Robots or Workers?
A Macro Analysis of Automation and Labor Markets

Sylvain Leduc[a] Zheng Liu[a]

[a]Federal Reserve Bank of San Francisco

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The rising threat of automation

- Fears that robots might displace jobs triggered policy debate (e.g., UBI)
- But automation doesn't necessarily reduce aggregate employment: as old tasks are automated, new tasks get created (e.g., Autor 2015; Acemoglu and Restrepo 2018)
- Did automation depress wages while boosting employment during the long expansion prior to COVID-19?
  - Answers can also inform post-pandemic labor market recovery

What we do

- Examine GE impacts of the threat of automation on U.S. labor market: wage growth and employment
- Generalize DMP model to incorporate automation decisions
  - Consumption goods can be produced with workers or robots
  - An unfilled vacancy can be automated at a fixed cost drawn from i.i.d. distribution
  - Adopt a robot if fixed cost below benefit $\rightarrow$ endogenous prob of automation
  - Our approach requires departure from textbook DMP model with free-entry; instead, vacancy creation is costly $\rightarrow$ unfilled vacancy has value (Leduc-Liu, 2020 AEJ Macro)

Theoretical insights

- Automation has both job-displacing and job-creating effects
  - Robots can substitute for workers in production ("robots" a metaphor for labor substituting technologies, different from traditional capital)
  - But option to automate raises vacancy value, boosting job creation
- Threat of automation raises firm reservation value, weakening worker bargaining power and pushing down wages: endogenous wage rigidity
  - Wage rigidities key for explaining large U fluctuations (e.g., Christiano, Eichenbaum, Trabandt, 2020)
- Increased automation also raises productivity, which, along with muted wage changes, amplifies U fluctuations

Quantitatively implications

- Estimate model to fit time series of U, v, wage, and productivity
  - Fitting productivity and wage data helps discipline model parameters and shocks
- The automation channel is quantitatively important
  1. for amplifying fluctuations in unemployment and vacancies
  2. for depressing wages while boosting productivity
  3. Absent automation channel, the Shimer volatility ratio (i.e., std(v/u)/std(w)) would have been 10, much smaller than data (39)
- Search frictions and automation both important for explaining labor market fluctuations

Labor market

- Job seekers

$$u_t = 1 - (1 - \delta_t) N_{t-1}$$

where δ_t denotes job separation rate and N_{t-1} is beginning-of-period employment

- Vacancies

$$v_t = (1 - q^v_{t-1})(1 - q^a_t) v_{t-1} + \delta_t N_{t-1} + \eta_t$$

where q^v_t denotes job filling rate, q^a_t denotes automation probability, and η_t denotes newly created vacancies

- Vacancy is a slow-moving state variable: different from standard DMP with free entry

Labor market

- Matching technology

$$m_t = \mu u_t^{\alpha} v_t^{1-\alpha}$$

- Aggregate employment dynamics

$$N_t = (1 - \delta_t) N_{t-1} + m_t$$

- End-of-period unemployment rate

$$U_t = u_t - m_t = 1 - N_t$$

- Job filling and finding rates

$$q_t^v = \frac{m_t}{v_t}, \quad q_t^u = \frac{m_t}{u_t}$$

Production

- A firm produces y_t units of consumption goods using either a worker or a robot

$$y_t = \begin{cases} Z_t & \text{if using one worker} \\ Z_t \zeta_t & \text{if using one robot} \end{cases}$$

- Aggregate output: sum of goods produced by N workers and A robots

$$Y_t = Z_t N_t + Z_t \zeta_t A_t$$

- Stock of automation (A_t)

$$A_t = (1 - \rho^o) A_{t-1} + q_t^a (1 - q_{t-1}^v) v_{t-1}$$

where ρ^o denotes obsolescence rate

Vacancy creation

- Creating a new vacancy incurs an entry cost e drawn from i.i.d. distribution $F(e)$
- Benefit of creating a vacancy is the vacancy value J_t^v
- New vacancy created if net value of entry is non-negative ($e \leq J_t^v$)
- Number of new vacancy being created

$$\eta_t = F(J_t^v)$$

Automation decision

- Adopting robot incurs fixed cost x drawn from i.i.d. distribution $G(x)$
- Net benefit of automation = value of robot net of value of foregone vacancy

$$x_t^* = J_t^a - J_t^v$$

- Value of a robot

$$J_t^a = Z_t \zeta_t - \kappa_a + (1 - \rho^o)\mathbb{E}_t D_{t,t+1} J_{t+1}^a$$

where κ_a is flow cost of operating robots and $D_{t,t+1}$ is SDF

- Automate if $x \leq x_t^* \Rightarrow$ prob of automating

$$q_t^a = G(x_t^*)$$

Values of an open vacancy and a filled position

- Value of an open vacancy (J_t^v)

