Robot Adopters and Integrators: Facts From Hungary

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The Rise of Robots

- robotics is changing the way in which goods and services are produced and delivered
  - more than 4 million robots in factories worldwide in 2024 (IFR)
  - annual increase of 10%
  - sales of service robots up 30%
- a growing literature studies the effects of robot adoption
- we focus on two questions:
  - how to measure robots at the firm level?
  - why robot adoption varies so much across firms and sectors?
- we sheds new light by focusing on *robot integrators*

Robot Integrators

- customize robots to fit the needs of the end user
  - provide engineering and programming services for robotic systems
  - generally recognized as important (Humlum, 2021; Brynjolfsson et al., 2023)
  - yet neglected due to lack of data
- we use administrative data and firm-to-firm transactions to trace robot adoption in Hungary
  - from foreign suppliers to final users
- this allows us to:
  - identify integrators and their characteristics
  - identify firms using integrators
  - build new measures of robot adoption and document some new facts

What We Find

- most firms buy robots from integrators rather than importing them directly
  - focusing on robot imports misses 95% of adoption!
- some new facts about robot integrators
  - robot integrators are larger, more productive and more capital intensive than other firms in their industries
  - integrators are particularly dependent on imports and exposed to foreign shocks
- adopters are larger, more productive and more capital intensive
  - yet firms using integrators are smaller, less productive and less capital intensive than robot importers
  - adoption through integrator is more lumpy than robot import
- key role of integrators for smaller and medium-sized firms

Firm-Level Evidence

- on integrators
  - Brynjolfsson et al. (2023): robot integrators correlate with "robot hubs"
  - *no direct data on integrators*
- import data to measure firm-level adoption
  - Canada: Dixon, Hong, and Wu (2021); France: Acemoglu, Lelarge, and Restrepo (2020), Bonfiglioli et al. (2024); Spain: Koch, Manulov, and Smolka (2021); Denmark: Humlum (2021)
  - *selected sample*
- firm-level surveys
  - US: Brynjolfsson et al. (2023), Doms, Dunne and Troske (1997), Dinlersoz and Wolf (2018), Acemoglu et al. (2022); Germany: Benmelech and Zator (2022), Findeisen, Dauth and Schlenker (2024). Spain: Koch, Manulov, and Smolka (2021). Denmark: Humlum (2021). Netherlands: Bessen et al. (2023)
  - *limitations in scope and coverage*

The Data

- automation in Hungary
  - robot density increased more than fourfold over 2010-2018 (IFR)
  - large manufacturing sector: 25% of workforce (more than 1/3 in automotive)
- universe of Hungarian firms 2015-2021
  - 547,136 firms, all economic activities (except government)
- customs data at the product level to measure imports, including robots
  - CN 84795000 and CN 84798950
- balance-sheet data
  - sales, employment, capital stock, value added
- firm-to-firm transactions from VAT data

Robot Integrators

- list of 181 robot integrators operating in Hungary in 2021
  - from HowToRobot and Hungarian partners of IFR's members
    - ★ exclude local branches of robotics multinationals not dealing robots in Hungary (e.g. 3M)
- firms operating in industries related to installation and sales of machinery
  - with significant robot imports (top quartile)
  - or with significant purchases from robot manufacturers/distributors (top quartile)
- total of 324 robot integrators
  - from 234 in 2015 to 309 in 2021 (+32%)

