

# AI, Worker-Replacing Technological Change and Income Distribution

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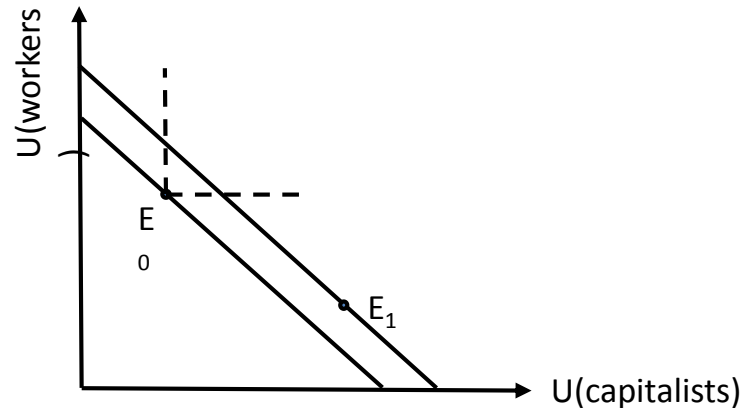
# Big concern

- Growth of labor-replacing robots will lead to even more inequality and unemployment
  - Machines have long been stronger than humans, better able to do many physical jobs
  - Computers are better at processing large amounts of information
  - AI means that robots may even be better at learning
  - Extent to which they can replace or outperform humans in immediate future uncertain—large variance in estimates
  - Alternative perspective: robots (AI) will be labor augmenting, increasing productivities of large proportion of population
  - This paper sets problem in more abstract analysis of consequences of economy wide labor replacing robots

# Technological possibilities and utility

Consider arrival of a new technology that replaces workers.  
Would their standard of living *necessarily* collapse?

1) If (i) the world is 1<sup>st</sup>-best and (ii) redistribution is *costless*, the utility possibilities frontier (UPF) moves out (even if competitive equilibrium wage decreases):

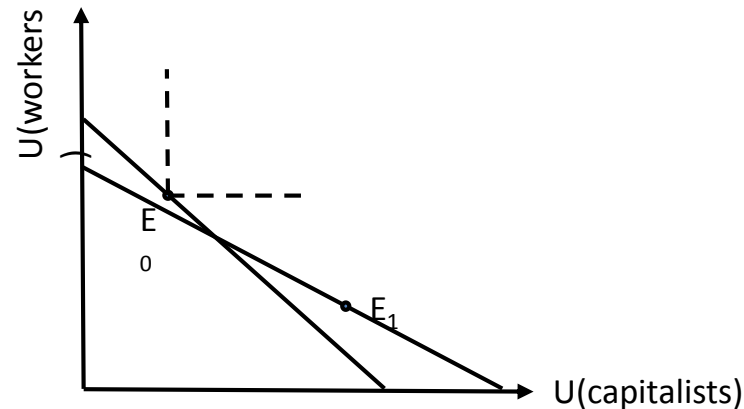


→ Redistribution can ensure that everyone is better off

# Technological possibilities and utility

Consider arrival of a new technology that replaces workers.  
Would their standard of living *necessarily* collapse?

2) If (i) the world is 1<sup>st</sup>-best but (ii) redistribution is *limited*, the *constrained* utility possibilities frontier (UPF) may not lie outside the original schedule:



→ Limiting technological change may be desirable for workers

# Technological possibilities and utility

More generally: the 1<sup>st</sup>-best UPF is the outer envelope of all possible constrained UPFs, which reflect all possible institutional regimes, e.g.:

- explicit redistribution systems
- intellectual property regimes
- market arrangements (e.g. market power)
- social norms (e.g. about charity or social equity)

