Artificial Intelligence, Automation, and Work.

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Motivation

- Growing concerns about the effects of automation, robots and artificial intelligence (AI) on work.
- This paper: *narrow* artificial intelligence—machines getting better than humans at narrow tasks.
- New automation technologies—narrow AI and robotics—continue an historical trend.
- Use of machines to substitute for human labor in a widening range of tasks and industrial processes.
- Machines: software+hardware.

Our contribution

Model substitution of machines and workers at the task level.

- *Displacement effect:* Automation displaces workers from automated tasks.
- *Productivity effect:* Cost savings trigger expansion of the economy.
- *New tasks:* employment not growing in old jobs that didn't get automated.
- Limits to the adjustment: skill mismatches and excessive automation.

Illustrate via historical examples.

Roadmap

- Task framework.
- The displacement effect.
- The productivity effect.
- New tasks.
- Constraints and inefficiencies.
    1. Mismatch of Technologies and Skills.
    2. Excessive automation.

Thinking in terms of tasks

- Production requires a range of tasks or industrial processes.
- Automation in history: machines and computers used to substitute for human labor in a widening range of tasks:
  1. In agriculture, horse-powered reapers, harvesters, and threshing machines replaced manual labor working with rudimentary tools.
  2. Machine tools, such as lathes and milling machines, replaced labor-intensive production techniques relying on skilled artisans.
  3. Industrial robotics automated remaining labor-intensive processes in some industries: welding, machining, assembly, and packaging.
  4. Software automated routine tasks performed by white-collar workers in clerical and sales jobs.
  5. Narrow AI will continue this trend of using machine learning to automate more complex labor intensive tasks, such as logistics, ...

Thinking in terms of tasks: Industrial robots

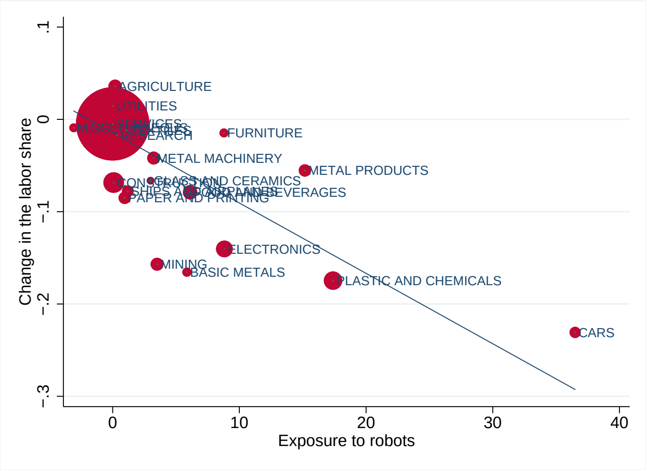

Figure: Use of industrial robots and the decline in the labor share—1990 to 2007.

Thinking in terms of tasks: Industrial robots

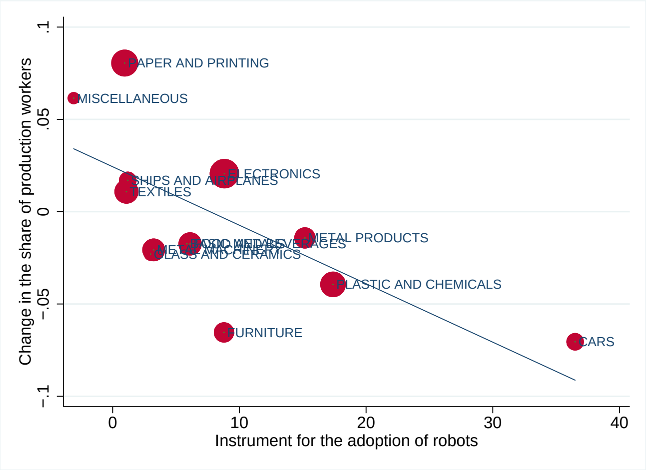

Figure: Use of industrial robots and the decline in the share of production workers—1990 to 2007.