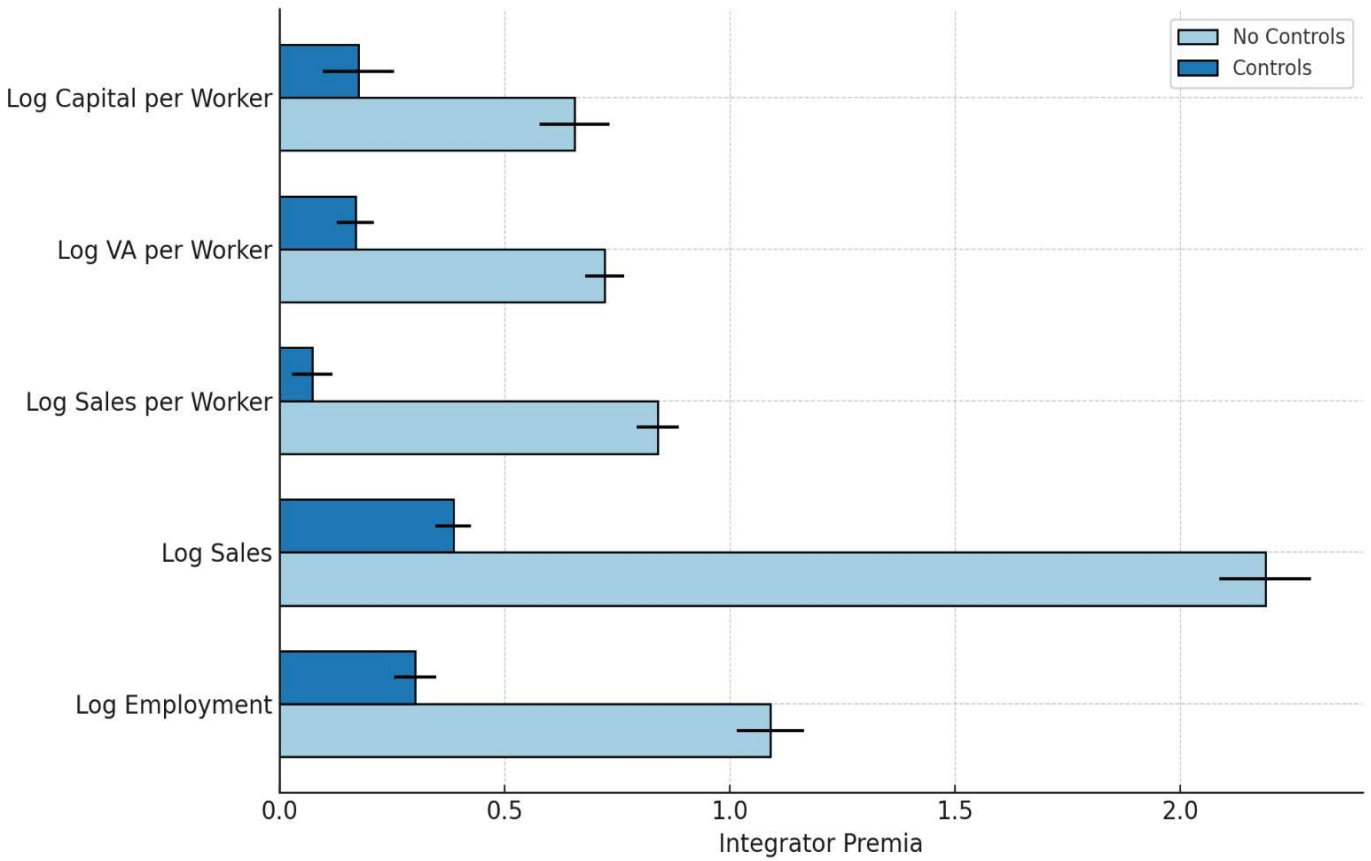
The Characteristics of Integrators

- main variables:
  - Y_{it} : log of sales, employment, sales per worker, VA per worker, capital per worker
  - $\mathbb{I}_i$: 1 for integrators
- regressions

$$Y_{it} = \alpha_{jt} + \beta \cdot \mathbb{I}_i + \mathbf{X}'_{it} \cdot \gamma + \varepsilon_{it}$$

  - i : firm, j : 3-digit NACE industry, t : years
  - controls $\mathbf{X}'_{it}$:
    - ★ baseline firm characteristics (log sales, indicators for importers, exporters and MNEs) $\times$ year dummies
  - standard errors clustered by firm

Integrator Premia



- integrators are prominent firms within their industries

Import Network of Integrators

- frequency of imports:
  - 75% of integrators vs 8% of other firms
- concentration of imports:
  - 83% of integrators source at least 50% of imports from a single country

Top 1 Robot Import Origin			Top 1 All Products Import Origin		
(1)	(2)	(3)	(4)	(5)	(6)
Country	Integrator-years	Frequency	Country	Integrator-years	Frequency
Germany	77	0.28	Germany	895	0.32
Austria	36	0.13	USA	344	0.12
Sweden	27	0.10	Austria	214	0.08
Japan	26	0.09	Switzerland	183	0.07
Netherlands	23	0.08	China	154	0.05
Denmark	18	0.06	Netherlands	115	0.04
China	12	0.04	Italy	92	0.03
Taiwan	8	0.03	Japan	90	0.03
USA	7	0.03	UK	74	0.03
Italy	7	0.03	Taiwan	71	0.03

