Industrial Robots and Where to Find Them: Evidence and Theory on Derobotization

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Motivation

- Robots and automation have become a staple of production in the 21st century.
- The literature on automation is growing, especially in macroeconomics (Acemoglu and Restrepo).
- However, the literature (and conversation) on deautomation (at least within the macro- literature) is absent.

Motivation

- Robots and automation have become a staple of production in the 21st century.
- The literature on automation is growing, especially in macroeconomics (Acemoglu and Restrepo).
- However, the literature (and conversation) on deautomation (at least within the macro- literature) is absent.
- The prevailing assumption is of permanent automation.

Related literature

- Task-based production function to model automation. (Acemoglu and Restrepo, 2018).
- Robot adoption model and GE simulations. (Humlum, 2019)
  - Calibration on Danish manufacturing firms.
  - Baseline to our model (permanent adoption).
- Previous findings from Spanish manufacturing firms (Koch et al., 2019)
  - Larger and more productive firms adopt robots more frequently.
  - Robot adoption leads to net job creation for both low- and high-skilled workers.
  - Nearly 40% of adopters **derobotize** at some point.

Related literature

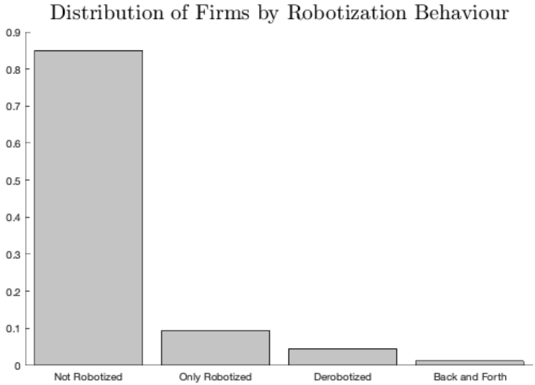

Figure: Koch et al (2019)

Kaplan-Meier estimates

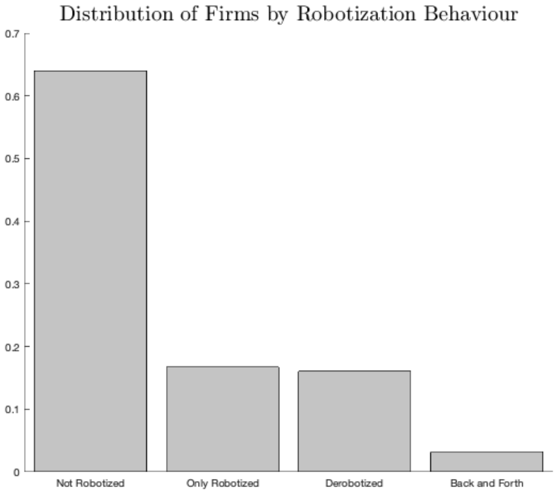

Figure: Camilo, Gokalp, Iurchenko, Klix, and Rubinoff (2020)

Data

- Annual survey of Spanish manufacturing firms from SEPI Foundation
  - Unbalanced panel from 1991-2014
  - Frequency: 4 years
  - Use of robots, firm size, capital, labor, and industry
- Data on 3,987 firms
  - 14,119 firm-year observations
  - 958 robotizations, and 755 derobotizations
- ESEE question:

  "State whether the production process uses any of the following systems:

  ..

  2. Robotics;

  .."

Empirical investigation

1. When does derobotization happen?

Empirical investigation

1. When does derobotization happen?
2. Which firms derobotize?

Empirical investigation

1. When does derobotization happen?
2. Which firms derobotize?
3. What happens after derobotization?

Derobotization Timing

- When does derobotization happen?

Fact

Derobotization is most likely in the first periods after adoption.

- This fact is indicative of a learning process.

Derobotization Timing

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Method:

- Kaplan-Meier estimator to adjust for censoring

Periods after Robotization	Derobotization % (KM)	Derobotization (Naive)
1	50.97%	64.64%
2	33.58%	26.62%
3	9.79%	5.56%
4	5.66%	3.18%

Derobotization and Size

- Which firms derobotize?

Fact

Larger firms are less likely to derobotize.

Derobotization and Size

- Which firms derobotize?

Fact

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Method:

- Cox proportional hazards model on robot usage duration
- Negative effect of size on hazard ratio

Derobotization Outcomes

- What happens after derobotization?

Fact

Derobotization is correlated negatively with labor inputs and positively with capital-to-labor ratio.

Derobotization Outcomes

- What happens after derobotization?

Fact

Derobotization is correlated negatively with labor inputs and positively with capital-to-labor ratio.

Method:

- Measure changes in labor (hours), capital, and K/L ratio
- Sample: firms robotizing/derobotizing once
- Event study with two-way fixed effects

Robotization and the Model

Task-based framework: each factor completes a set of tasks for production.

Given a set of factors in production, robot adoption:

- Affects each factors productivity in production (productivity)
- Implies a reassignment of tasks between factors (substitution)
- Create new tasks (reinstatement)

Model

Then production can be formulated as:

$$Y_t(M_t, L_t|R_t, \varphi_t) := z_{Ht}\left(M_t^{\frac{\sigma-1}{\sigma}} + \sum_{o\in\{1,2\}} z_{ot}^{\frac{1}{\sigma}} L_{ot}^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$$

where $z_{xt}(R_t, \varphi_{xt}) := \exp(\varphi_{xt} + \gamma_x R_t)$ for $x \in \{H, 1, 2\}$.

$$\implies \pi_t(R, \varphi) \equiv \max_{X\in\mathbb{R}^3_+} \left\{P_M Y_M^{\frac{1}{\varepsilon}} Y_t(X|R, \varphi)^{\frac{\varepsilon-1}{\varepsilon}} - w^T X\right\}$$

Firms maximize expected discounted value of all future profits.