→ changing any of these institutions may improve workers' welfare

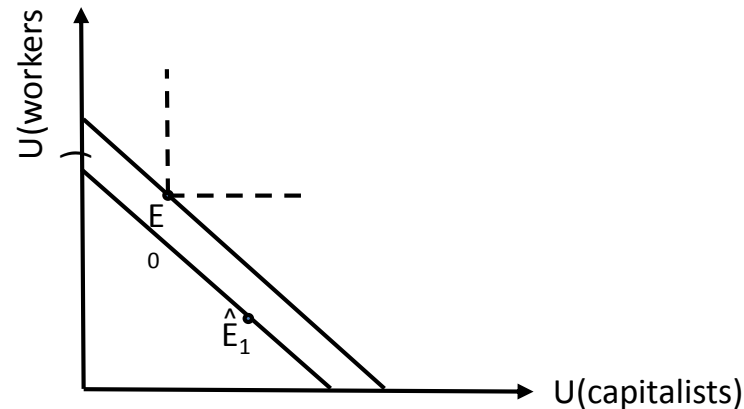
→ If redistributions limited, may have to rely more on other institutional changes

→ Limits on IP limit rents that accrue to innovators; may also limit pace of innovation

# Technological possibilities and utility

Consider arrival of a new technology that replaces workers.  
Would their standard of living *necessarily* collapse?

3) If the world is *not* 1<sup>st</sup>-best, the utility possibilities frontier may move inwards (even with costless distribution):



→ Limiting technological change may be desirable for everyone

# Incentives for Innovation and Welfare

No 1<sup>st</sup> welfare theorem for innovation

4) Privately optimal innovation may shift the utility possibilities frontier inward (even with costless redistribution)

→ Intervening in the innovation process may generate Pareto improvements

(Examples: high-frequency trading; markets focusing on unskilled labor replacing innovation, even when shadow price of labor is low, ignoring importance of carbon innovation)

# Critical question: public policy

- Are there public policies which would ensure that everyone would be better off?
- Political economy: will these policies emerge out of our political processes?

The remainder of this lecture focuses on first question.

Constructs two simple models analyzing:

- (a) What happens when machines replace workers?
- (b) What are l.r. consequences of different policies?



# Worker-Replacing Technological Change

$Q = F(K, H + M)$  ... constant returns to scale

where  $Q$  is output,  $K$  is capital,  $H$  is human labor, and  $M$  is machine labor, which can be produced at cost  $\gamma$

Competitive equilibrium

$$w = F_L$$

Two Questions:

- 1) What does worker-replacing technological change do to wages?
- 2) What can public policy do about it?

# Machine Labor and Factor Earnings

**Proposition 1: Machine Labor and Factor Earnings** (short-run, before other factors adjust): adding a marginal unit of machine labor reduces human wages but increases returns of complementary factors in a zero-sum manner

Euler's Theorem:  $(H + M)F_L(\cdot) + KF_K(\cdot) = F(K, H + M)$

Additional unit of M:  $F_L + (H + M)F_{LL} + KF_{KL} = F_L$

or simplified: 
$$\underbrace{(H + M)F_{LL}}_{\text{decline in wage bill}} + \underbrace{KF_{KL}}_{\text{increase in return to K}} = 0$$

- adding machine labor creates redistribution toward complementary factors  
= *pecuniary externality*
- increased returns for complementary factor owners are like *unearned rents*

# Machine Labor and Factor Earnings

Proposition 1 holds for all factors in the production function, e.g.:

- Labor vs capital
  - Labor vs land
  - Unskilled labor (replaced by machines) vs skilled labor
  - Labor vs Entrepreneurial rents
- policy can undo the redistribution by taxing unearned rents
- taxes on previously accumulated factors are non-distortionary (they automatically identify out-of-equilibrium returns)
- at the margin, Pareto-improvement

# Panglossian world: singularity

Labor is most important factor of production

→ scarcity of labor = biggest constraint on output

→ machine labor makes this factor easily reproducible

**Proposition 2: Machine Labor and Singularity:** if machine labor is sufficiently cheap and all other factors are also reproducible, the economy experiences a singularity, leading to:

- exponential growth driven by factor accumulation (AK-style)
- unchanged level of wages, but human labor share  $\rightarrow 0$

→ outcome benign if workers care about absolute level of labor earnings

# The Return of Scarcity

Although singularity may lead to significant growth, it is likely it will eventually be limited by scarcity of other non-reproducible factors, e.g. land or energy

**Proposition 3: Machine Labor and Return of Scarcity:** if there are non-reproducible factors, they will eventually limit growth