Thinking in terms of tasks: Routine jobs and the first wave of software

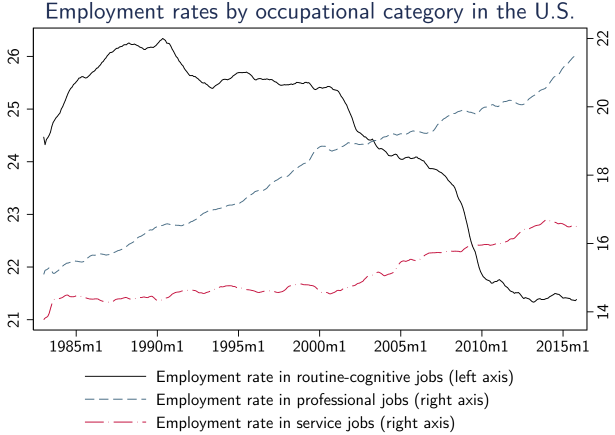

Figure: Decline of routine jobs, defined by clerical and sales occupations.

Thinking in terms of tasks

- Automation and narrow AI: widening of the range of tasks in which machines substitute for labor.
- Automation displaces labor and makes the production process less labor intensive.
- Usual representation of technology

$$F(A_L L, A_K K).$$

- Not clear how the examples we described map to $\{A_L, A_K\}$.
- To understand automation, and technology in general, we need to model the substitution of labor for machines at the task level.
- We present such a framework building on Zeira (1998) and Acemoglu and Autor (2011).

Task Framework: Model

- Aggregate output, Y, is produced by combining the services, $y(x)$, of a unit measure of tasks $x \in [N-1, N]$:

$$\ln Y = \int_{N-1}^{N} \ln y(x) dx, \tag{1}$$

- Tasks produced by human labor, $\ell(x)$, or by machines, $m(x)$. Tasks above I are not automated and must be produced by labor:

$$y(x) = \begin{cases} \gamma_L(x)\ell(x) + \gamma_M(x)m(x) & \text{if } x \in [0, I] \\ \gamma_L(x)\ell(x) & \text{if } x \in (I, N]. \end{cases} \tag{2}$$

- $\gamma_L(x)$ =productivity of labor in task x, increasing in x.
- $\gamma_M(x)$ =productivity of machines in automated tasks.
- *comparative advantage:* $\gamma_L(x)/\gamma_M(x)$ is increasing in x.
- L workers and K units of capital (machines) supplied inelastically.

Task Framework: Aggregate Output

- Expositional assumption:

$$\frac{\gamma_L(N)}{\gamma_M(N-1)} > \frac{W}{R} > \frac{\gamma_L(I)}{\gamma_M(I)}. \tag{A1}$$

  Tasks below I produced with machines. New tasks raise output.

- Aggregate output takes the form

$$Y = BK^{I-N+1}L^{N-I}$$

- where B is given by:

$$B = (I-N+1)^{N-I-1}(N-I)^{I-N}\exp\left(\int_{N-1}^{I}\ln\gamma_M(x)dx + \int_{I}^{N}\ln\gamma_L(x)dx\right).$$

Task Framework: The Demand for Labor

- The demand for labor is given by:

$$W = (N - I)\frac{Y}{L}. \tag{3}$$

- The share of labor in national income is given by

$$s_L = \frac{WL}{Y} = N - I. \tag{4}$$

The Displacement Effect

- From equation (3) we directly obtain

$$\frac{d\ln W}{dI} = \underbrace{\frac{d\ln(N-I)}{dI}}_{\substack{\text{Displacement} \\ \text{effect} < 0}} + \underbrace{\frac{d\ln(Y/L)}{dI}}_{\substack{\text{Productivity} \\ \text{effect} > 0}} . \tag{5}$$

- Wages can decline, despite rising output per worker.
- Decoupling of wage growth from increases in output per worker.
- Moreover, the labor share declines:

$$\frac{ds_L}{dI} = -1 < 0, \tag{6}$$

- Logic behind displacement effect: labor runs against marginal diminishing returns in the $N - I$ non-automated tasks.

The Productivity Effect

- By reducing the cost of producing a subset of tasks, automation raises the demand for labor in non-automated tasks:

$$\frac{d\ln(Y/L)}{dI} = \ln\left(\frac{W}{\gamma_L(I)}\right) - \ln\left(\frac{R}{\gamma_M(I)}\right) > 0,$$

and the overall impact on labor demand can be written as

$$\frac{d\ln W}{dI} = \underbrace{-\frac{1}{N-I}}_{\substack{\text{Displacement}\\ \text{effect} < 0}} + \underbrace{\ln\left(\frac{W}{\gamma_L(I)}\right) - \ln\left(\frac{R}{\gamma_M(I)}\right)}_{\substack{\text{Productivity}\\ \text{effect} > 0}}.$$

Countervailing Forces: The Productivity Effect

- Two manifestations of the productivity effect.