Timing and Structure

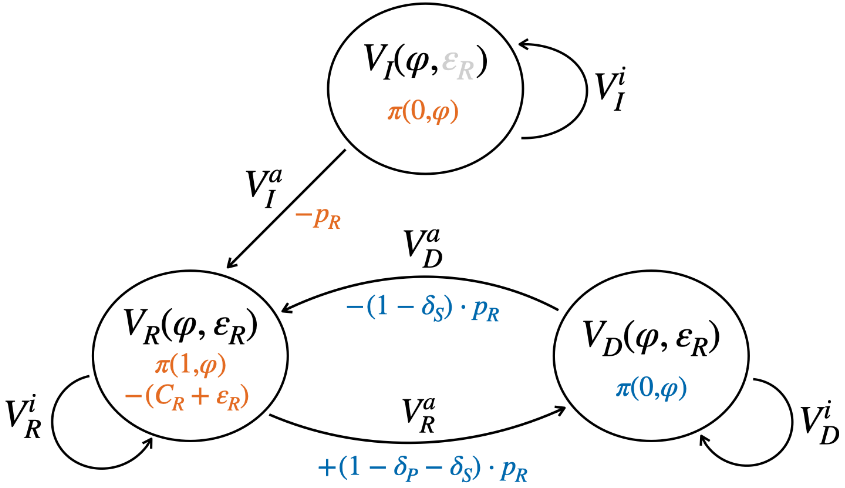
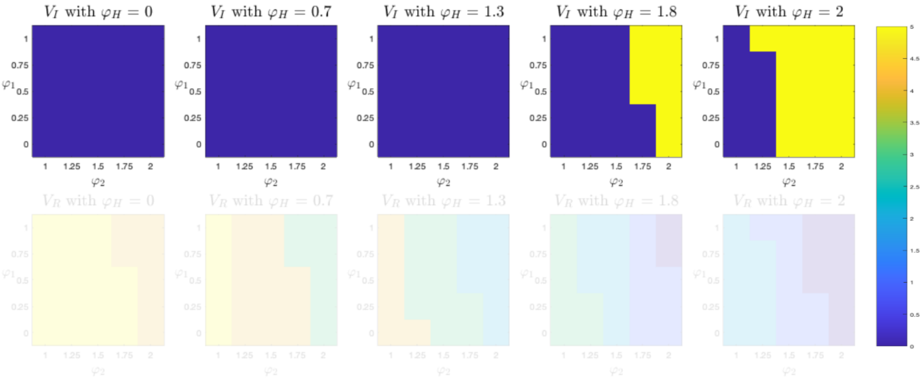


Figure: Value function structure

Robot adoption - Policy function

Figure: Action-Inaction regions by productivity φ and cost-type ε_R

Robot adoption - Policy function



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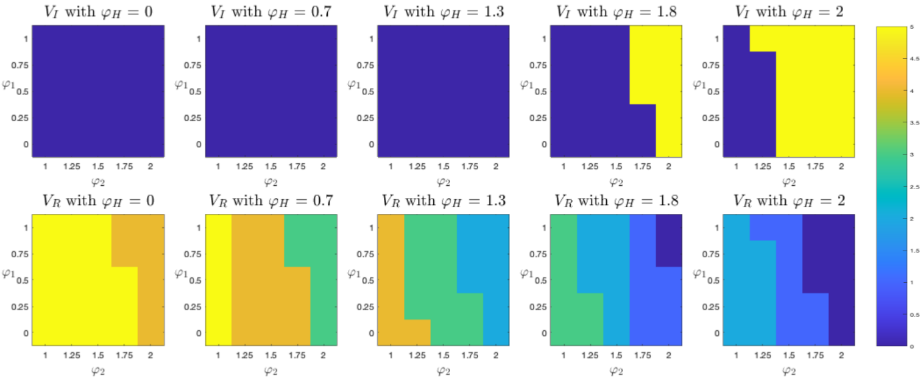

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Robot adoption - Policy function

- Determinants of derobotization
  - *Productivity effect*: Decrease in productivity
  - *Revelation effect*: Above-average robotization costs

Robot adoption - Policy function

- Determinants of derobotization
    - *Productivity effect*: Decrease in productivity
    - *Revelation effect*: Above-average robotization costs
- φ_H indicates firm size (Humlum 2019)

Observation

Larger firms are less likely to derobotize.

Robotization behaviour

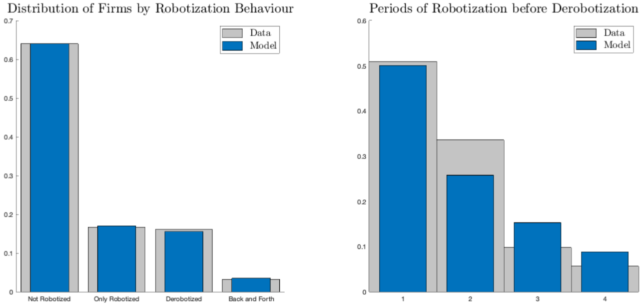
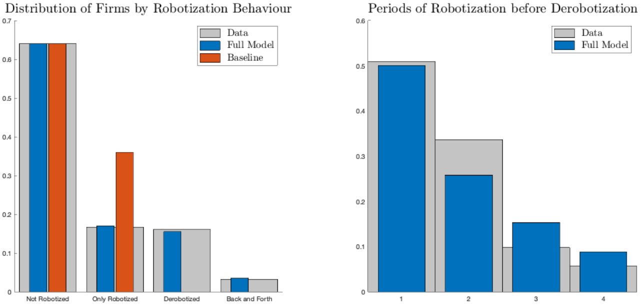


Figure: Adoption behaviour of firms in simulated time series.

Observation

Derobotization is most likely in the first periods after adoption.

