Artificial Intelligence, Automation and Work

Daron Acemoglu and Pascual Restrepo

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Reporters

Sun Jialing, Zhang Hongbing, XU Rui,

Xue Fenyun, Xue Wensi

Author-Daron Acemoglu

Academic Position

Elizabeth and James Killian , Professor Department of Economics , Massachusetts Institute of Technology

Education

London School of Economics	Ph.D.	1992
London School of Economics	MSc.	1990
University of York	B.A.	1989

Fields

Political Economy, Economic Development, Economic Growth, Economic Theory, Technology, Income and Wage Inequality, Human Capital and Training, Labor Economics, Network Economics.

Publications

- - (With Tarek A. Hassan and Ahmed Tahoun) The Power of the Street: Evidence from Egypt's Arab Spring, forthcoming *Review of Financial Studies*
- - (With Suresh Naidu, Pascual Restrepo and James A. Robinson) Democracy Does Cause Growth, forthcoming *Journal of Political Economy*
- - (With Pascual Restrepo)The Race Between Machine and Man: Implications of Technology for Growth, Factor Shares and Employment, forthcoming *Social Science Electronic Publishing*

Author- Pascual Restrepo

Academic Position
Professor , Department of Economics , Boston University

Education

B.A. in Economics and Mathematics , 2010

Ph.D. In Economics , MIT , 2016

Fields

Primary Fields: Macroeconomics and Labor

Secondary Fields: Political Economy

Publications

- “Crime and Conspicuous Consumption,” Joint with Daniel Mejia, Journal of Public Economics, 2015.
- “The Economics of the War on Illegal Drug Production and Trafficking,” with Daniel Mejia. Journal of Economic Behavior and Organizations, 2015.
- “On the Effects of Enforcement on Illegal Markets: Evidence from a Quasi Experiment in Colombia,” Joint with Daniel Mejia and Sandra Rozo, World Bank Economic Review, 2015.

Introduction

Research Question

- The implications of automation and AI on the demand for labor, wages, and employment.

Motivation

- Much of the debate in both the popular press and academic circles centers around a false dichotomy.

Overview

- Tasks, Technologies and Displacement
- Countervailing Effects
  - The productivity effect
  - Capital accumulation
  - Deepening of automation
- New Tasks

- Mismatch between Skills and Technologies
- Missing Productivity and Excessive Automation

A Model of Automation, Tasks, and the Demand for Labor

- A Task-Based Framework
- Types of Technological Change
- Equilibrium

A Task-Based Framework

$$Y = \left(\int_{N-1}^{N} y(i)^{\frac{\sigma-1}{\sigma}} di\right)^{\frac{\sigma}{\sigma-1}}.$$

$\sigma \in (0, +\infty)$: Elasticity of substitution

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

Y is aggregate output

$y(x)$ is output of task x

A Task-Based Framework

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

$\ell(\mathrm{x})$:labor

$\mathrm{m(x)}$:machines

x:tasks

$\gamma_L(x)$: the productivity of labor in task x， and is assumed to be increasing