$$J_t^v = -\kappa + q_t^v J_t^e + (1 - q_t^v)\mathbb{E}_t D_{t,t+1}\left[q_{t+1}^a J_{t+1}^a + (1 - q_{t+1}^a) J_{t+1}^v\right]$$

where κ is vacancy posting cost

- Value of a filled position (J_t^e)

$$J_t^e = Z_t - w_t + \mathbb{E}_t D_{t,t+1}\left[(1 - \delta_{t+1}) J_{t+1}^e + \delta_{t+1} J_{t+1}^v\right]$$

where w_t is wage rate

Representative household

- Utility function

$$\mathbb{E}\sum_{t=0}^{\infty}\beta^t\Theta_t\left(\ln C_t-\chi N_t\right)$$

- Budget constraint

$$C_t+\frac{B_t}{r_t}=B_{t-1}+w_tN_t+\phi(1-N_t)+d_t-T_t$$

- Employment surplus

$$S_t^H=w_t-\phi-\frac{\chi}{\Lambda_t}+\mathbb{E}_tD_{t,t+1}(1-q_{t+1}^u)(1-\delta_{t+1})S_{t+1}^H$$

Wage determination

- Wages are determined by Nash bargaining

$$\max_{w_t} \quad \left(S_t^H\right)^b (J_t^e - J_t^v)^{1-b}$$

- Steady state wage

$$w^N = \phi + \frac{\chi}{\Lambda} + \frac{b}{1-b}[1 - \beta(1 - q^u)(1 - \delta)](J^e - J^v)$$

  - Wage increases with both worker reservation value $\phi + \frac{\chi}{\Lambda}$ and worker bargaining weight b
  - Wage decreases with firm reservation value J^v
  - Threat of automation (q^a) raises J^v and thus lowers wage

Government policy and market clearing

- Government policy

$$\phi(1 - N_t) = T_t$$

- Bond market clearing

$$B_t = 0$$

- Final goods market clearing

$$C_t + \kappa v_t + \kappa_a A_t + (1 - q_{t-1}^v) v_{t-1} \int_0^{x_t^*} x dG(x) + \int_0^{J_t^v} e dF(e) = Y_t$$

- Aggregate output

$$Y_t = Z_t N_t + Z_t \zeta_t A_t$$

Empirical strategy

- Calibrate a subset of parameters to match SS observations
- Estimate remaining models parameters (in shock processes and in fixed cost distributions) using Bayesian methods
- Vacancy creation and robot adoption cost distributions

$$F(e) = \left(\frac{e}{\bar{e}}\right)^{\eta_v} \quad G(x) = \left(\frac{x}{\bar{x}}\right)^{\eta_a}$$

- Set $\eta_v = \eta_a = 1$
- Estimate $\bar{e}$, $\bar{x}$, and the shock parameters ρ_k and σ_k, for $k \in \{\theta, \zeta, z, \delta\}$
- Fit model to time series of unemployment, vacancies, real wage growth, and average labor productivity growth (1985:Q1-2018:Q4)

Steady state and calibrated parameters

	Parameter Description	value
β	Subjective discount factor	0.99
ϕ	Unemployment benefit	0.25
α	Elasticity of matching function	0.50
b	Nash bargaining weight	0.50
ρ^o	Automation obsolescence rate	0.03
κ_a	Flow cost of automated production	0.98
$\bar{\delta}$	Job separation rate	0.10
μ	Matching efficiency	0.66
κ	Vacancy posting cost	0.09
χ	Disutility of working	0.73

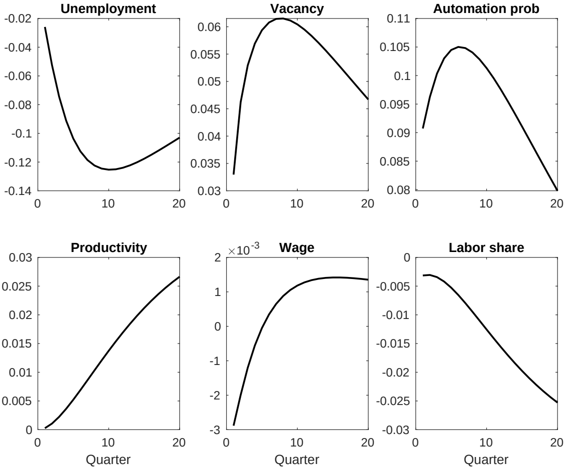
- Average unemployment rate from 1985-2018: $U = 0.06$
- Quarterly average job separation rate (JOLTS): $\bar{\delta} = 0.1$
- Quarterly job filling rate (den Haan et al, 2000): $q^v = 0.71$
- Vacancy posting costs (Leduc-Liu, 2019): $\kappa v = 0.01Y$