Robotization behaviour



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Event Study: Derobotization Event

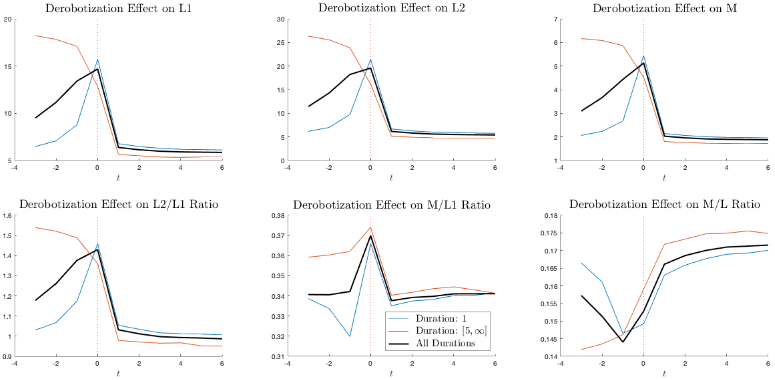

Figure: Derobotization event in the simulated time series

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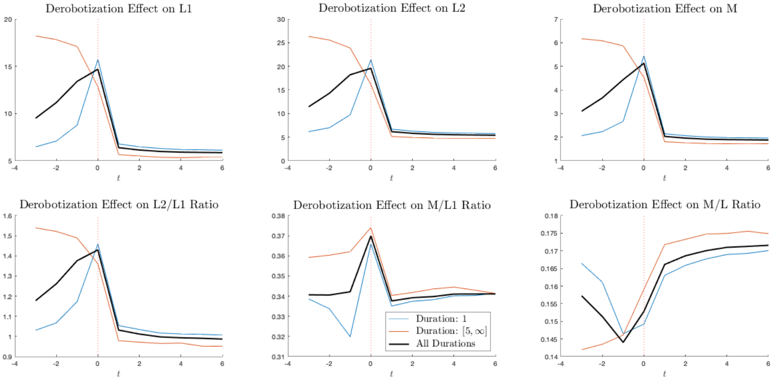
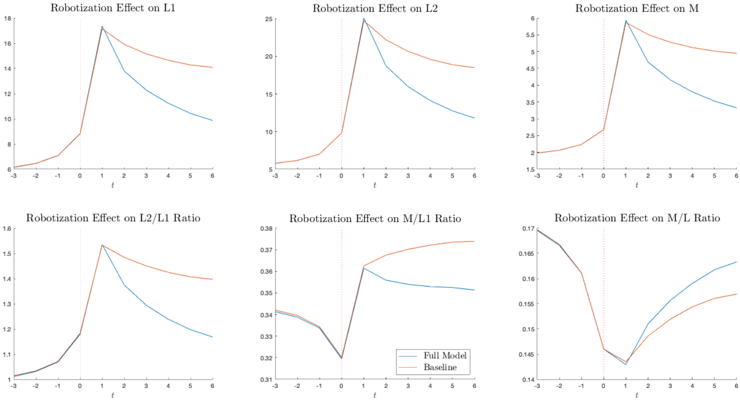


Figure: Derobotization event in the simulated time series

Observation

Derobotization causes a drop in labor demand. Furthermore it leads to an increase in the intermediate-to-labor ratio.

Event Study: Robotization Event



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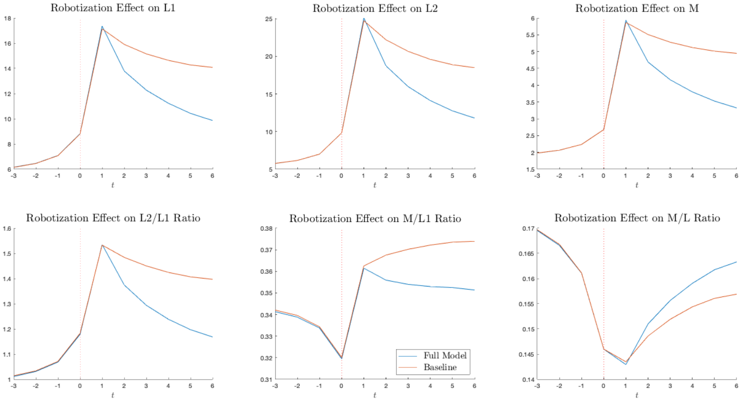


Figure: Robotization event in the simulated time series

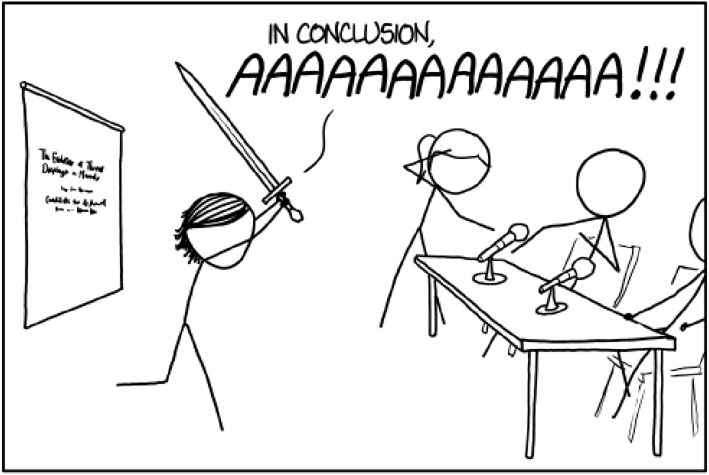
Observation

The permanent adoption model overestimates the effects of robotization.

Conclusion

- First paper (to our knowledge) to analyze this behaviour in depth
- Permanent adoption models are incomplete
- Our biggest contribution is opening avenues of future research:
  - Implications for business cycles
  - A repeat of our analysis in other countries (Acemoglu et al., 2020 but with deautomation)
  - An analysis on deautomation which includes depth (IFR data)

The End

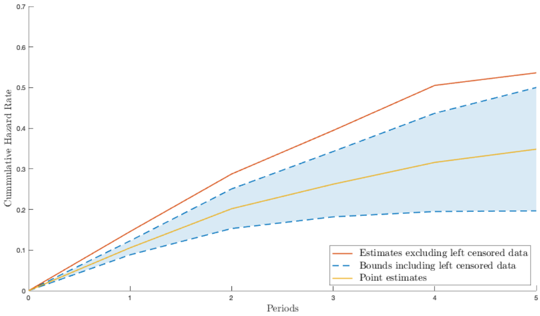


THE BEST THESIS DEFENSE IS A GOOD THESIS OFFENSE.