$\gamma_M(x)$: the productivity of machines in automated tasks

I: denotes the frontier of automation possibilities

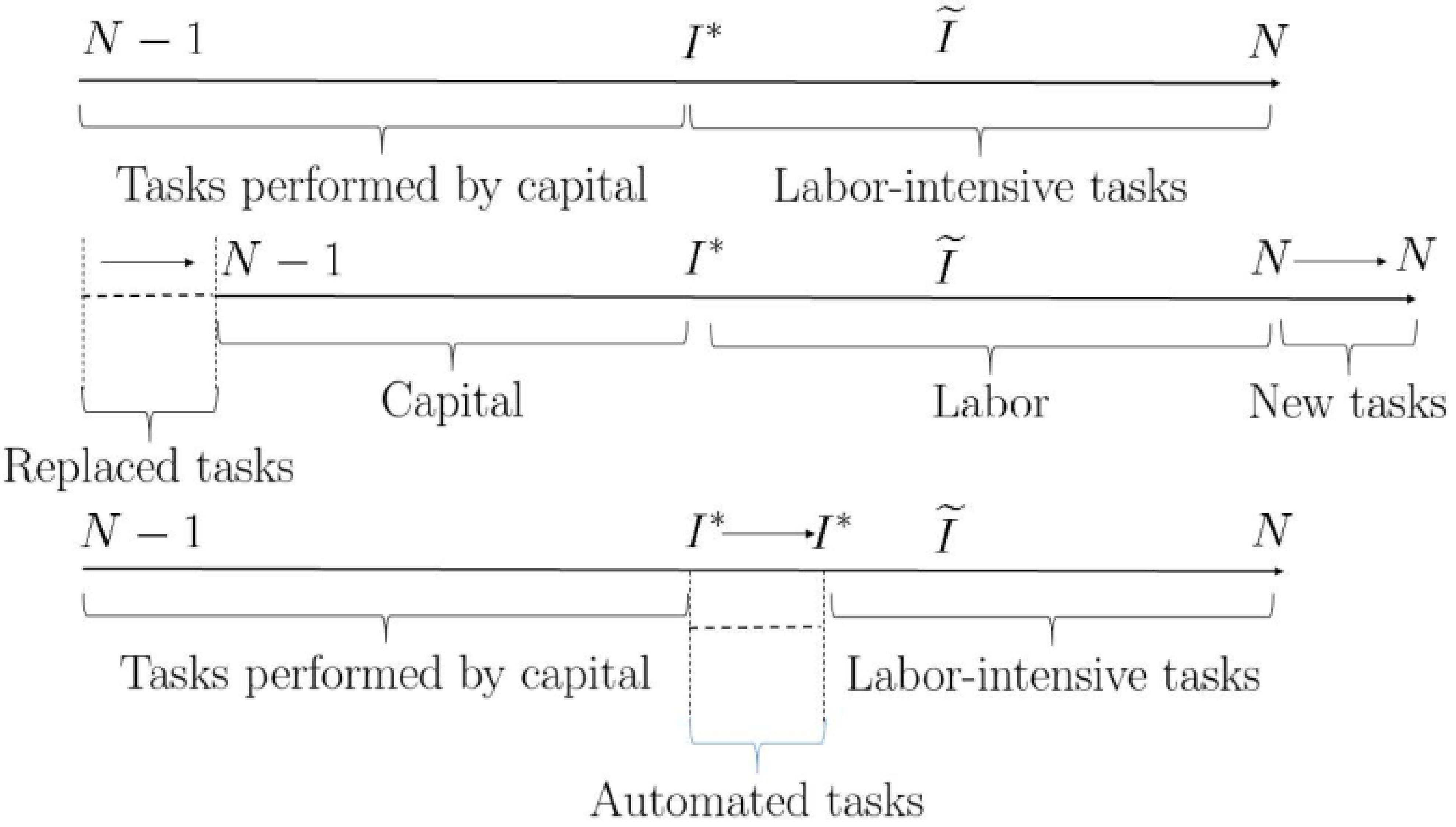
Assumption:

1. $\gamma_L(x)/\gamma_M(x)$ is increasing in x
2. both the supply of labor, L, and the supply of machines, K, are fixed and inelastic

Types of Technological Change

1. Labor-augmenting technological advances
   increases in the function $\gamma_L(x)$
2. Automation (at the extensive margin)
   increase in I
3. Deepening of automation (or automation at the intensive margin)
   increase in the $\gamma_{\mathrm{M}}(x)$ function for tasks $x < I$
4. Creation of new tasks
   increase in N

Types of Technological Change



Equilibrium

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

Two meanings:
- The first inequality implies that the introduction of new tasks—an increase in N — will increase aggregate output.
- The second inequality implies that all tasks in $[N-1, I]$ will be produced by machines.

