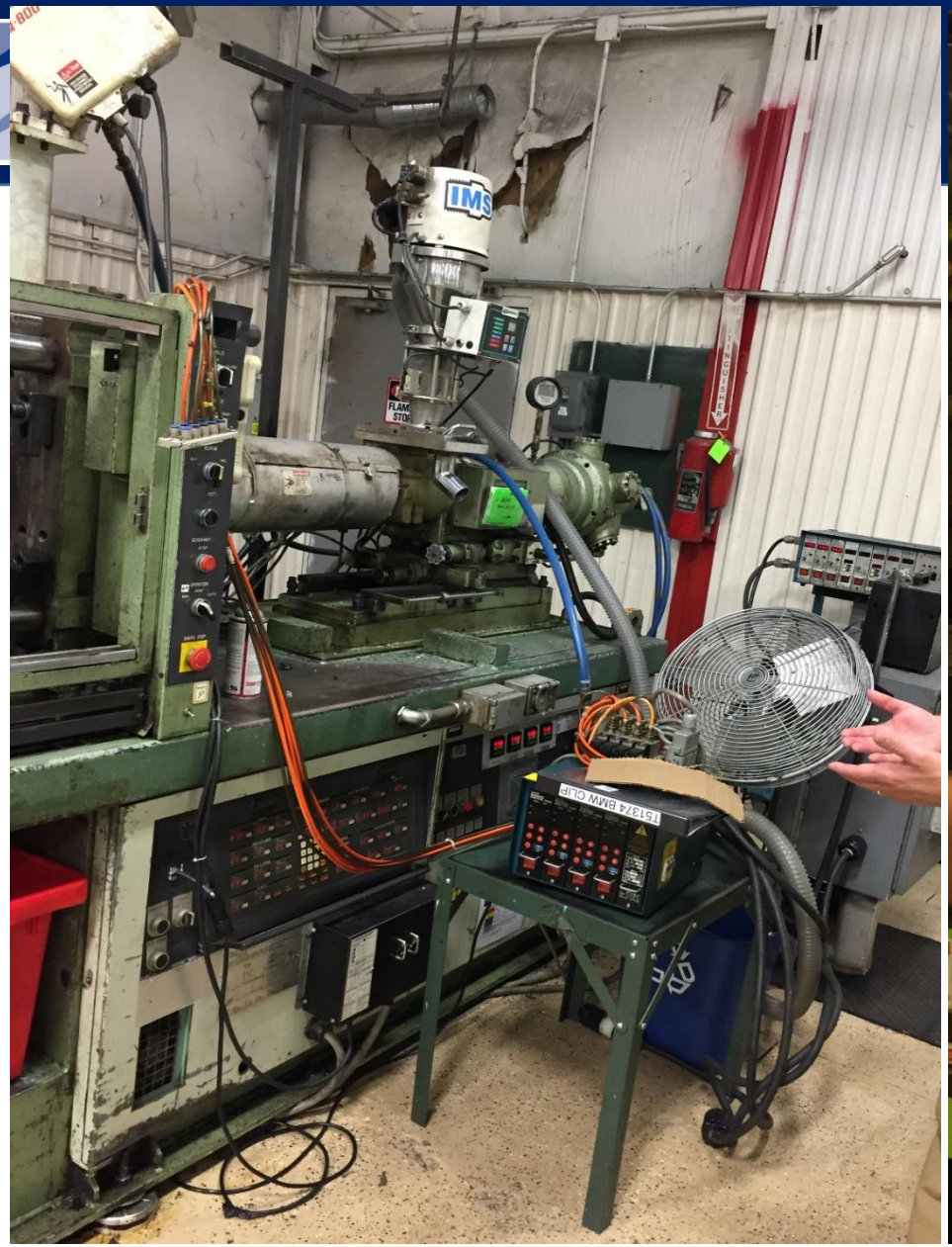
Research questions:

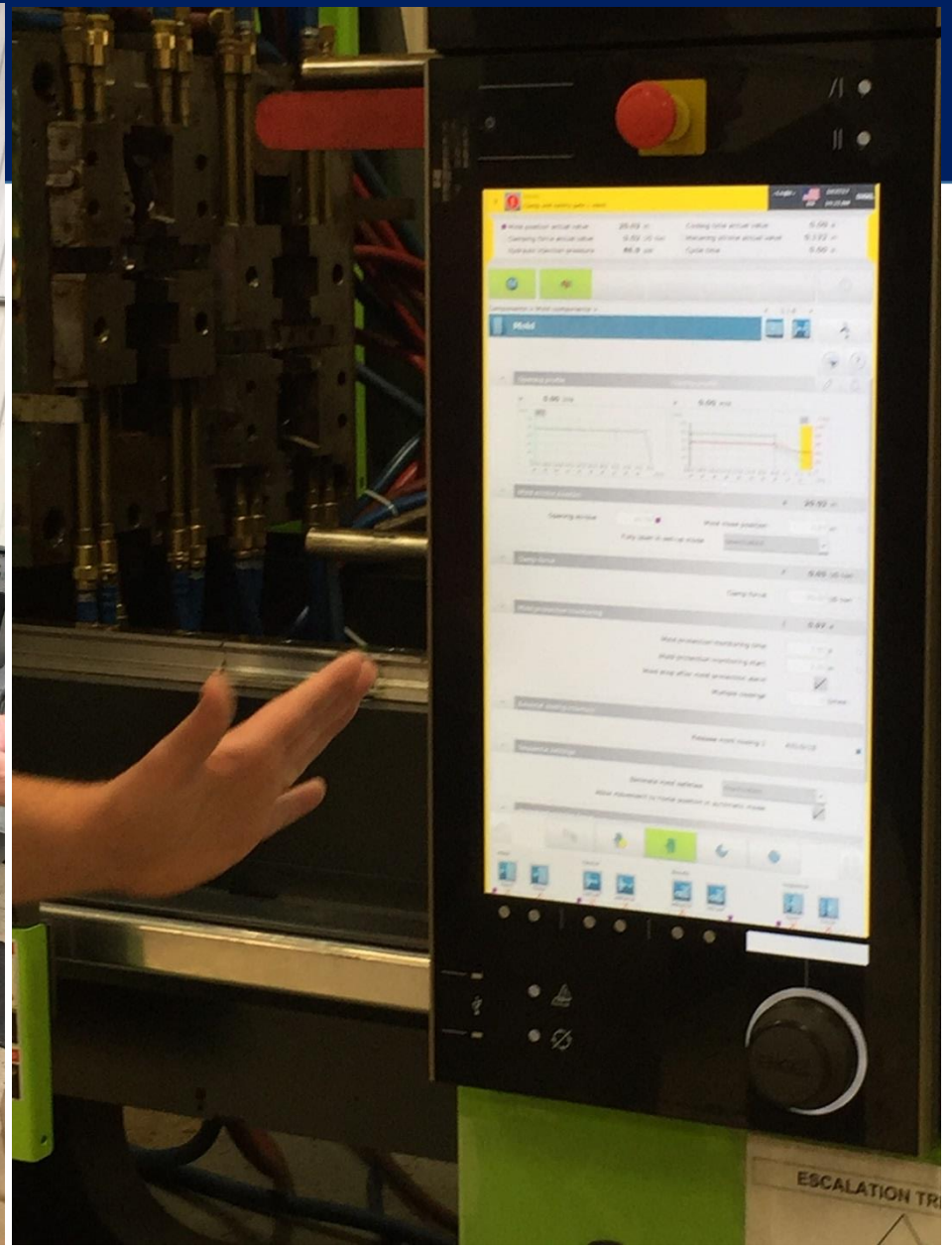
- What drives adoption of robots and other new technologies?
- How does management's relationship with labor affect how new tech is used?

Methods:

- Approx. three dozen site visits between 2017-2019
- Data from our survey of tech adoption and use at auto supply firms (N~100 in 2018; also 2011 survey); multiple questions on robots
- Goal: complementary effort to our ongoing work with US Census Bureau to measure establishment-level adoption of robots (Brynjolfsson, Helper and Seamans)

Lean before automation





Evolving interfaces: Automation in plastic injection molders

Observation 1: Two management "paradigms"

- Taylorist: Labor and tech are substitutes
  - Specialization is valuable; helps separate brain from hand work, planning from execution
  - Robots are ideal workers: repeatable, reliable, don't complain or tire
  - Automation allows engineers' ideas to be implemented directly, w/o humans

- Pragmatist: Labor and tech complement each other
  - The person closest to production has expertise that no one else has
  - Big role for learning-by-doing
    - "machines can't learn, only people can"
  - Don't automate until you have first simplified the production process

→There may or may not be differences in adoption, but likely differences in uses

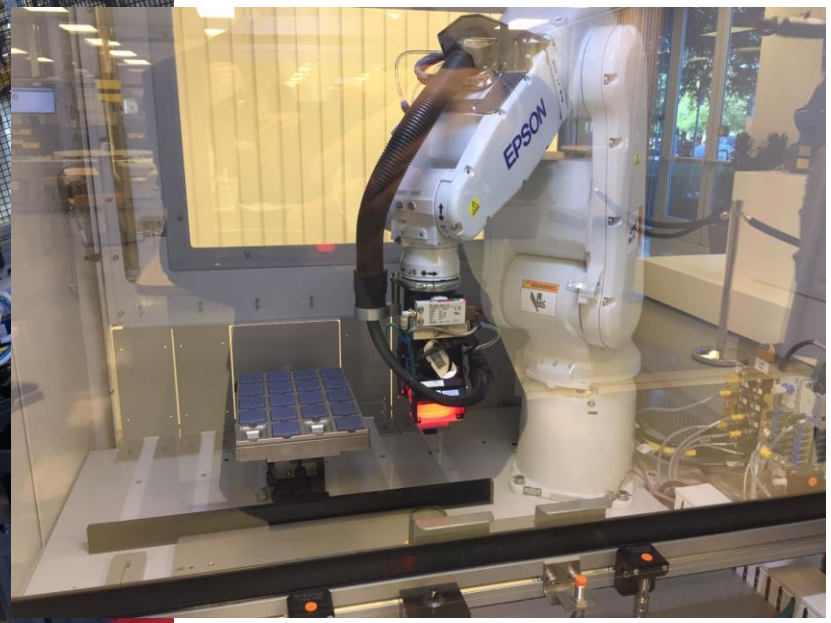
Observation 2: Recent rise of integrators

- Integrators adapt robotics and other tech to the needs of manufacturers by:
  - diagnosing the customer's manufacturing requirements
  - designing a plan for automation
  - installing and testing robotic and other equipment in accordance to this plan
  - training workers on the factory floor and engineers
  - providing ongoing maintenance and upgrades
- Integrators work across firms & industries, collecting "tips and tricks" as they go.
- Analogy to "IT Systems Integrators" (e.g., Sapient) circa 1999; machine tools, 19th c.

→Integrators may facilitate tech adoption and use, though strategic considerations (who captures value) may affect other dimensions (hiring; data protection)

- Large role for integrators
- Lots of customization

Integrators design, assemble a system



How do firms learn to automate?