Appendix

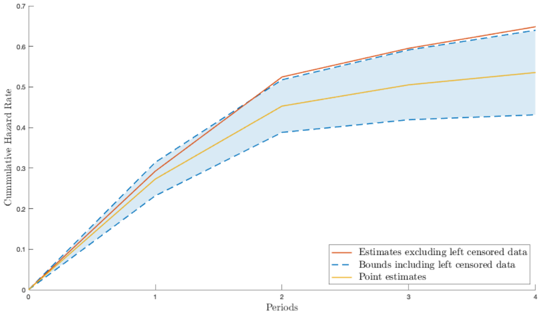
- KM: Robot. Classes
- KM: Derobotization
- Regression: Size
- Robustness Test: Size
- Regression: Inputs
- Microfoundations
- Value Functions
- Action-Region Graph
- Parametrization
- Determining Effects
- Policy functions
- CF: Certain Costs
- CF: No Setup Costs
- CF: Reversed Persistence
- Derobotization Event
- Robotization Event

Kaplan-Meier: Robotization Behaviour



- Kaplan-Meier estimation is used to adjust for right-censoring

Kaplan-Meier: Derobotization Behaviour



- Kaplan-Meier estimation is used to adjust for right-censoring
- The area in the bounds represents possible rates of derobotization
- We use the midpoint as our estimate

Appendix: duration model

$$\lambda(t_i|X_i) = \lambda_0(t_i) \times \exp\left(\beta_1 \mathrm{size}_i + \beta_2 \mathrm{prevrob}_i + \beta_3 log(K/L)_i\right) (1)$$

Table: Duration of robot usage and firm size

Specification	(1)	(2)
size		
from 100 to 500	-0.42***	-0.35**
	(0.15)	(0.15)
from 500	-0.47**	-0.44**
	(0.21)	(0.22)
Controls		yes

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

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Appendix: Robustness Test

$$\text{derobotization}_{it} = \beta_1 \text{size}_{it-1} + \beta_2 \log(K/L)_{it-1} + \beta_3' \times \text{industry}_{it} + \tau_t + \varepsilon_{it}. \quad (2)$$

Table: Robustness test: disaggregated data

	(1)	(2)	(3)	(4)
Size_{t-1}				
From 100 to 500	-0.09***	-0.08***	-0.08***	-0.06***
	(0.02)	(0.02)	(0.02)	(0.02)
From 500	-0.17***	-0.16***	-0.16***	-0.14***
	(0.02)	(0.02)	(0.02)	(0.03)
$\log(K/L)_{t-1}$		-0.02*	-0.02	-0.02**
		(0.01)	(0.01)	(0.01)
Time FE			yes	yes
Industry FE				yes
Observations	1560	1538	1538	1529

Appendix: Event Study

$$y_{it} = \beta_1 \text{derobotization}_{it} + \beta_2 \text{derobotization}_{it-1} + \mu_i + \tau_t + \varepsilon_{it}. \quad (3)$$

Table: Derobotization and Firm Outcomes

	log(*capital*)		log(*hours*)		log(*K*/*L*)	
Specification	(1)	(2)	(3)	(4)	(5)	(6)
derobotization_t	-0.00	-0.00	-0.09**	-0.08**	0.09*	0.09*
	(0.06)	(0.06)	(0.04)	(0.04)	(0.05)	(0.05)
$\text{derobotization}_{t-1}$		0.02		-0.06		0.06
		(0.05)		(0.03)		(0.04)
cumulative effect	0.00	0.02	-0.09**	-0.14**	0.09*	0.15**

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

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Microfoundations for Task-Based model (1/3)

- Firm operates with a task-based production function back

$$Y := \left(\int_0^1 y(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}}, \tag{4}$$

- Production of task i conditional on robotization:

$$y(i) := z_o(i, R) X_o(i). \tag{5}$$

- Firms solves the problem

$$\max_{\{X_o(i)\}_{o=1}^{|\{1,2\}|}} \left(\int_0^1 y(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} - \sum_{o=1}^{|\{1,2\}|} \left(\int_0^1 p_o X_o(i) di \right), \tag{6}$$

Microfoundations for Task-Based model (2/3)

Given a set of factors in production, robot adoption:

- Affects each factors productivity in production (productivity)
- Implies reassignment of tasks between factors (substitution)
- Create new tasks (reinstatement)

Microfoundations for Task-Based model (3/3)

- The solution to this problem is given by: back

$$Y \equiv \left\{ \sum_{o=1}^{2} \left(z_o \mathbf{X}_o \right)^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}} \tag{7}$$

$$z_o := \left(\int_{A_o} z_o(i)^{\sigma} di \right) \left(\int_{A_o} z_o(i)^{\sigma-1} di \right)^{-1} \tag{8}$$

$$z_o = \exp(\varphi_o + R\gamma_o) \tag{9}$$

$$\varphi_o = \log \frac{\int_{A_o} z_o(i,0)^{\sigma} di}{\int_{A_o} z_o(i,0)^{\sigma-1} di} \tag{10}$$

$$\gamma_o = \log \frac{\int_{A_o} z_o(i,1)^{\sigma} di}{\int_{A_o} z_o(i,1)^{\sigma-1} di} - \log \frac{\int_{A_o} z_o(i,0)^{\sigma} di}{\int_{A_o} z_o(i,0)^{\sigma-1} di} \tag{11}$$

Model

Then production can be formulated as:

$$Y_t(M_t, L_t|R_t, \varphi_t) := z_{Ht}(\varphi_{Ht}, R_t)\Big(M_t^{\frac{\sigma-1}{\sigma}} + \sum_{o\in\{1,2\}} z_{ot}(\varphi_{ot}, R_t)^{\frac{1}{\sigma}} L_{ot}^{\frac{\sigma-1}{\sigma}}\Big)^{\frac{\sigma}{\sigma-1}}$$

where

$$z_{Ht}(R_t, \varphi_t) := \exp(\varphi_{Ht} + \gamma_H R_t),$$
$$z_{ot}(R_t, \varphi_t) := \exp(\varphi_{ot} + \gamma_o R_t),$$

back App.