Foreign Exposure of Integrators

- leverage on integrators' import network
- for each integrator i, build the Export Supply Shock:

$$ESS_{it} = \sum_{o \in O} \sum_{p \in P} \omega_{iop} \cdot \ln EXP_{opt},$$

  - $\ln EXP_{opt}$ = log export of 6-digit HS product p from origin country o in year t to middle-income economies
  - ω_{iop} = share of i's imports of product p from country o in the first sample year
- estimate regressions

$$Y_{it} = \alpha_i + \alpha_{jt} + \beta \cdot ESS_{it} + \mathbf{X}'_{it} \cdot \gamma + \varepsilon_{it}$$

  - i : firm, j : 3-digit NACE industry, t : years
  - controls $\mathbf{X}'_{it}$: baseline firm characteristics $\times$ year dummies
  - dependent variables Y_{it}: $\ln Sales$ and $\ln Emp$

Export Supply Shocks and Integrators Size

	(1)	(2)	(3)	(4)
	Log Employment	Log Employment	Log Sales	Log Sales
ESS	0.188**	0.186**	0.148**	0.140**
	[0.077]	[0.077]	[0.065]	[0.065]
Observations	1,222	1,222	1,106	1,106
R-squared	0.953	0.954	0.962	0.964
Firm FE	Yes	Yes	Yes	Yes
Ind x Year FE	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes

- sourcing patters of integrators make them particularly sensitive to global shocks

The Customers of Robot Integrators

- robot buyers:
  - firms with purchases from integrators $\geq$ 15,000 € in any given year
  - 6,414 unique buyers: from 1,605 in 2015 to 3,036 in 2021 (+89%)

Buyers' Sector	Purchases		Value of Purchases		Integrators per Buyer
	(1)	(2)	(3)	(4)	(5)
	Number	% of Total	Mln €	% of Total	Number
Construction-utilities	1652	0.11	45	0.05	1.37
Manufacturing	8219	0.53	588	0.65	2.57
Primary	108	0.01	2	0.00	1.11
Services	2232	0.14	66	0.07	1.27
Transport-post	399	0.03	19	0.02	1.20
Wholesale-retail	3016	0.19	181	0.20	1.29
Total	15626	1.00	900	1.00	

Robot Adopters

- robot adopter:
  - robot imports + purchases from integrators $\geq$ 15,000 € in at least one year
    - ★ 3,586 = 0.7% of all firms
    - ★ 11.7% of balanced sample
- only a minor fraction of adopters import robots directly
  - 177 (4.7%) importers; 3,409 (95.3%) buyers from integrators
- importers more prevalent in industries more prone to automation:
  - nearly 7% of adopters in manufacturing vs 1% in services
- what drives different adoption strategies?

Robot Adopters: Buyers and Importers

Adopters' Sector	Buyers		Importers		Importers Share of Adopters
	(1)	(2)	(3)	(4)	(5)
	Number	% of Total	Number	% of Total	%
Construction-utilities	430	0.13	0	0.00	0.00
Manufacturing	1813	0.53	134	0.76	0.07
Services	230	0.07	3	0.02	0.01
Transport-post	105	0.03	0	0.00	0.00
Wholesale-retail	831	0.24	38	0.21	0.04
Total	3409	1.00	177	1.00	0.05

Robot Adoption Strategies: A Simple Model

- consider a firm facing CES demand:

$$y = Ap^{-\sigma}, \ \sigma > 1$$

- production function:
  - labor (l) and capital (k) performing a unit measure of tasks

$$y = \varphi \exp\left(\int_0^1 \ln x(z) \mathrm{d}z\right) = \varphi \left(\frac{k}{\alpha}\right)^{\alpha} \left(\frac{l}{1-\alpha}\right)^{1-\alpha}$$

    - ★ φ : firm productivity
    - ★ α : share of tasks performed by k = capital intensity
    - ★ assume price of capital $r <$ wage $w = 1$

- revenue:

$$p_n y_n = A\left[\varphi\left(1 - \frac{1}{\sigma}\right) r^{-\alpha}\right]^{\sigma-1}$$