- human wages fall; owners of non-reproducible factors absorb all the rents
- at the margin, redistribution from workers to non-reproducible factor owners is zero sum
- taxes on non-reproducible factors are by definition non-distortionary
- scope for non-distortionary redistribution; at the margin Pareto improvement
- Technological change gives rise to rents which can be taxed, and revenues used to compensate workers

# Intellectual Property Rights and Redistribution

If outright redistribution is infeasible, intervention to steer technological progress may act as a 2<sup>nd</sup>-best device

Example: assume we have a distortionary tax  $\tau$  leading to capital  $K(\tau)$  and machine labor  $M(z)$  is function of patent life  $z$ .

$$Q = F(K(\tau), M(z) + H)$$

Where  $H$  is number of workers

Government maximizes  $W$  w.r.t.  $\tau$  and  $z \geq z^*$ ,  $M(z^*) = 0$ , where  $W$  is social welfare

# Maximizing well-being of workers

Define  $\tau^*(M)$  as value of tax, redistributed to workers, which keeps workers just as well off. Representative worker income  $I$  is given by

$$I = w + \tau^* K(\tau)/H$$

Where  $w = F_L$  : workers' receive marginal product

Machines decrease marginal product (compete with humans).

Hence, as  $M$  increases,  $\tau$  must increase. But increase in  $\tau$  decreases capital stock, and that hurts workers.

**Proposition 4.** So long as the elasticity of capital supply is not too large, we can always increase  $\tau$  and compensate workers

# Reframing the issue

- Assume a growth rate  $g(z, \tau)$ , function of the length of the patent and tax rate, assume  $b(z, \tau)$  fraction of output that can be appropriated by innovator, then p.d.v. of income of workers approximately given by

$$Y^* = (1 - b(1 - \tau))(1 - c(g)) / (1 + g - \delta)$$

If we choose  $\{z, \tau\}$  to maximize  $Y^*$ , in general, the optimum will not be a corner solution in which innovation necessarily hurts workers

We can extend that to include capital, skilled and unskilled workers.

Implication:

**Proposition 5 in general, the optimal  $\{z^*, \tau^*\}$  entails  $g > 0$ .**

**i.e. t.c. *can* improve well-being of workers**, but pace of t.c. that maximizes workers likely to be well below maximal feasible pace, or even pace which maximizes well-being of innovators



# How to help ensure evolution of technology is likely to be welfare increasing

- Economy will be evolving towards service sector economy
- Among key service sectors are education, health, and other public services
- Value of those services is largely socially determined—not “just” a market process
- If we value those services highly—pay good wages, provide good working conditions, and create sufficient number of jobs—that will limit growth in market income inequality
  - Including jobs with limited skill requirements
  - Higher pay will result in such jobs having higher “respect”
  - Private sector wages will follow public sector wages
  - May need also to provide wage subsidy for low wage jobs, to encourage demand for such jobs and increase wages
- If elasticity of entrepreneurial services is low, we can impose high taxes to finance these jobs

- Under these conditions, benefits of growth can be shared equitably, and in ways that ensure full employment
  - Larger pie—so everyone can be better off
- Such an outcome is economically feasible
- But economy may not go in that direction
  - Politics matters
  - And even the conditions for economic feasibility are restrictive

# Endogenous factor bias

- If endogenously determined bias of technological change works as it should, as wages get low, focus is on capital and resource augmenting technical change
  - Limiting decline in share of labor (in stable equilibrium) and in inequality
  - (Can describe dynamics with standard wage-setting mechanism: system stable so long as elasticity of substitution is less than unity)

# Disequilibrium

- **Transition may not be easy**
- Markets on their own are not good at structural transformation
- Great Depression can be viewed as being caused by rapid pace of innovation in agriculture
  - Fewer workers needed
  - Resulting in marked decline in agriculture income
  - Leading to decline in demand for urban products
  - Latter effect was so large that long standing migration patterns were reversed
  - What *might* have been a Pareto improvement turned out to be immiserizing technological change, as both those in the urban and rural sector suffered
- General result: (a) **with mobility frictions and rigidities technological change can be welfare decreasing**

# Government intervention in transition enabled the successful structural transformation

- By-product of World War II
- It was not only a Keynesian stimulus
- But facilitated move from rural to urban and the retraining of the labor force
  - A successful industrial policy

# Disequilibrium impacts on inequality

- Technological change has large distributive effects
- Destruction of value of physical and human capital
- Only if the individual could obtain perfect insurance at the time of birth (or before the conception of the innovation) would information about the advent of the job replacing innovation, and the advent itself, not be welfare reducing.
- But someone born as an unskilled worker today, even under these conditions where he could buy insurance, will be worse off than he would have been had there not been such a possibility—unless the government engages in ex ante lump sum redistributions to compensate the individuals for the decrease in ex ante expected utility.