Value functions

Unrobotized: $V_I = \max\{V_I^a, V_I^i\}$

$$V_I^a(\varphi_t, \varepsilon_R) = \pi(0, \varphi_t) - p_R + \beta \mathbb{E}[V_R(\varphi_{t+1}, \varepsilon_R)|\varphi_t]$$
$$V_I^i(\varphi_t, \varepsilon_R) = \pi(0, \varphi_t) \qquad + \beta \mathbb{E}[V_I(\varphi_{t+1}, \varepsilon_R)|\varphi_t]$$

Robotized: $V_R = \max\{V_R^a, V_R^i\}$

$$V_R^a(\varphi_t, \varepsilon_R) = \pi(1, \varphi_t) - c_R + (1-\delta) p_R + \beta \mathbb{E}[V_I(\varphi_{t+1}, \varepsilon_R)|\varphi_t, \varepsilon_R]$$
$$V_R^i(\varphi_t, \varepsilon_R) = \pi(1, \varphi_t) - c_R \qquad + \beta \mathbb{E}[V_R(\varphi_{t+1}, \varepsilon_R)|\varphi_t, \varepsilon_R]$$
$$\text{where } \ c_R = C_R + \varepsilon_R, \quad \delta = \delta_S + \delta_P$$

Derobotized $V_D = \max\{V_D^a, V_D^i\}$

$$V_R^a(0, \varphi_t, \varepsilon_R) = \pi(0, \varphi_t) - (1-\delta_S) \cdot p_R + \beta \mathbb{E}[V(1, \varphi_{t+1}, \varepsilon_R)|\varphi_t, \varepsilon_R]$$
$$V_R^i(0, \varphi_t, \varepsilon_R) = \pi(0, \varphi_t) \qquad + \beta \mathbb{E}[V_R(0, \varphi_{t+1}, \varepsilon_R)|\varphi_t, \varepsilon_R]$$

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Action-Inaction region

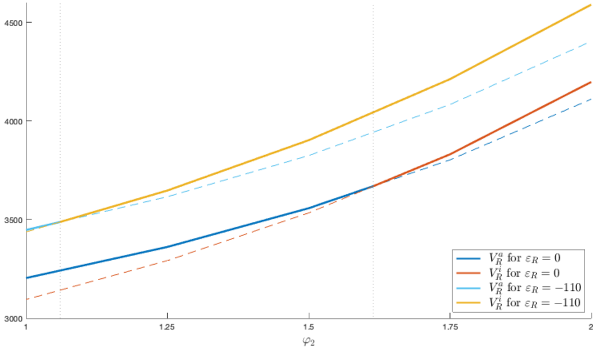

Figure: Action-Inaction regions of V_R at $(\varphi_H, \varphi_1) = (1.3, 1)$

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Parametrization

Table: Parametrization

Parameter	Full Model	Parameter	Full Model
β	0.8	C_R	500
σ	1.5	p_R	1260
γ_H	1.74	δ_P	0.03
γ_1	-0.1	δ_S	0.17
γ_2	0.2	φ_H	[0,0.7,1.3,1.8,2]
w_M	15	φ_1	[0,0.25,0.5,0.75,1]
w_1	10	φ_2	[1,1.25,1.5,1.75,2]
w_2	20	ε_R	[-220,-110,0,110,220]
ε	1.5	ρ_H	$2/3$
Y_M	10	ρ_1	0.3
P_M	10	ρ_2	0.5

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Robot adoption - Determining Effects

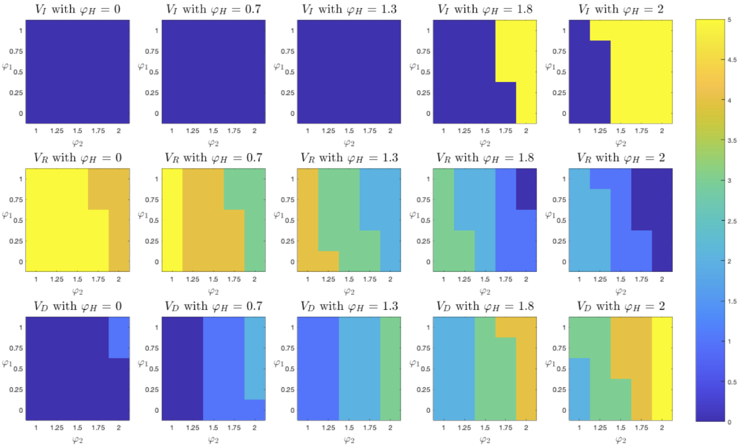

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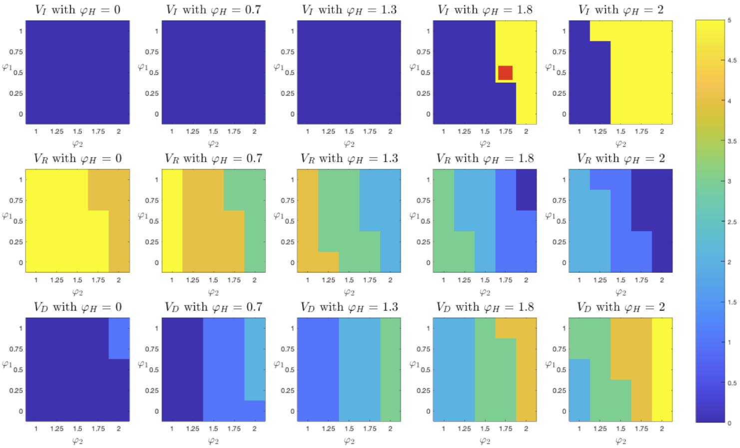
Figure: Action-Inaction regions by productivity φ and cost-type ε_R

Robot adoption - Determining Effects



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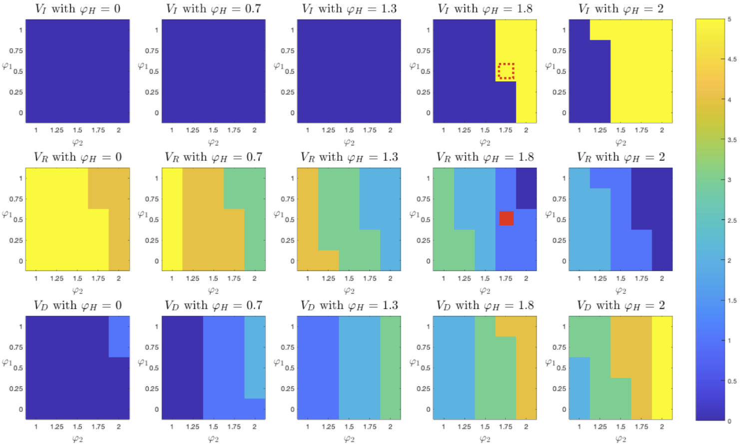