Automation: Discrete Choice

- firms can automate an additional measure κ of tasks either:
  - importing robots directly$_{(i)}$ or buying robots from integrators$_{(b)}$
- adoption trade-off:
  - cost saving on κ tasks

$$\gamma_i \equiv r_i^{-\kappa(\sigma-1)} > \gamma_b \equiv r_b^{-\kappa(\sigma-1)} > 1$$

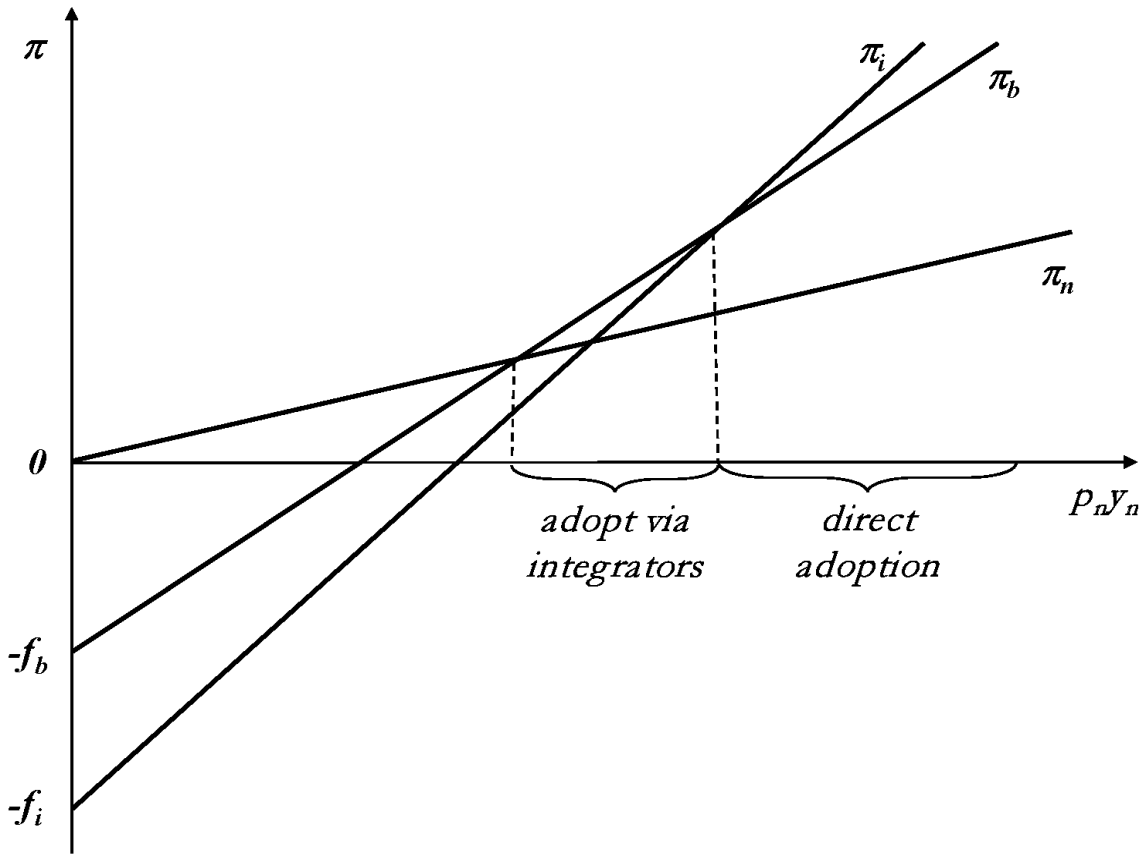
    - ★ $\gamma_i > \gamma_b$ due to intermediation costs
  - fixed cost of adoption

$$f_i > f_b$$

    - ★ finding a local integrator is cheaper than importing robots
  - profits

$$\begin{aligned} \text{no adoption} &: \pi_n = p_n y_n / \sigma \\ \text{adopter-importer} &: \pi_b = (p_n y_n / \sigma)\gamma_b - f_b \\ \text{adopter-buyer} &: \pi_i = (p_n y_n / \sigma)\gamma_i - f_i \end{aligned}$$

Robot Adoption Strategies



- size matters:
  - automation not profitable for smaller firms (low A, φ and α)
  - direct import chosen by larger and more capital-intensive firms