- Adopting automation and big data requires new capabilities.
  - Internal: firm management and/or shop floor workers
  - External: “integrators”
    - integrators represent a productive division of labor that can share insights across firms (the machine tool example), and guide firms as they develop their own capabilities.
    - Integrators could also extract all the value from manufacturers, and also lead to a loss of capability inside the firm.

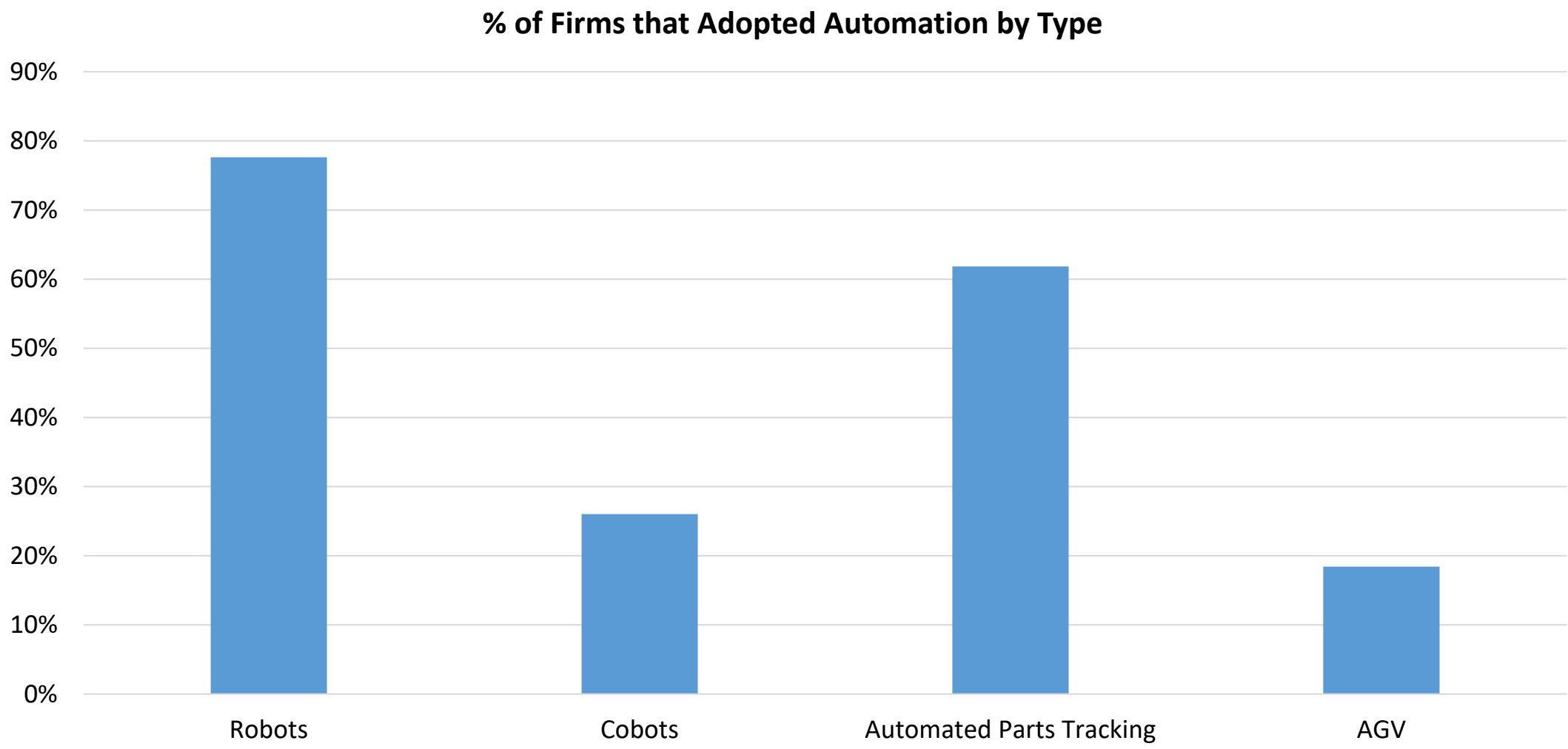
- So far, looks like the former -- firms that use integrators increase their number of process engineers; only 13% send their data to integrators