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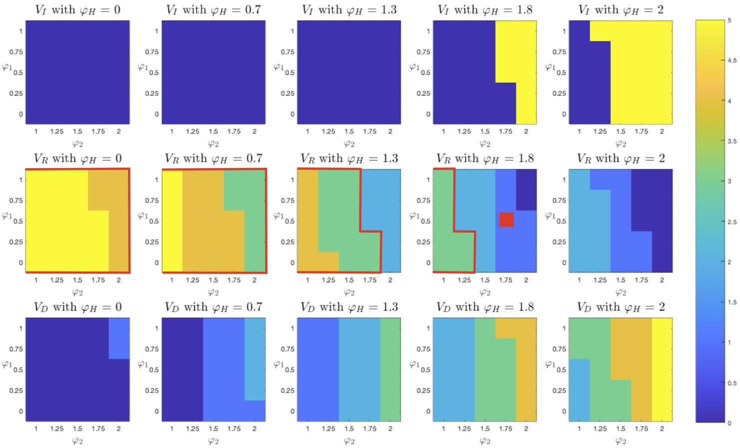

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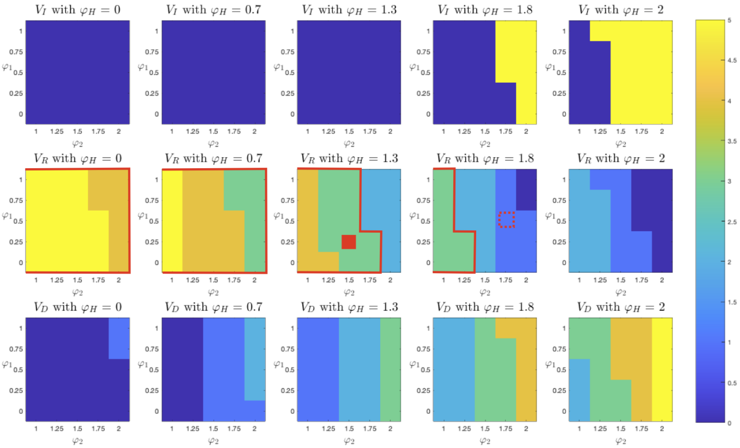

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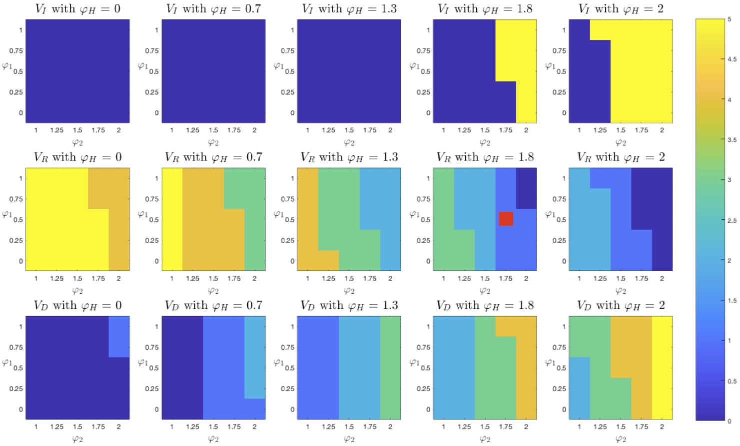

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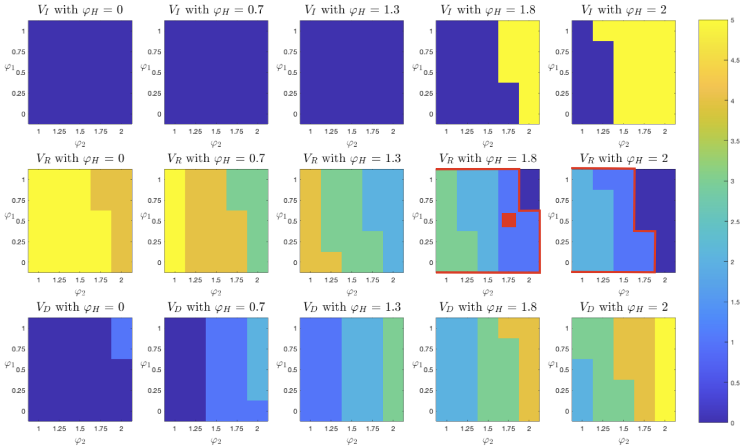

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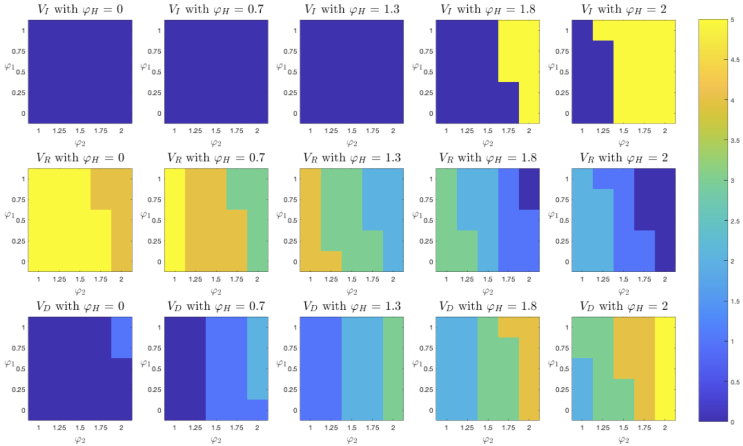