Heterogeneous Costs of Automation

- assume:

$$f_b = \varepsilon_b \quad \text{and} \quad f_i = \varepsilon_i + \Delta$$

  - $\varepsilon_b, \varepsilon_i$ are iid draws from a distribution with positive support and a non-increasing density
  - $\Delta > 0$

- adoption probabilities
  - probability of importing $\Pr(I)$ or buying $\Pr(B)$:

$$\begin{aligned} \Pr(I) &= \Pr(\pi_i > \max(\pi_n, \pi_b)) \\ \Pr(B) &= \Pr(\pi_b > \max(\pi_n, \pi_i)) \end{aligned}$$

- implications:
  - $\Pr(I)$ increases monotonically with firm size
  - $\Pr(B)$ is an inverted-U function of firm size
  - $\frac{\Pr(I)}{\Pr(B)}$ increases with firm size and the scope of adoption κ
  - adoption is lumpy, especially for smaller adopters

Comparing Adoption Strategies

- compare adopters-importers vs adopters-buyers and rest of firms
- main variables:
  - Y_{it} : log of sales, employment, sales per worker, VA per worker, capital per worker
  - dummies for robot importers and buyers
- regressions

$$Y_{it} = \alpha_{jt} + \beta \cdot \textit{Adopter-Buyer}_i + \gamma \cdot \textit{Adopter-Importer}_i + \mathbf{X}'_{it} \cdot \boldsymbol{\gamma} + \varepsilon_{it},$$

  - i : firm, j : 4-digit NACE industry, t : years
  - controls $\mathbf{X}'_{it}$: baseline firm characteristics $\times$ year dummies
  - balanced sample

Characteristics of Robot Adopters

	(1) Log Empl.	(2) Log Empl.	(3) Log Sales	(4) Log Sales	(5) Log Sales per Worker	(6) Log Sales per Worker	(7) Log VA per Worker	(8) Log VA per Worker	(9) Log Capital per Worker	(10) Log Capital per Worker
Adopter-importer	1.875***	0.551***	2.595***	0.370***	0.723***	-0.178***	0.578***	-0.045	0.940***	0.397***
	[0.102]	[0.055]	[0.123]	[0.036]	[0.055]	[0.051]	[0.042]	[0.044]	[0.074]	[0.079]
Adopter-buyer	1.162***	0.323***	1.655***	0.213***	0.472***	-0.110***	0.382***	0.010	0.689***	0.249***
	[0.022]	[0.014]	[0.028]	[0.011]	[0.014]	[0.014]	[0.012]	[0.012]	[0.023]	[0.025]
Observations	214,708	214,708	196,044	196,044	196,044	196,044	191,481	191,481	184,901	184,901
R-squared	0.31	0.668	0.322	0.868	0.341	0.556	0.199	0.299	0.2	0.251
Diff(importer-buyer)	0.713***	0.228***	0.939***	0.156***	0.251***	-0.067	0.196***	-0.055	0.251***	0.148*
	[0.103]	[0.055]	[0.124]	[0.035]	[0.055]	[0.050]	[0.042]	[0.0434]	[0.074]	[0.078]
Ind x Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes

- direct adoption more likely among larger firms, the role of productivity is mediated by size

Lumpiness of Robot Adoption

- index of lumpiness:

$$S_i = \frac{\text{max robot purchase}_i}{\text{mean robot purchase}_i} \in [1, 7]$$

  - $S_i = 1 \rightarrow$ constant adoption
  - $S_i = 7 \rightarrow$ single purchase