1. Increases the demand for labor in non-automated tasks in the industries or occupations where automation is ongoing.
   - ATMs raised demand for tellers (Bensen, 2016).
   - Automation in weaving increased the price of yarn and the demand for the complementary task of spinning (Mantoux, 1928).
   - Requires elastic demand for output .
2. Raising the demand for labor in complementary industries.
   - By reducing food prices, mechanization of agriculture enriched consumers who then demanded more non-agricultural goods (Herrendorf, Rogerson and Valentinyi, 2013).
   - Benefits dispersed.

Deepening of automation

$$\frac{d \ln W}{dI} = -\frac{1}{N-I} + \ln\left(\frac{W}{\gamma_L(I)}\right) - \ln\left(\frac{R}{\gamma_M(I)}\right).$$

- $\gamma_M(I)/R \approx \gamma_L(I)/W$: wages fall when new technologies are *so-so*.
- $\gamma_M(I)/R >> \gamma_L(I)/W$: wages increase when new technologies are way better than human labor.
- Deepening of automation:
  1. Initial deployment of so-so technologies do not bring large productivity gains but reduce wages.
  2. Subsequent improvements to machines (increases in $\gamma_K(I)$) enhance the productivity effect and raise wages.
  3. No displacement effect: new machines replace old ones, not workers.
- Example: move from numerical control to computer numerical control machines benefit operators and manufacturing workers (Groover, 1983).

Production of more smart machines

$$\frac{d \ln W}{dI} = -\frac{1}{N - I} + \ln\left(\frac{W}{\gamma_L(I)}\right) - \ln\left(\frac{R}{\gamma_M(I)}\right).$$

- Short run: fixed supply of machines constraints the productivity effect (R increases with automation).
- Long run: supply of machines used in newly automated tasks expands, bolstering the productivity effect.
- If machines reproducible at a fixed marginal cost, wages increase:

$$s_L d \ln W + s_K d \ln R = \frac{d \ln(Y/L)}{dI}.$$

- In practice, providers of automation services or owners of other factors of production may get rents, sustaining $d \ln W < 0$.
- Example: rapid capital accumulation during the Industrial Revolution and the mechanization of agriculture in the U.S. (Allen, 2009; Olmstead and Rhode, 2001).

New tasks and the demand for labor

Figure: Employment growth from 1980 to 2010 in occupations in which new job titles are being introduced (Acemoglu and Restrepo, 2016).

- Employment growth not driven by occupations that have always existed but did not get automated.
- The creation of new labor-intensive tasks may be the most powerful force balancing the growth process in the face of rapid automation.

New tasks and the demand for labor

- An increase in N—the creation of new tasks—raises productivity by

$$\frac{d \ln Y/L}{dN} = \ln\left(\frac{R}{\gamma_M(N-1)}\right) - \ln\left(\frac{W}{\gamma_L(N)}\right) > 0,$$

  which is positive from Assumption A1.

- New tasks also increase labor demand and equilibrium wages by creating a *reinstatement effect*:

$$\frac{d \ln W}{dN} = \underbrace{\ln\left(\frac{R}{\gamma_M(N-1)}\right) - \ln\left(\frac{W}{\gamma_L(N)}\right)}_{\substack{\text{Productivity} \\ \text{effect} > 0}} + \underbrace{\frac{1}{N-I}}_{\substack{\text{Reinstatement} \\ \text{effect} > 0}}.$$

- Logic behind reinstatement effect: new tasks are useful in avoiding marginal diminishing returns in non-automated tasks.

New tasks and the demand for labor

- Putting together the impact of automation and new tasks on wages yields

$$d \ln W = \frac{d \ln Y/L}{dN} dN + \frac{d \ln Y/L}{dI} dI + \frac{1}{N-I}(dN - dI),$$

and also for the labor share, we get

$$ds_L = dN - dI.$$

- The future of employment depends on the evolution of $N - I$, which is in turn determine by the direction of technical change.
- Some reasons why new tasks, N, will keep up with automation, but we may also be heading to a new equilibrium with a lower $N - I$.