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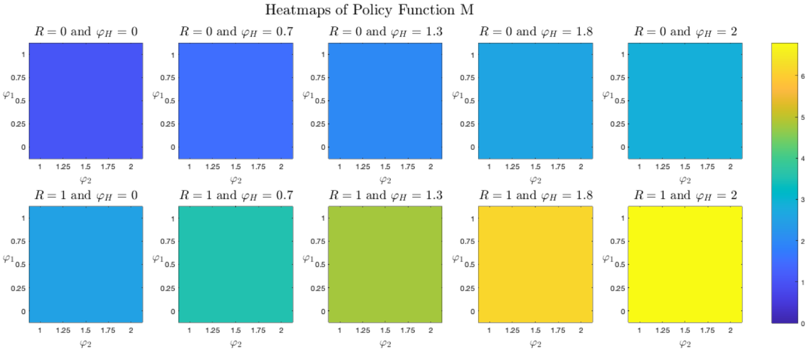
Policy functions



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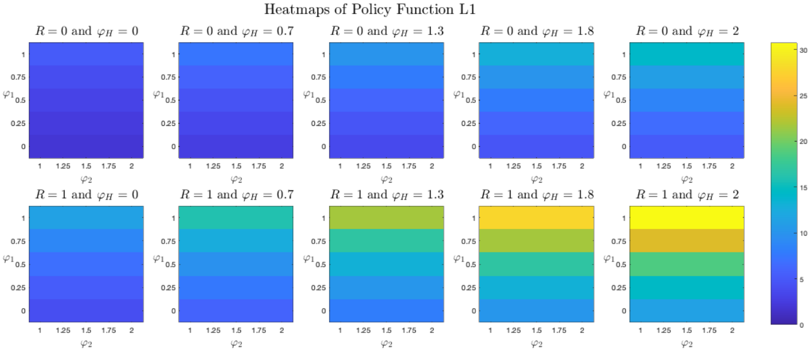

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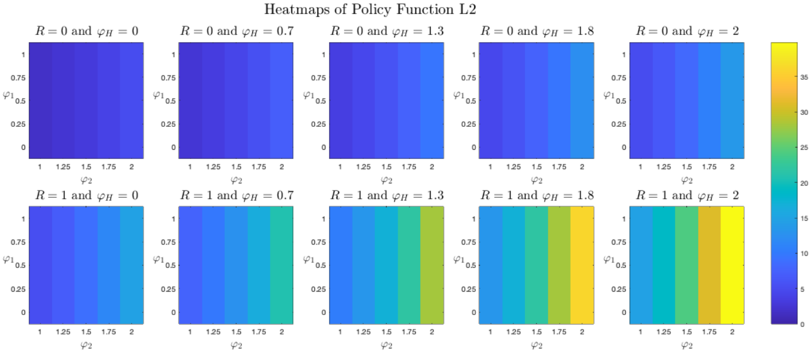

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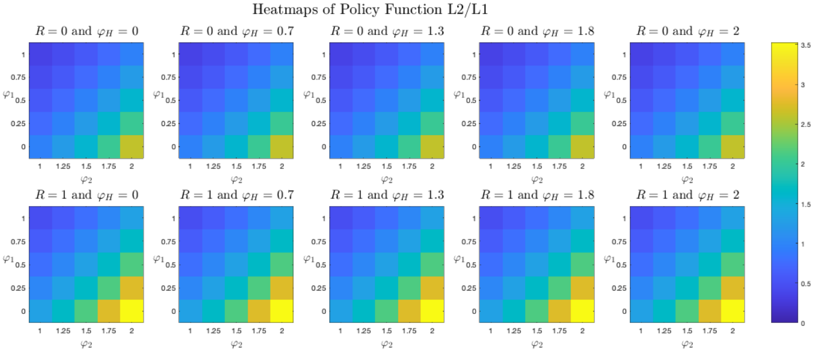

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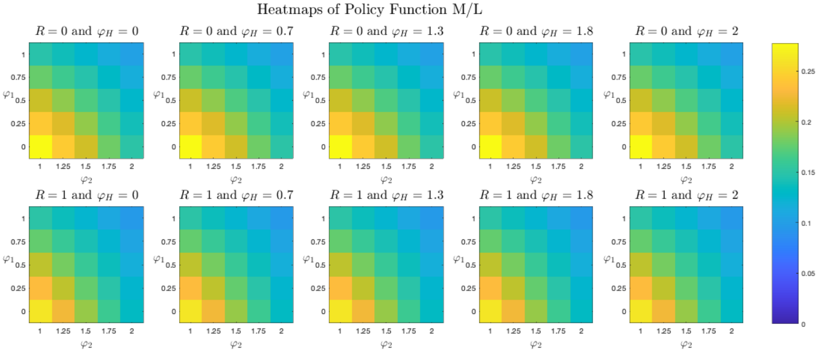

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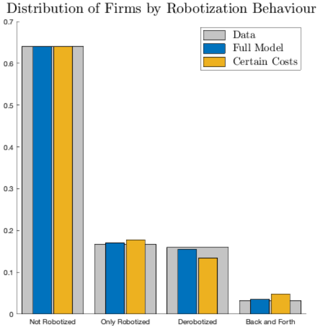
Counterfactuals: Certain Costs



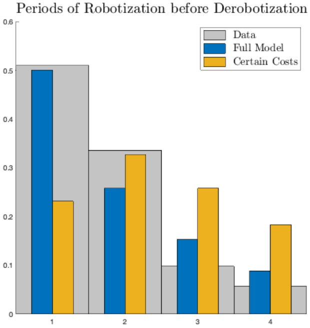


Figure: Adoption behaviour of firms in simulated time series with Certain Costs

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Counterfactuals: No Setup Costs

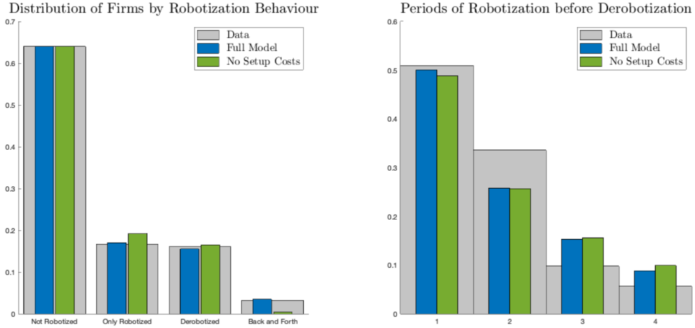

Figure: Adoption behaviour of firms in simulated time series with No Setup Costs

back App.