# Clear parallels to situation today

Economy could be caught in a low level equilibrium trap

**Government can play an important role in increasing welfare, in some cases, a Pareto improvement, in others reducing inequality, improving the plight of workers**

Policies to facilitate transition and ensure a welfare enhancing long run equilibrium include:

- Policies to increase wages of even low skilled jobs
  - High aggregate demand—to ensure low unemployment rate
  - Wage subsidy
  - Minimum wage—also would (together with other measures) help encourage innovations that increase productivity of labor at the bottom
  - High wages in public sector—to help drive up wages in economy more generally
    - Other policies to encourage attractiveness of such jobs and increase respect for them
- Vastly expanded Earned income tax credit—to ensure that no one who works full time is in poverty
  - Does it make a difference whether *individuals* or *jobs* are subsidized?
- High carbon tax—to encourage resource saving innovation, at the expense of labor saving innovation
  - Would simultaneously address two of most serious global problems

# Further policies

- Elimination of tax deduction for interest and the imposition of a tax on capital—to induce more capital augmenting innovation
- “Wage share” tax: profit tax increased if wage share (appropriately defined) is lower
- Narrowing breadth and duration of patents
  - And circumscribing use of patents to create monopolies
- More reliance on public research
  - With government appropriating returns
  - Directing research towards resource saving innovation and away from labor using innovation
- More effective anti-trust laws, more effectively enforced
- An increase in labor-demand increasing public investments



# UBI not solution

- Human jobs provide not only income but also mental services in the form of meaning, status, and fulfillment
- If this is so, shift from focusing on pure redistribution of income to generation of jobs or other activities
- But this could be just a characteristic of current generation

# Relationship between Technological Progress and Globalization

- Globalization can be viewed as a change in technology—expanding production possibilities
- Ideas presented here apply:
  - In standard neoclassical model, new equilibrium entails unskilled workers worse off in advanced countries (factor price equalization theorem, illustrated by figure 1)
  - Weakening of workers' bargaining power moves new equilibrium to an even more disadvantageous position
  - Argument that redistribution is costly implies we are in regime illustrated by figure 2—workers objecting to trade liberalization understandable
  - With imperfect risk and capital markets and frictions free trade may be Pareto inferior (Newbery Stiglitz 1984, Stiglitz 2017) (Figure 3)
    - Especially relevant for recent trade agreements: effect of TPP on GDP negligible, but it may still have had distributive effects

# Malthusian perspective on the proliferation of artificial intelligence

- If basic human intelligence is made redundant and the marginal product of human labor would fall below the human subsistence level, if redistribution is deemed infeasible, society faces two unpleasant alternatives:
  - halting AI or
  - allowing Malthusian forces to play out.

Extended utilitarian traditions provide a way of approaching this choice.

# Concluding remarks

- Worker-replacing technological change can be unambiguously positive in a 1st-best economy, or if it is coupled with the right form of redistribution that undoes pecuniary externalities that arise in response to rapid innovation in the economy.
  - In the absence of such intervention, there is a presumption that worker-replacing technological change will not only lead to workers getting a diminishing share of national income, but actually being worse off.
- The scope for redistribution is facilitated by the fact that the changes in factor prices create windfall gains on the complementary factors and that should make it rather easy to achieve Pareto improvements.

# Concluding remarks

- The more willing society is to support the necessary transition and to provide support to those who are “left behind,” the faster the pace of innovation that society can accommodate, and still ensure that the outcomes are Pareto improvements
- A society that is not willing to engage in such actions should expect resistance to innovation, with uncertain political and economic consequences.