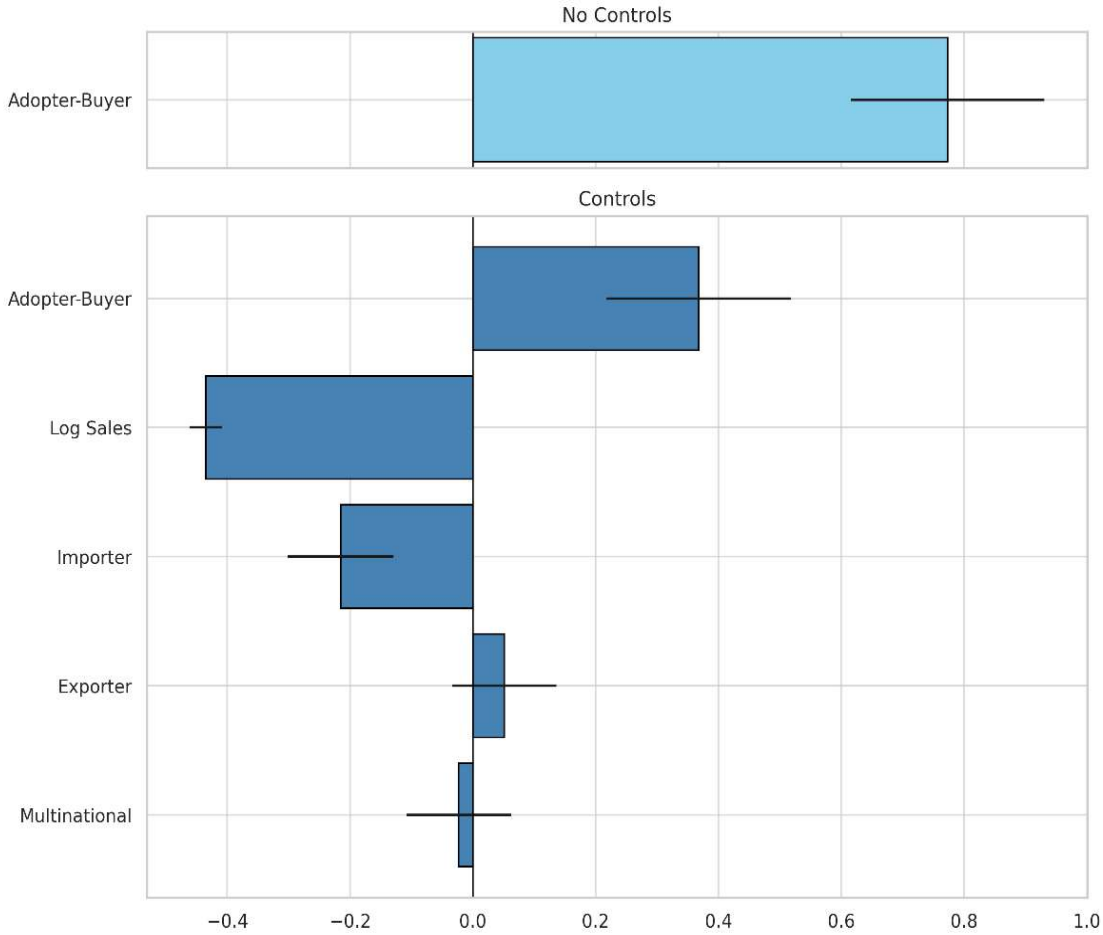
- distribution of spikes
  - 55% single purchase ($S_i = 7$)
  - 67% "spiky" adoption ($S_i > 3.5$)
  - 8.5% continuous adoption ($S_i \in [1, 2)$)

- focus on adopters only and regress:

$$S_i = \alpha_j + \beta \cdot \textit{Adopter-Buyer}_i + \mathbf{X}_i' \cdot \gamma + \varepsilon_i,$$

  - i : firm, j : 4-digit NACE industry
  - $\mathbf{X}_i$ firm controls: initial values