Equilibrium Derivation

- Denote by $p(x)$ the price of task x. Assumption implies

$$p(x) = \begin{cases} \frac{R}{\gamma_M(x)} & \text{if } x \in [0, I] \\ \frac{W}{\gamma_L(x)} & \text{if } x \in (I, N]. \end{cases}$$

- In addition, the demand for task x is given by

$$y(x) = \frac{Y}{p(x)}.$$

Equilibrium Derivation

Thus, the demand for smart machines in task x is

$$k(x) = \begin{cases} \frac{Y}{R} & \text{if } x \in [0, I] \\ 0 & \text{if } x \in (I, N] \end{cases},$$

the demand for labor in task x is

$$\ell(x) = \begin{cases} 0 & \text{if } x \in [0, I] \\ \frac{Y}{W} & \text{if } x \in (I, N] \end{cases}.$$

Equilibrium Derivation

- The market-clearing conditions for capital and labor are

$$K = \frac{Y}{R}(I - N + 1). \qquad L = \frac{Y}{W}(N - I).$$

- The equilibrium rental rate and wage can be obtained as

$$R = \frac{Y}{K}(I - N + 1) \qquad W = \frac{Y}{L}(N - I),$$

- Normalize the price of the final good to 1 as numeraire, we have

$$\int_{N-1}^{N} \ln p(x)dx = 0.$$

Equilibrium Derivation

$$\int_{N-1}^{I} [\ln R - \ln \gamma_M(x)]dx + \int_{I}^{N} [\ln W - \ln \gamma_L(x)]dx = 0$$

$$\int_{N-1}^{I} [\ln Y - \ln(K/(I-N+1)) - \ln \gamma_M(x)]dx + \int_{I}^{N} [\ln Y - \ln(L/(N-I)) - \ln \gamma_L(x)]dx = 0.$$

$$\begin{aligned}
\ln Y &= \int_{N-1}^{I} \left[\ln\left(\frac{K}{I-N+1}\right) + \ln \gamma_M(x)\right] dx + \int_{I}^{N} \left[\ln\left(\frac{L}{N-1}\right) + \ln \gamma_L(x)\right] dx \\
&= \int_{N-1}^{I} \ln \gamma_M(x)dx + \int_{I}^{N} \ln \gamma_L(x)dx \\
&\quad + (I-N+1)\ln\left(\frac{K}{I-N+1}\right) + (N-I)\ln\left(\frac{L}{N-I}\right),
\end{aligned}$$

Equilibrium Derivation

- The equilibrium is

$$Y = B\left(\frac{K}{I-N+1}\right)^{I-N+1}\left(\frac{L}{N-I}\right)^{N-I},$$

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

- The demand for labor can be expressed as

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

- the share of labor in national income is given by

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

Technology and Labor Demand

Displacement Effect

Counteracting the Displacement Effect

- The Productivity Effects
- Capital Accumulation
- Deepening of Automation

New Tasks and the Comparative Advantage of Labor

Technology and Labor Demand

4.1 The Displacement Effect

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

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

Technology and Labor Demand

4.2 Counteracting the Displacement Effect I: The Productivity Effects

$$Y = B\left(\frac{K}{I-N+1}\right)^{I-N+1}\left(\frac{L}{N-I}\right)^{N-I},$$

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

$$\Rightarrow \quad ln\frac{Y}{L} = \int_{N-1}^{I} \ln\gamma_M(x)dx + \int_{I}^{N} ln\gamma_L(x)dx - lnL + (I-N+1)ln\frac{K}{I-N+1}$$

Technology and Labor Demand

4.2 Counteracting the Displacement Effect I: The Productivity Effects

$$R = \frac{Y}{K}(I - N + 1)$$

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

$$\Rightarrow \quad \begin{aligned} \frac{dln(Y/L)}{dI} &= ln\gamma_M\ (I) - ln\gamma_L(I) + ln\frac{K}{I-N+1} - ln\frac{L}{N-L} \\ &= ln\gamma_M\ (I) - ln\gamma_L(I) + ln\frac{Y}{R} - ln\frac{Y}{W} \\ &= ln\frac{W}{\gamma_L(I)} - ln\frac{R}{\gamma_M(I)} \end{aligned}$$

Technology and Labor Demand

4.2 Counteracting the Displacement Effect I: The Productivity Effects

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

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

Technology and Labor Demand

4.2 Counteracting the Displacement Effect I: The Productivity Effects

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

$$\Rightarrow \qquad \frac{ds_L}{dI} = -1 < 0$$

Technology and Labor Demand

4.2 Counteracting the Displacement Effect II: Capital Accumulation

An increase in the capital stock, with the level of employment held constant at L, increases the real wage and reduces the rental rate.