Counterfactuals: Reversed Persistences

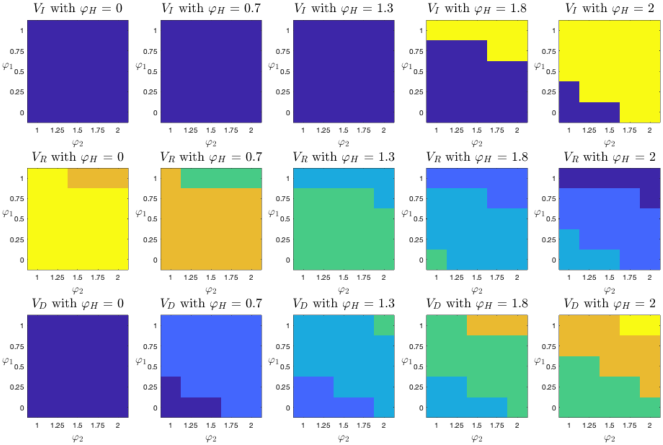

Figure: Heatmaps of policy function R with reversed persistences

App.

Event Study Appendix: Derobotization Event

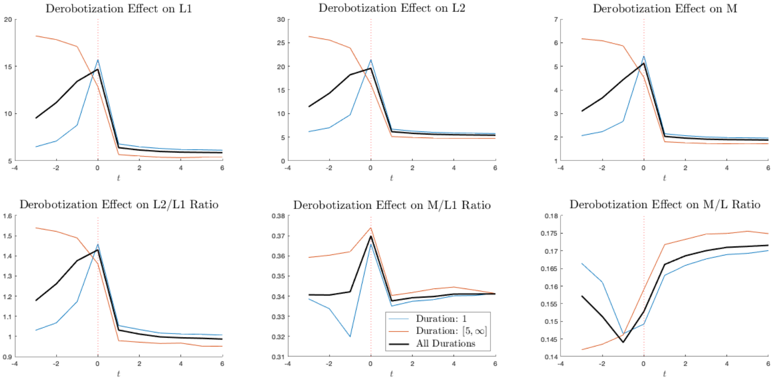

Figure: Derobotization event in the simulated time series

Observation

Long term adopters exhibit lower L_2/L_1 ratios prior to derobotization.

Event Study Appendix: Derobotization Event

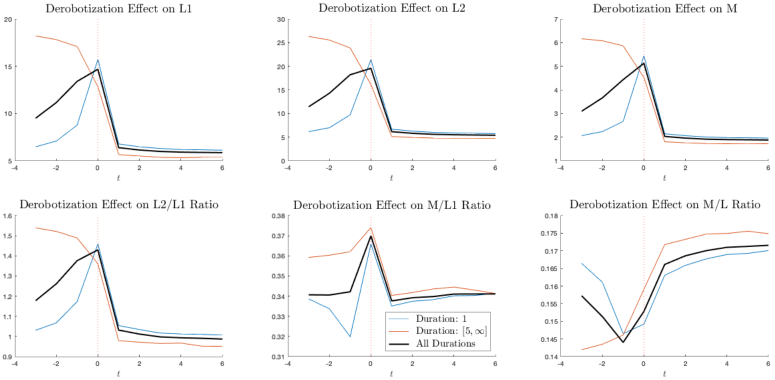

Figure: Derobotization event in the simulated time series

Observation

Long term adopters exhibit higher M/L_1 ratios prior to derobotization.

Event Study Appendix: Derobotization Event

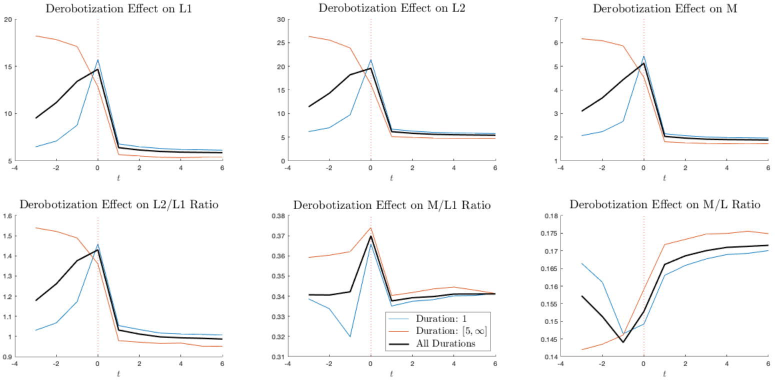

Figure: Derobotization event in the simulated time series

Observation

Those firms which take longer to derobotize do so following a sequence of low productivity shocks. ▸ back ▸ App.

Event Study: Robotization Event

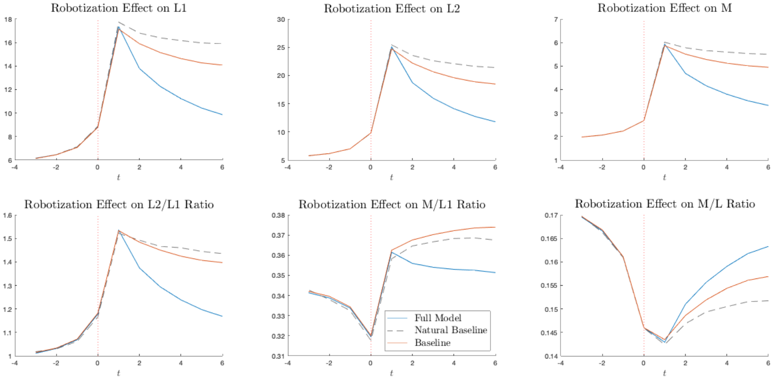

Figure: Robotization event in the simulated time series

Observation

Robotization increases high-skill labor and intermediate demand more than it increases low-skill labor demand. ▸ back ▸ App.