Overview of auto supplier survey

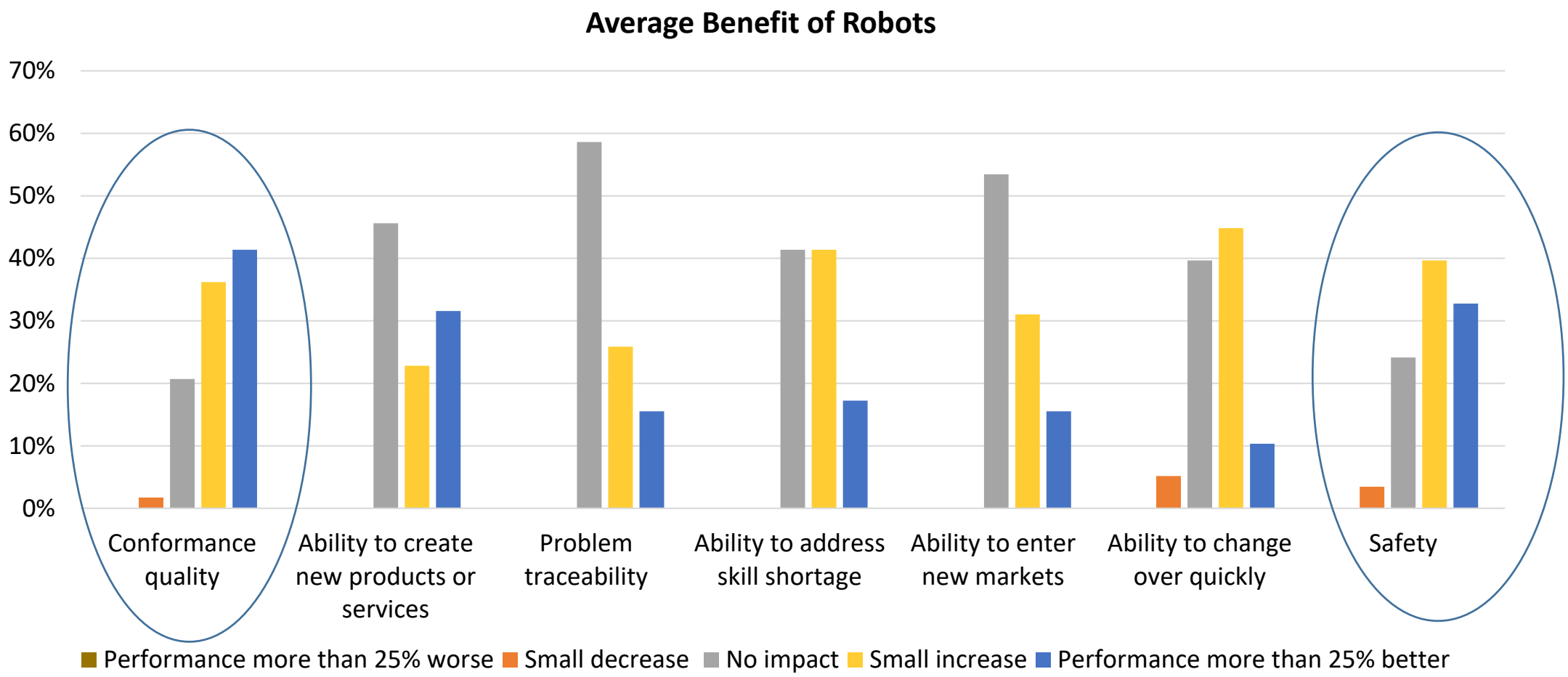
- Auto industry is “bellwether” for technology adoption
  - Accounts for 39% of US stock of robots (Acemoglu and Restrepo, 2017)
- Detailed survey of auto supply firms conducted in 2018 (also 2011 survey)
  - Separate surveys for plant, sales and HR managers
- Partnered with Center for Automotive Research (CAR), Precision Metalforming Association (PMA), and two automakers’ parts suppliers associations
  - Response rates 1-2% for 2011 survey resample and 15-30% for automakers

Number of Plant Surveys	119
Number of Sales Surveys	128
Number of HR Surveys	91
Median Employment	300
Median Sales	$83,500,000