Mismatch of technology and skills

- Potential mismatch between the requirements of new tasks and the skills of the workforce.
- Two types of workers: low-skill with supply L and high-skill with supply H.
- Low-skill workers can only perform tasks below a threshold $S \in (I, N)$, while high-skill workers can perform all tasks.
- The productivity of both low-skill and high-skill workers in the tasks that they can perform is still given by $\gamma_L(x)$.
- Assume that $\frac{N-S}{S-I} > \frac{H}{L}$, so that high-skill workers are scarce.
- The threshold S is an inverse measure of the mismatch between new technologies and skills.

Mismatch of Technology and Skills

- In equilibrium, $W_H > W_L$.
- Low-skill workers produce the tasks in (I, S); high-skill workers produce the tasks in $[S, N]$.
- Equilibrium wages satisfy

$$W_H = \frac{Y}{H}(N - S) \qquad \text{and} \qquad W_L = \frac{Y}{L}(S - I).$$

- The impact of automation on inequality is given by

$$\frac{d \ln W_H / W_L}{dI} = \frac{1}{S - I} > 0.$$

- When $S \to I$, the mismatch worsens and automation has a larger impact on inequality.

Mismatch of Technology and Skills

- The mismatch also dampens the productivity gains from both automation and the creation of new tasks.
- In particular, we have

$$\frac{d\ln(Y/L)}{dI} = \ln\left(\frac{W_L}{\gamma_L(I)}\right) - \ln\left(\frac{R}{\gamma_M(I)}\right) > 0,$$

  which shows that the productivity gains from automation are lower when there is a worst mismatch (W_L/R is *lower* in that case).
- Likewise,

$$\frac{d\ln(Y/L)}{dN} = \ln\left(\frac{R}{\gamma_M(N-I)}\right) - \ln\left(\frac{W_H}{\gamma_H(N)}\right) > 0,$$

  which shows that the productivity gains from new tasks are lower when there is a worst mismatch (W_H/R is *higher* in that case).

Excessive automation

- Suppose that machines used in automation are produced—as intermediate goods—using the final good at a fixed cost R.
- Two reasons for excessive automation:
  1. Subsidies to capital τ (accelerated depreciation allowances, tax credits, or implicit subsidy from taxes on employing workers).
  2. Labor market imperfections: efficiency wages.

Excessive automation due to subsidies to capital

- Computing GDP as value added yields

$$GDP = Y - RK.$$

- An increase in automation has the following effect on GDP

$$\begin{aligned}\frac{dGDP}{dI} &= \ln\left(\frac{W}{\gamma_L(I)}\right) - \ln\left(\frac{R(1-\tau)}{\gamma_M(I)}\right) + R(1-\tau)\frac{dK}{dI} - R\frac{dK}{dI} \\ &= \underbrace{\ln\left(\frac{W}{\gamma_L(I)}\right) - \ln\left(\frac{R(1-\tau)}{\gamma_M(I)}\right)}_{\substack{\text{Productivity} \\ \text{effect} > 0}} - \underbrace{R\tau\frac{dK}{dI}}_{\substack{\text{Excessive} \\ \text{automation} < 0}}.\end{aligned}$$

- The first term is positive and captures the productivity increase generated by automation.
- When $\tau > 0$ we have an additional negative effect: excessive use of resources to produce machines.

Excessive automation due to labor market frictions

- A threshold $J \in (I, N)$ such that workers earn rents $\omega > 0$ proportional to their wage in tasks $[I, J]$.
- Workers are paid a wage W to produce tasks in $[J, N]$, and a wage $W(1+\omega)$ to produce tasks in (I, J).
- Let L_A denote the total amount of labor allocated to the tasks in (I, J). Because workers in (I, J) get displaced, L_A is decreasing in I.
- The impact of automation on GDP is now given by

$$\frac{dGDP}{dI} = \underbrace{\ln\left(\frac{W(1+\omega)}{\gamma_L(I)}\right) - \ln\left(\frac{R(1-\tau)}{\gamma_M(I)}\right)}_{\substack{\text{Productivity} \\ \text{effect} > 0}} - \underbrace{R\tau\frac{dK}{dI}}_{\substack{\text{Excess} \\ \text{autom} < 0}} + \underbrace{W\omega\frac{dL_A}{dI}}_{\substack{\text{Excess displ.} \\ \text{of labor} < 0}}.$$

- The new term $W\omega\frac{dL_A}{dI}$ captures the first-order losses from a decline in employment in tasks (I, J).