Robot Adoption Spikes and Firm Characteristics



- robot adoption is more lumpy for adopter-buyers and smaller firms

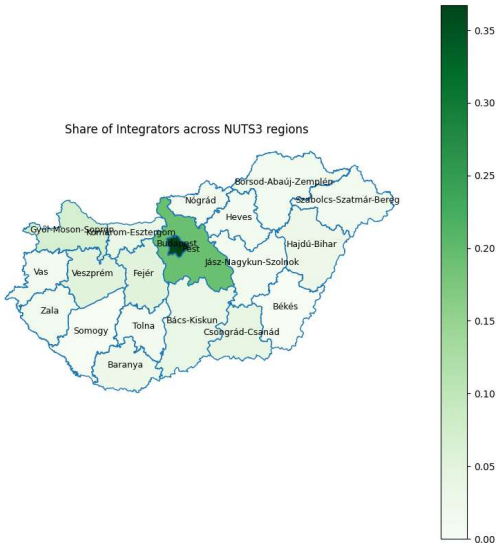
Conclusions

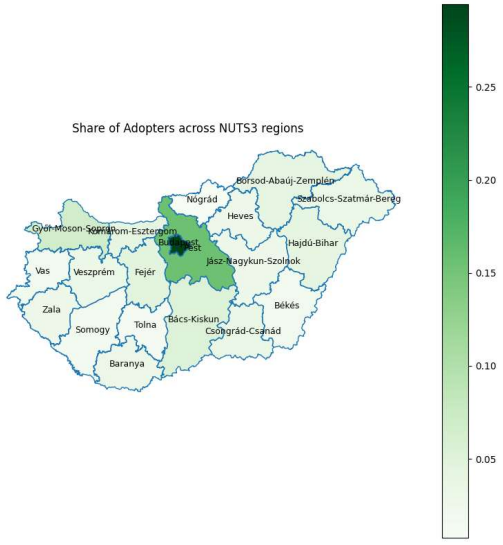
- first paper to use firm-to-firm transaction to
  - study the role of robot integrators
  - build a comprehensive measure of robot adoption
- five main takeaways
  1. most firms adopting robots do so through integrators
  2. integrators significantly benefit small and medium-sized firms
  3. robot adoption though integrators tends to be more lumpy than robot imports
  4. robot integrators are larger, more productive and more capital intensive than other firms
  5. integrators are particularly dependent on imports and exposed to foreign shocks

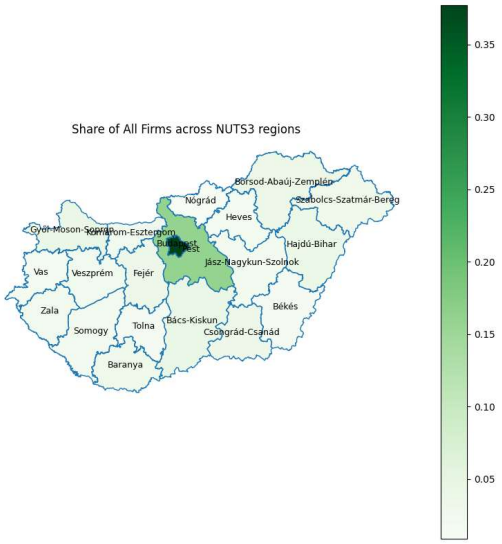
Characteristics of Robot Integrators

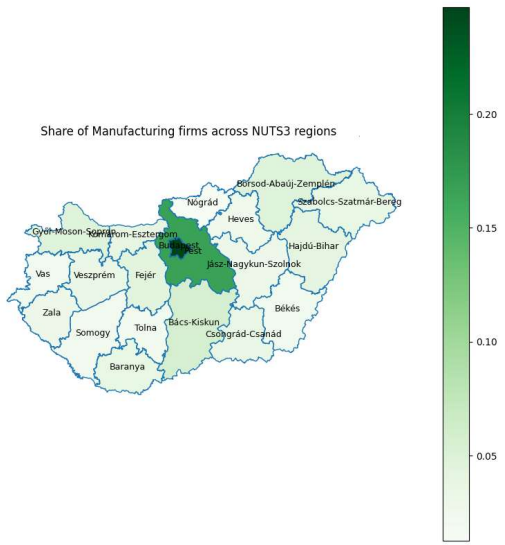
	(1) Log Employment	(2) Log Employment	(3) Log Sales	(4) Log Sales	(5) Log Sales per Worker	(6) Log Sales per Worker	(7) Log VA per Worker	(8) Log VA per Worker	(9) Log Capital per Worker	(10) Log Capital per Worker
	a) Baseline									
Integrator	1.090***	0.301***	2.188***	0.386***	0.840***	0.073	0.722***	0.169***	0.655***	0.176**
	[0.075]	[0.046]	[0.102]	[0.040]	[0.046]	[0.045]	[0.043]	[0.041]	[0.078]	[0.079]
Observations	739,624	697,903	745,425	745,425	619,922	619,922	562,023	561,845	499,469	495,853
R-squared	0.12	0.509	0.105	0.758	0.079	0.502	0.06	0.289	0.111	0.183
Ind x Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes

Geographical Concentration of Integrators and Adopters









Robot Adoption Spikes and Firm Characteristics

	(1)	(2)
	Spikiness Ratio	Spikiness Ratio
Adopter-buyer	0.773***	0.368**
	[0.158]	[0.150]
Log sales		-0.435***
		[0.026]
Importer		-0.215**
		[0.086]
Exporter		0.051
		[0.085]
Multinational		-0.023
		[0.085]
Observations	3,555	3,555
R-squared	0.145	0.254
Ind FE	Yes	Yes