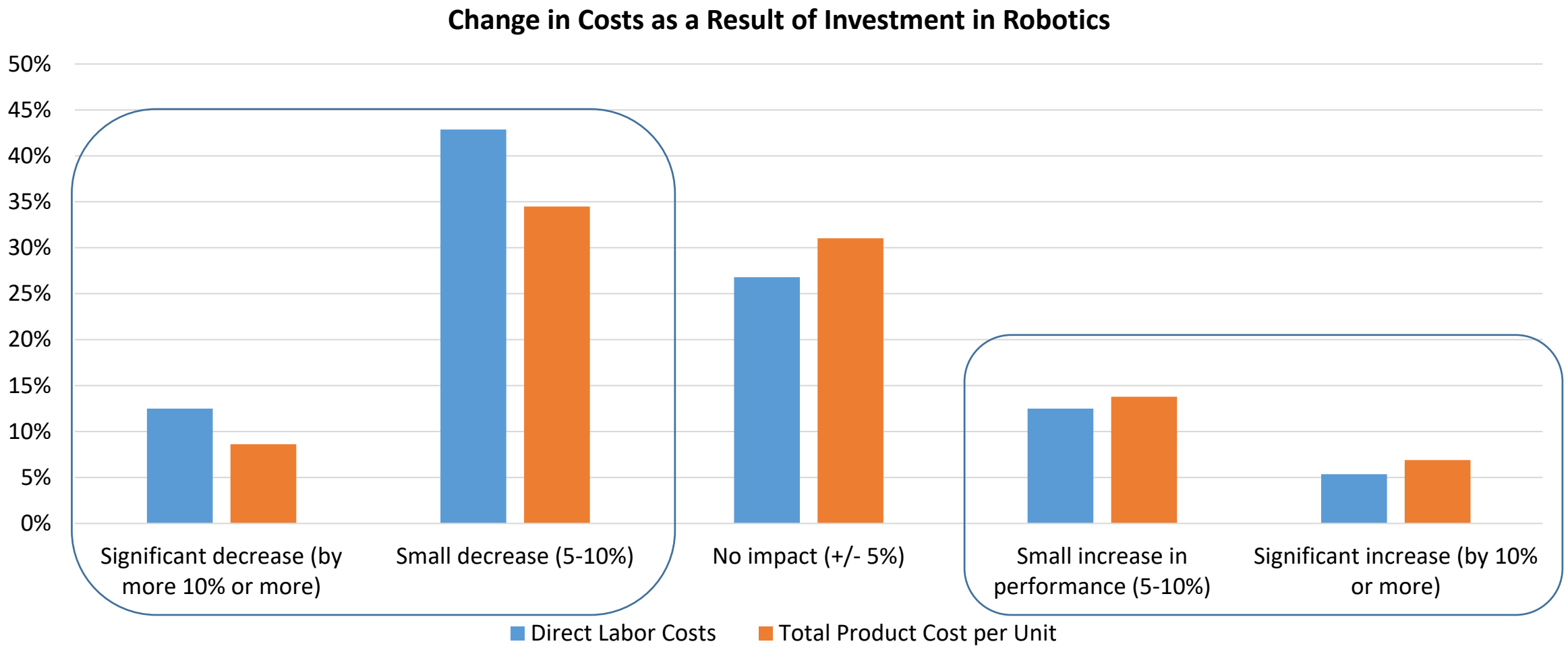
Lots of adoption of new technologies



Robots may improve quality and safety



Robots may also decrease costs



Measures of pragmatism, data-driven decisions

- Pragmatism (Prag) measures involvement of production workers in problem-solving and data interpretation:
  - "see workers as complement to IT" + "diagnose equipment problems" + "use quality assurance data to recommend improvements" + "modify programs on computerized equipment" "meet with customers" + "managers expect them to improve work methods"

- Data driven decision making (DDD) measures data practices:
  - "frequently use data on defects" + "base decisions on data" + "use data to predict downtime" – "intuitive decision-making" – "data is in siloes"

Aside: tasks and occupations

- Sig. heterogeneity in tasks done by workers in “same” occupation.
- Example: production workers in auto suppliers that focus on assembly of components.
    - Survey-based measure: (similar results using Burning Glass data)

Value of prag	Percent
0	14
1	35
2	14
3	36
4	11
total	100

Measures of robot uses

- Robot reduces labor cost, total cost:
  - Dummy = 1 if firm indicates that there was a small (5-10%) or significant (10+%) decrease in direct labor costs or total costs as a result of its investment in robotics since 2014.

- Robot increases quality, safety:
  - Dummy = 1 if firm indicates that there was a small or significant (25+%) increase in performance along the dimension (Quality, Safety) as a result of its investment in robotics.

Sample statistics

Variable	Mean	SD	Min	Max
Robots	0.78	0.41	0.00	1.00
Cobots	0.26	0.44	0.00	1.00
Automated Parts Tracking	0.68	0.47	0.00	1.00
Autonomous Guided Vehicles	0.22	0.41	0.00	1.00
Robots Increase Quality	0.76	0.43	0.00	1.00
Robots Increase Safety	0.69	0.47	0.00	1.00
Robots Reduce Labor	0.58	0.50	0.00	1.00
Robots Reduce Costs	0.49	0.50	0.00	1.00
DDD Measure	1.93	1.14	0.00	4.00
Pragmatism Measure	1.74	1.20	0.00	4.00
Used Integrator	0.43	0.50	0.00	1.00
Log Employees	5.49	1.17	1.39	7.86
% Population w/ HS Degree	0.70	0.02	0.62	0.74
Indiana	0.13	0.34	0.00	1.00
Kentucky	0.16	0.37	0.00	1.00
Michigan	0.31	0.47	0.00	1.00
Ohio	0.15	0.36	0.00	1.00

What types of firms adopt these technologies?

Dependent Variable: Firm Adopts……	*Robots*	*Cobots*	*Automated Parts Tracking*	*Autonomous Guided Vehicles*
DDD Measure	-0.021	0.022	-0.029	0.000
	[0.034]	[0.056]	[0.051]	[0.050]
Pragmatism Measure	0.027	-0.002	0.027	-0.025
	[0.036]	[0.051]	[0.052]	[0.041]
Used Integrator	0.136**	0.338***	0.061	0.048
	[0.067]	[0.105]	[0.121]	[0.108]
Ln Number of Employees	0.107**	0.025	0.056	0.060
	[0.047]	[0.034]	[0.052]	[0.039]
% High School	-2.073	-1.976	1.839	-1.869
	[1.778]	[1.846]	[2.351]	[2.011]
Observations	72	69	72	72
R-squared	0.209	0.196	0.036	0.071

When are robots used to decrease costs?

Dependent Variable: Robots Decrease Costs……	*Labor*	*Labor*	*Labor*	*Total*	*Total*	*Total*
DDD Measure	0.032	0.034	0.035	0.047	0.045	0.047
	[0.061]	[0.063]	[0.064]	[0.063]	[0.064]	[0.064]
Pragmatism Measure	-0.038	-0.038	-0.029	0.009	0.01	0.031
	[0.058]	[0.058]	[0.062]	[0.058]	[0.060]	[0.061]
Used Integrator		-0.044	-0.051		0.083	0.083
		[0.131]	[0.137]		[0.136]	[0.133]
% HS & Log Employment	No	No	Yes	No	No	Yes
Observations	60	60	57	59	59	56
R-squared	0.01	0.012	0.065	0.012	0.019	0.11

When are robots used to increase other performance?

Dependent Variable: Robots Increase……	*Quality*	*Quality*	*Quality*	*Safety*	*Safety*	*Safety*
DDD Measure	-0.032	-0.041	-0.051	0.032	0.03	0.007
	[0.043]	[0.043]	[0.044]	[0.051]	[0.051]	[0.053]
Pragmatism Measure	0.089**	0.091**	0.074*	-0.052	-0.051	-0.071
	[0.038]	[0.040]	[0.039]	[0.050]	[0.050]	[0.051]
Used Integrator		0.178*	0.199*		0.063	0.07
		[0.103]	[0.106]		[0.121]	[0.129]
% HS & Log Employment	No	No	Yes	No	No	Yes
Observations	62	62	59	61	61	58
R-squared	0.065	0.115	0.116	0.018	0.023	0.077

Pragmatists: robots are complements to shop-floor experience

- That is, robots increase the value of those with such experience

Dep variable: operator compensation	coeff
prag	-1.5207
multiplant	3.687688**
Robots per wkr	-30.8426*
Prag*robot	21.38992**
% high school	0.062001
union	-0.51964
Log plant employment	-1.60298*
_cons	25.03221***
Obs/R2	36/ 0.32