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

This equation shows that this change in factor prices makes the productivity effect more powerful and the impact on the wage more likely to be positive.

4.3 Counteracting the Displacement Effect III: Deepening of Automation

The increase in the productivity of machines in tasks that are already automated corresponds in our model to an increase in the function $\gamma_M(x)$ in tasks below I.

Suppose that $\gamma_M(x) = \gamma_M$ in all automated task, and consider an increase in the productivity of machines by $dln\gamma_M > 0$, with no change in the extensive margin of automation, I.

Technology and Labor Demand

4.3 Counteracting the Displacement Effect III: Deepening of Automation

$$
\begin{aligned}
ln\frac{Y}{L} &= \int_{N-1}^{I} \mathrm{ln}\gamma_M(x)dx + \int_{I}^{N} ln\gamma_L(x)dx - lnL + (I-N+1)ln\frac{K}{I-N+1} \\
&= \int_{N-1}^{I} \mathrm{ln}\gamma_M dx + \int_{I}^{N} ln\gamma_L(x)dx - lnL + (I-N+1)ln\frac{K}{I-N+1} \\
&= (I-N+1)\gamma_M + \int_{I}^{N} ln\gamma_L(x)dx - lnL + (I-N+1)ln\frac{K}{I-N+1}
\end{aligned}
$$

$$\Rightarrow\ dlnW = dln(N-I) + dln(Y/L) = dln(Y/L) = (I-N+1)\mathrm{dln}\gamma_M > 0$$

Technology and Labor Demand

4.4 New Tasks and the Comparative Advantage of Labor

$$ln\frac{Y}{L} = \int_{N-1}^{I} \ln\gamma_M(x)dx + \int_{I}^{N} ln\gamma_L(x)dx - lnL + (I - N + 1)ln\frac{K}{I - N + 1}$$

$$\Rightarrow \quad \frac{dln(Y/L)}{dN} = -ln\gamma_M\ (N - I) + ln\gamma_L(N) - ln\frac{K}{I - N + 1} + ln\frac{L}{N - L}$$

$$= -ln\gamma_M\ (N - I) + ln\gamma_L(N) - ln\frac{Y}{R} + ln\frac{Y}{W}$$

$$= ln\frac{R}{\gamma_M(N - I)} - ln\frac{W}{\gamma_L(N)} > 0$$

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

Technology and Labor Demand

4.4 New Tasks and the Comparative Advantage of Labor

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

$$\Rightarrow \qquad \frac{ds_L}{dN} = 1$$

Technology and Labor Demand

4.4 New Tasks and the Comparative Advantage of Labor

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

$$ds_L = dN - dI.$$

$If\ dN = dI,$

$$d \ln W = \left[\ln\left(\frac{\gamma_L(N)}{\gamma_M(N-1)} \right) - \ln\left(\frac{\gamma_L(I)}{\gamma_M(I)} \right) \right] dI > 0$$

Constraints and Inefficiencies

Displacement Effect: Reduces the labor demand

Countervailing Forces: Limits the displacement effect

Constraints and inefficiencies:

Limits the labor market’s adjustment& productivity effect

Constraints and Inefficiencies

Mismatch of Technologies and Skills

Automation at the Expense of New Tasks

Excessive Automation

Mismatch of Technologies and Inefficiencies

Previous Version: New tasks counter-balances the negative effects of automation on labor share. While ignoring the potential mismatch between new tasks and the skills of workers.

What is mismatch?

Automation creates new tasks.

New tasks require skills of a higher level. => Worker's skills can't match New tasks

Many workers don't have the required skills.