Estimation results

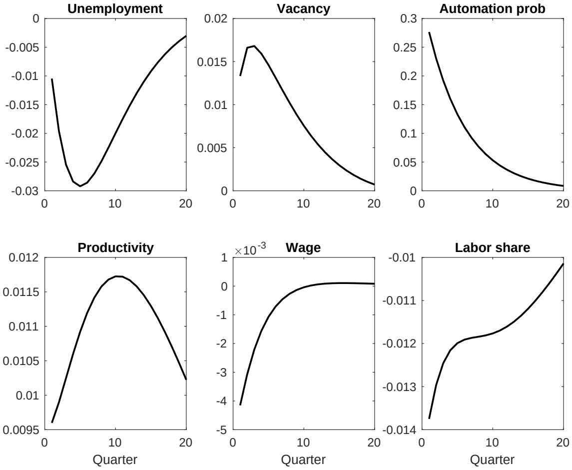
		Posterior		
	Parameter description	Mean	5%	95%
$\bar{e}$	scale for vacancy creation cost	9.57	7.45	11.82
$\bar{x}$	scale for robot adoption cost	2.43	1.78	3.04
ρ_z	AR(1) of neutral technology shock	0.97	0.96	0.98
ρ_θ	AR(1) of discount factor shock	0.98	0.97	0.99
ρ_δ	AR(1) of separation shock	0.94	0.91	0.97
ρ_ζ	AR(1) of automation-specific shock	0.76	0.72	0.79
σ_z	std of tech shock	0.01	0.01	0.01
σ_θ	std of discount factor shock	0.01	0.01	0.02
σ_δ	std of separation shock	0.05	0.05	0.05
σ_ζ	std of automation-specific shock	0.04	0.03	0.05

- Estimation implies that 24% jobs are performed by robots in steady state, in line with empirical literature (e.g., Nedelkoska and Quintini, 2018)

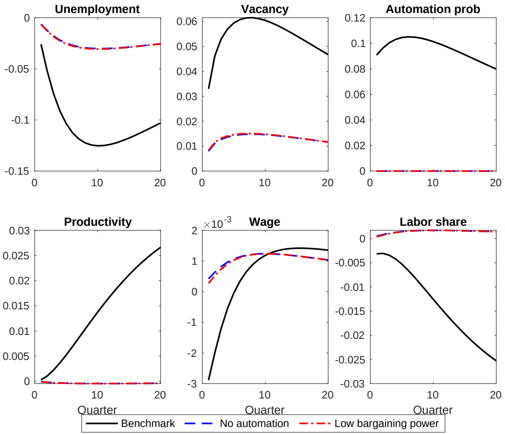
Discount factor shock raises productivity, reduces wages and labor share



Automation shock boosts productivity but depresses wages and labor share

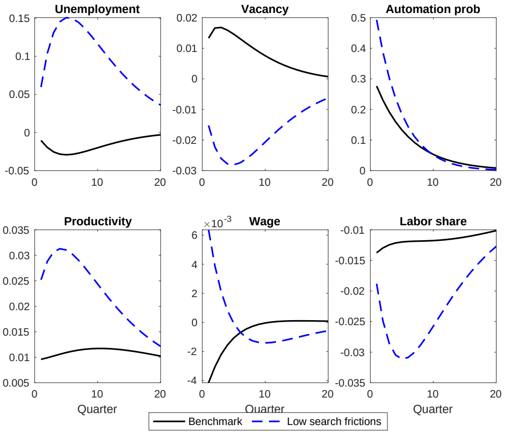


Automation threat more powerful amplification than reducing worker bargaining power (θ shock)



- Automation mechanism important for countercyclical labor share

Model mechanism depends on both automation and labor search frictions (ζ shock)



- Job displacing dominates job creation with low search frictions

Automation and labor search frictions both important for explaining Shimer (2005) volatility puzzle

Model	Labor market tightness	Real wage	Relative volatility
Benchmark/Data	1.16	0.03	39.47
No automation	0.30	0.03	9.56
Low search friction	0.99	0.03	29.48

Model mechanism consistent with micro evidence

- Plant-level evidence: more automated manufacturing establishments have higher labor productivity, smaller fraction of high-wage workers, and smaller labor share (Dinlersoz and Wolf, 2018)
- Occupation-level evidence: occupations at higher risks of automation have lower wage growth (Arnoud, 2018)
- International industry-level evidence: robot adoptions boost productivity, with much smaller positive effects on wages (Graetz and Michaels, 2018)
- U.S. industry-level evidence: robot adoptions boost productivity but reduce local employment and wages (Acemoglu and Restrepo, 2020)

Conclusion

- We incorporate automation decisions in a DMP framework, and obtained a few insights
  - Threat of automation raises firms' reservation value in wage bargaining, reducing wages
  - Automation amplifies fluctuations in unemployment and vacancies
  - Automation boosts productivity and depresses wages: a powerful amplification mechanism for labor market fluctuations
- Extensions and open questions:
  - Worker heterogeneity (e.g., skilled vs unskilled): How does automation affect income distribution and welfare? What's optimal policy?
  - Pandemic uncertainty: Could it stimulate automation? How would automation affect labor market recovery? (Leduc-Liu, 2020)