Workers in top quartile of prag paid 20% more than those at bottom, for mean robot/wkr

Additional findings

Management paradigms

- Our measures of data driven decision making and pragmatism are positively, significantly correlated (correlation coeff ~0.3)

  → In our and other settings, quality may covary with management paradigm

Integrators

- Firms that use integrators increased their hiring of process engineers since 2014
- Firms that use integrators are more likely to retain data in-house

  → When working with integrators, firms appear to use strategies to increase learning spillovers and limit loss of value to integrator

Potential takeaways

Management Paradigms: Firms pursue different management "paradigms" (Taylorist, pragmatist) when adopting & using new technologies

- Doesn't seem to affect adoption decision much
- May affect use of technology: When pragmatists adopt robots, appears to be tied to quality improvements, but does not to labor cost reduction

Integrators: May affect adoption and use of technology:

"smart factory as a service"

- Other dimensions (hiring, data sharing) are also affected:

→ Separating data from context increases risk of value capture by integrator

So far, firms appear to use strategies to increase learning spillovers, limit loss of value to integrator

Next steps

Explore instrumental variables for adoption, use (eg, location near integrator)

Further probe role of data-driven decision making

- In our context, not much evidence that data-driven decision making affects adoption and use of these new technologies.

Validate pragmatism measure using separate dataset

- Initial work with Burning Glass data

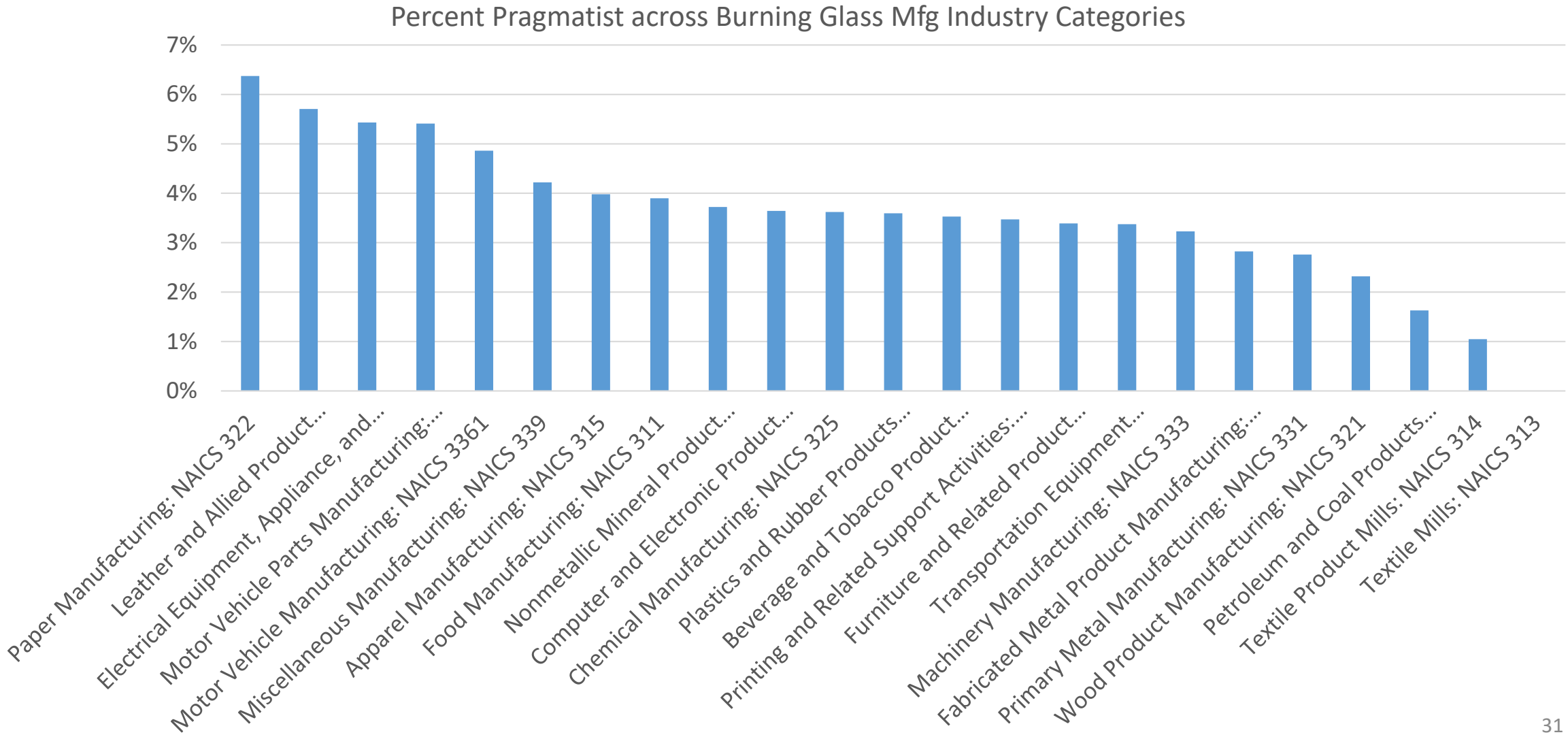
Study similar outcomes using Census data

- Robot adoption by firm type: size, quality, “paradigm” (perhaps using BG data)
- Effect of robot adoption on establishment outcomes (productivity, employment)

Thank you

Backup slides follow

Use of BG to measure management paradigms



Census ASM robotics questions

In (1), report capital expenditures in 2018 for new and used industrial robotic equipment for this plant. Include other one-time costs, including software and installation.