Punishments of ignoring it

increases inequality && limits adjustment of labor market && hinders productivity effect

High School Movement:

America 1910-1940

Provides support to the accumulation of human capital of workers laid off from agriculture department

Mismatch of Technologies and Inefficiencies

Assumptions:

i. Two types of workers: high-skill && low-skill

ii. Supply of workers: H && L , both elastic

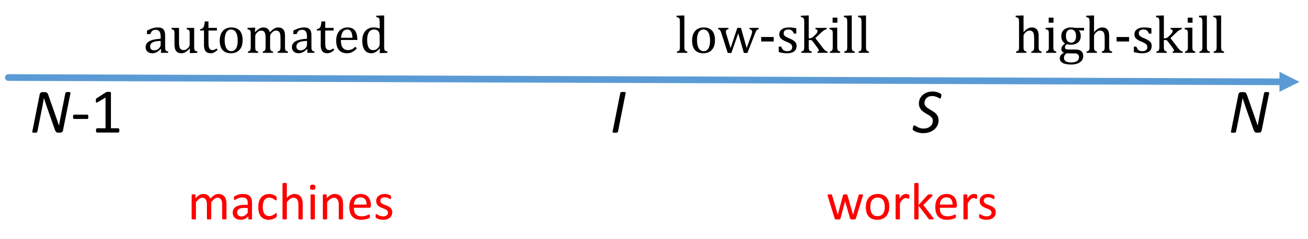
iii. Denote S: I < S < N; low-skill: I ~ S; high-skill: I ~ N

iv. Share the same productivity γ(x)

v. Wage rate at equilibrium: $W_H > W_L$

$$\frac{N-S}{S-I} > \frac{H}{L}$$: high-skill workers are scarce

* S: inverse measure of the mismatch between now technologies & skills



Mismatch of Technologies and Inefficiencies

p(x): price of task x $(W_H < W_L)$

$$p(x) = \begin{cases} \frac{R}{\gamma_M(x)} & \text{if } x \in [0, I] \\ \frac{W_L}{\gamma_L(x)} & \text{if } x \in (I, S) \\ \frac{W_H}{\gamma_L(x)} & \text{if } x \in [S, N] \end{cases}$$

Demand for high-skill labor h(x) & low-skill labor l(x) of task x:

$$h(x) = \begin{cases} 0 & \text{if } x \in [0, I] \\ 0 & \text{if } x \in (I, S) \\ \frac{Y}{W_H} & \text{if } x \in [S, N]. \end{cases} \qquad \ell(x) = \begin{cases} 0 & \text{if } x \in [0, I] \\ \frac{Y}{W_L} & \text{if } x \in (I, S) \\ 0 & \text{if } x \in [S, N]. \end{cases}$$

With market-clearing: $L = \frac{Y}{W_L}(S - I)$ $\quad H = \frac{Y}{W_H}(N - S)$ $\quad K = \frac{Y}{R}(I - N + 1)$

Finally: $W_H = \frac{Y}{H}(N - S)$ $\quad W_L = \frac{Y}{L}(S - I)$

Mismatch of Technologies and Inefficiencies

Inequality brought by automation

$$\frac{d \ln WH/WL}{dI} = \frac{1}{S-I} > 0$$

* the difference between the two wages increase with an increasing I

=> Automation makes the society more unequal

The degree of inequality with a mismatch

with S closer to I, (S-I) will decrease while the inequality effect increases

thus with S -> I, inequality arise

=> when S is close to I, the low-skill workers laid off will have a narrow choice between S~I, the increase of labor supply reduces the wage sharply, making the workers uncomfortable

Mismatch of Technologies and Inefficiencies

Influence of *Automation* on Productivity Effect with a mismatch

Productivity Effect:

$$\frac{dln(Y/L)}{dI} = ln\left(\frac{W_L}{y_L(I)}\right) - ln\left(\frac{R}{y_M(I)}\right) > 0$$

the effect depends on W_L / R:

$$\frac{W_L}{R} = \frac{S-I}{I-N+1}\frac{K}{L}$$

S -> I => W_L -> R => productivity effect decrease

$\Rightarrow$ With a severe mismatch, productivity effect will be *limited* and the benefit will be reduced

$\Rightarrow$ Mismatch hinders the *reallocation* of labor, thus the labor released from automated tasks cannot be used completely