In (2) and (3), report the number of industrial robots in operation at this plant and purchased for this plant in 2018.

For robots purchased as part of a work cell or other integrated robotic equipment, it may not be possible to report the expenditures on only the robots. In this case, report the expenditures on the integrated robotic equipment.

Examples of operations industrial robotic equipment can perform may include:

- Palletizing
- Pick and place
- Machine tending
- Material handling
- Dispensing
- Welding
- Packing/repacking

Exclude:

- Automated guided vehicles (AGVs)
- Driverless forklifts
- Automatic storage and retrieval systems
- CNC machining equipment

Census ASM robotics questions

Report capital expenditures in thousands of dollars. Estimates are acceptable.

	Check if none	2018
1. Capital expenditures in 2018 for new and used industrial robotic equipment, including software, installation, and other one-time costs	☐	

Report the number of robots. Estimates are acceptable.

	Check if none	2018
2. Number of industrial robots IN OPERATION at this plant in 2018	☐	

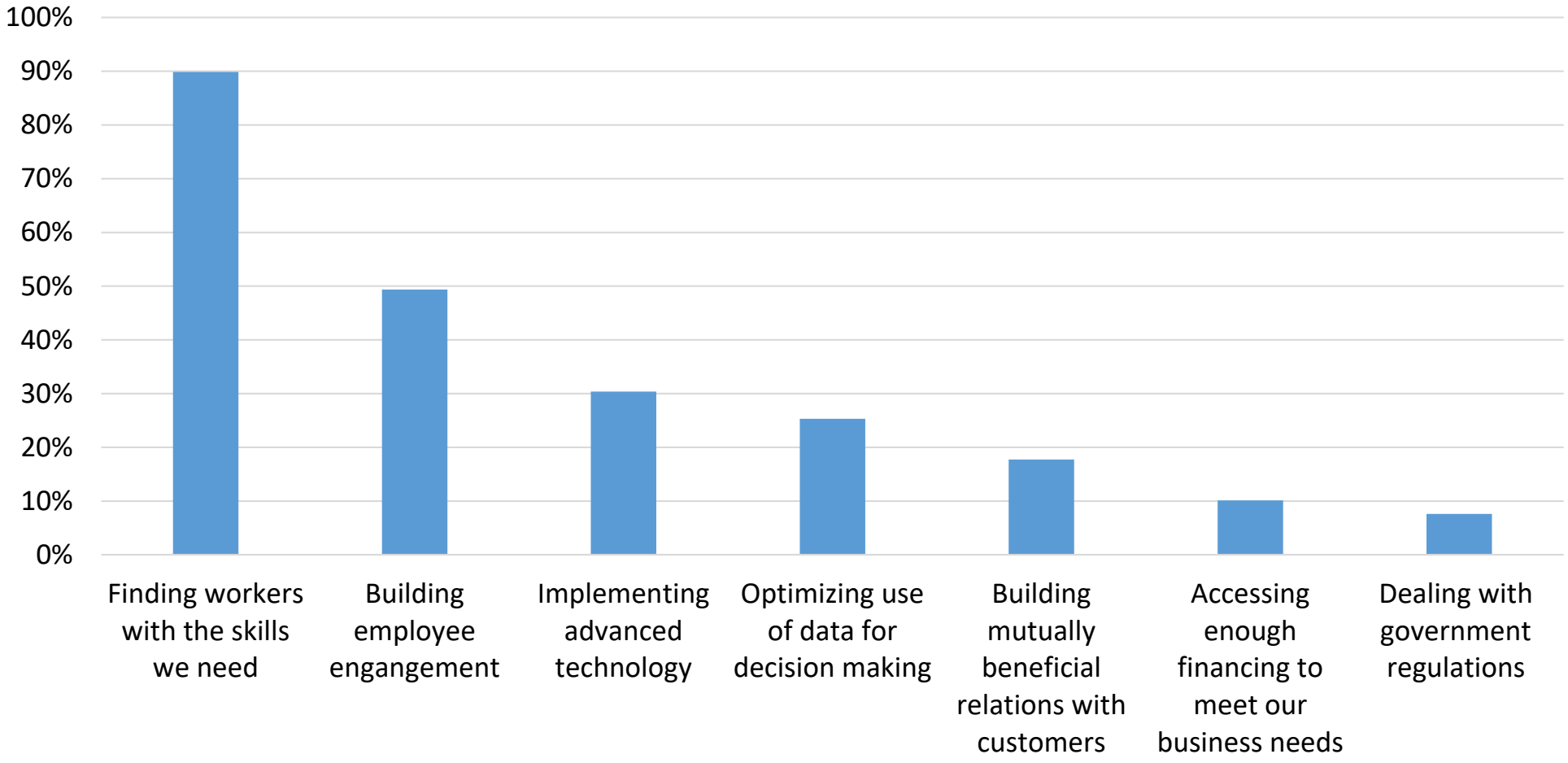
	Check if none	2018
3. Number of industrial robots PURCHASED for this plant in 2018	☐	

Selected pairwise correlations

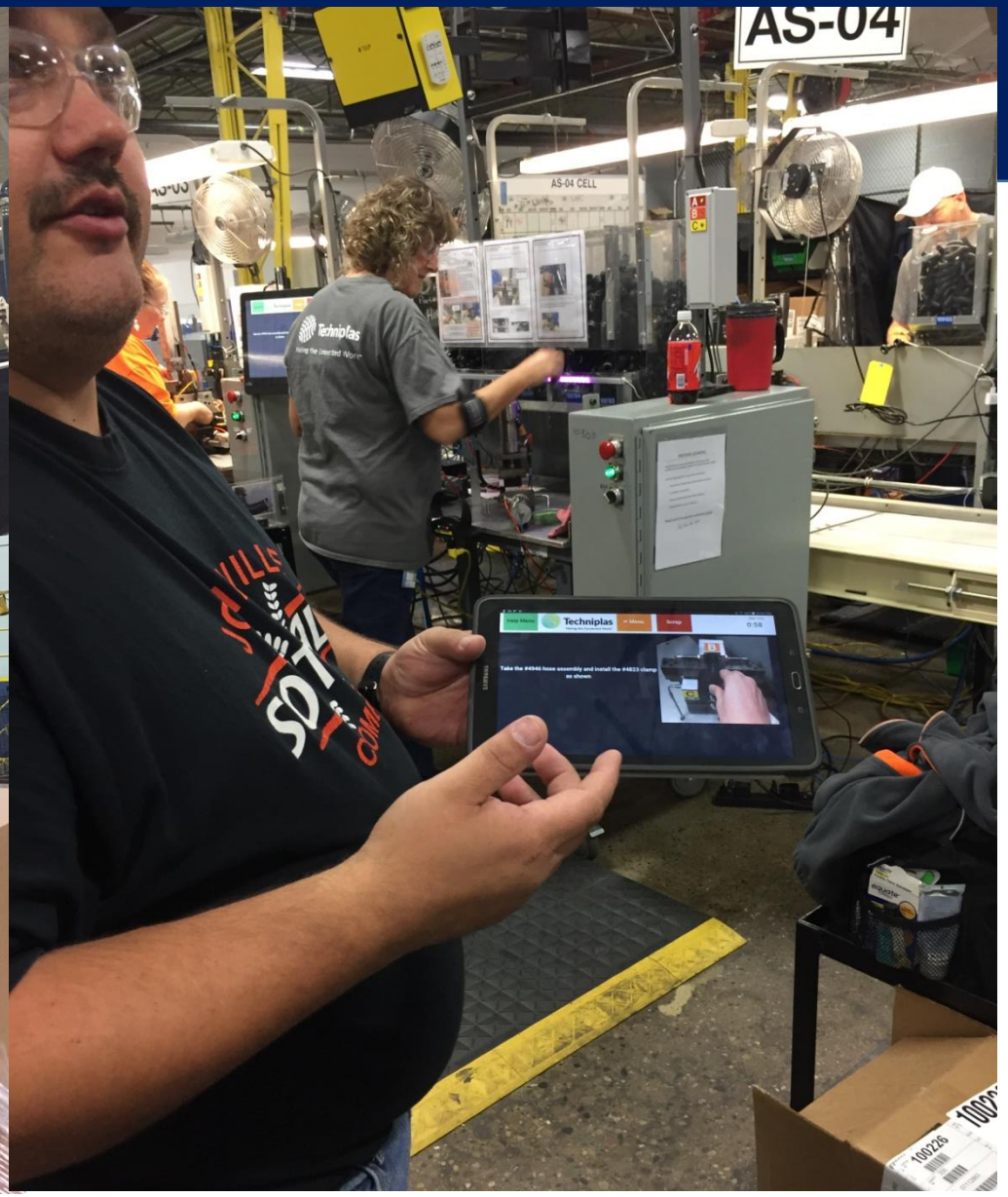
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Robots	1.0																
2	Cobots	0.2	1.0															
3	Automated Parts Tracking	0.1	0.2	1.0														
4	Autonomous Guided Vehicles	0.1	0.4	0.1	1.0													
5	Robots Increase Quality	.	0.1	0.0	-0.2	1.0												
6	Robots Increase Safety	.	-0.1	0.1	0.1	0.2	1.0											
7	Robots Reduce Labor	.	-0.3	0.1	-0.1	-0.1	0.0	1.0										
8	Robots Reduce Costs	.	-0.1	0.0	-0.1	0.0	-0.1	0.6	1.0									
9	DDD Measure	0.1	0.1	0.0	0.0	-0.1	0.1	0.1	0.1	1.0								
10	Pragmatism Measure	0.0	0.0	0.0	-0.1	0.3	-0.1	-0.1	0.1	0.3	1.0							
11	Used Integrator	0.3	0.2	0.1	0.0	0.2	0.1	0.0	0.0	0.1	-0.1	1.0						
12	Log Employees	0.5	0.2	0.1	0.2	0.0	0.2	-0.1	-0.1	0.1	-0.1	0.3	1.0					
13	% Population w/ HS Degree	-0.2	-0.1	0.0	-0.2	0.1	0.0	-0.2	-0.2	0.0	0.2	0.0	-0.3	1.0				
14	Indiana	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.3	-0.2	0.0	-0.1	0.3	-0.3	1.0			
15	Kentucky	0.2	0.1	0.2	0.3	-0.2	0.1	0.2	-0.1	0.1	-0.3	0.2	0.2	-0.6	-0.2	1.0		
16	Michigan	-0.1	0.0	0.1	-0.2	0.1	0.1	-0.2	-0.1	0.0	0.3	0.1	-0.2	0.7	-0.3	-0.3	1.0	
17	Ohio	-0.1	-0.1	-0.2	0.0	0.0	-0.2	-0.2	-0.2	0.0	0.0	-0.1	-0.2	0.2	-0.2	-0.2	-0.3	1.0

Skilled workforce is a big challenge

90% report that finding skilled workers is a “top three” challenge



Using machine vision for inspection



-Lots of heterogeneity across firms (management practices and degree of automation)

- Long lasting capital investment

- Evidence of automation augmenting labor