Mismatch of Technologies and Inefficiencies

Influence of *New Tasks* on Productivity Effect with a mismatch

Productivity Effect:

$$\frac{dln(Y/L)}{dN} = ln\left(\frac{R}{y_M(N-1)}\right) - ln\left(\frac{W_H}{y_H(N)}\right) > 0$$

the effect depends on R / W_H :

$$\frac{R}{W_H} = \frac{I-N+1}{N-S}\frac{L}{K}$$

S -> I => (N-S) increases => R is closer to W_H => productivity effect decreases

⇒ With a severe mismatch, productivity effect will be *limited* and the benefit will be reduced

⇒ Mismatch makes the new tasks need more scarce and expensive high-skill labor

Mismatch of Technologies and Inefficiencies

Mismatch:

I. Mismatch arises when the workers 'skill cannot catch up with the technology required by tasks.

II. Mismatch is bad. It will make society more unequal and reduce the productivity gains since it hinders the reallocation of labor market.

III. Thus, society needs to simultaneously increase the supply of skills to make sure that high-skill workers grow in tandem with technology trends.

Automation at the Expense of New Tasks

A deep puzzle: New Technologies and Missing Productivity

Mismeasurement?
- Pervasive nature of this slow down
- It is even more severe in industries that have made greater investments in information technology!

Three novel reasons
- Mismatch of Technologies and Skills
- A slow down in the creation of new tasks and investments in other technologies
- Socially excessive automation

Automation at the Expense of New Tasks

Redirection from the creation of new tasks to automation

Exogenous

- We may be running out of good ideas to create new jobs, sectors, and products capable of expanding the demand for labor.

Endogenous

- The rapid introduction of new automation technologies may redirect resources that were devoted to other technological advances.

Automation at the Expense of New Tasks

New Tasks

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

Automation

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

Which one is larger?

Excessive Automation

Distortion

- Fiscal bias
- Labor market imperfections and frictions

Machines used in automation are produced using the final good at fixed cost R

Capital receives a marginal subsidy of $\tau > 0$.

Excessive Automation

Rental rate $R(1-\tau)$

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

$$GDP = Y - RK$$

$$\frac{dGDP}{dI} = \left.\frac{dY}{dI}\right|_K + R(1-\tau)\frac{dK}{dI} - R\frac{dK}{dI}$$

Excessive Automation

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

Subsidies induce firms to ***substitute capital for labor*** *even when this is not socially cost-saving.*

Excessive Automation

When there are also labor market frictions:

A threshold $J \in (I, N)$

Wage of tasks in $[I, J]$: $W(1 + \omega \ )$

Wage of tasks in $[J, N]$: W

Assumption A1 now becomes:

$$\frac{\gamma_L(N)}{\gamma_M(N-1)} > \frac{W}{R(1-\tau)} > \frac{1}{1+\omega} \frac{\gamma_L(I)}{\gamma_M(I)}$$

Excessive Automation

$$p(x) = \begin{cases} \frac{R(1-\tau)}{\gamma_M(x)} & \text{if } x \in [0, I] \\ \frac{W(1+\omega\ )}{\gamma_L(x)} & \text{if } x \in (I, J) \\ \frac{W}{\gamma_L(x)} & \text{if } x \in [J, N]. \end{cases}$$

$$K = \frac{Y}{R(1-\tau)}(I - N + 1)$$

Excessive Automation

$$\ell(x) = \begin{cases} 0 & \text{if } x \in [0, I] \\ \frac{Y}{W(1+\omega)} & \text{if } x \in (I, J) \\ \frac{Y}{W} & \text{if } x \in [J, N] \end{cases}$$

Labor with rents: $$L_A = \frac{Y}{W(1+\omega)}(J - I)$$

Labor without rents: $$L - L_A = \frac{Y}{W}(N - J)$$

The total number of workers earning rents declines with automation.

Excessive Automation

$$\int_{N-1}^{N} \ln p(x)dx = 0$$

$$Y = B\left(\frac{K}{I - N + 1}\right)^{I-N+1} \left(\frac{L_A}{J - I}\right)^{J-I} \left(\frac{L - L_A}{N - J}\right)^{N-J}$$

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

By automating jobs where workers earn rents, firms are effectively displacing workers to other tasks in which they have a lower marginal product and earn a strictly lower wage, which ***increases the extent of misallocation****.*