Growth, Automation and the Long-Run Share of Labor

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What This Paper Does

Theory of Endogenous Automation

- with implications for long-run growth and distribution

- Automation: substitution of human labor by robot labor/digital services

- Driven by falling relative price of robot labor . . . driven in turn by capital accumulation

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- Dynamic multi-sector GE model:

- Both physical and human capital accumulation

- The latter incorporates human responses to automation

Key Feature #1

Physical capital relates to human labor in two ways:

- As complement (machines)
- As substitute (robots)

Key Feature #1, contd.

- Sector j production function:

$$y_j = f_j(k_j, \ell_j)$$

- f_j smooth, CRS, increasing, $y_j = 0$ if $k_j \ell_j = 0$.

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- Producing labor:

$$\ell_j = \ell_j(h_j, r_j)$$

- [substitutability] cheaper robots decrease demand for labor.

Key Feature #1 of the Model, contd.

$$\ell_j = \ell_j(h_j, r_j)$$

- Production with full automation technically feasible: $\ell_j(0, r_j) > 0$ if $r_j > 0$.
- But may or may not be *economically* viable, depending on relative factor prices
- r_j is itself procured from sector producing robot services:

$$y_r = f_r(k_r, \ell_r(h_r, r_r))$$

- Exactly the same considerations apply to that sector.

Key Feature #2

Human-Physical Asymmetry:

- Any agent can scale *quantities* of physical capital without bound.
- But each agent has a fixed labor endowment in natural units.
- Human capital accumulation takes the form of raising labor *quality*
- Acquiring education $e(j, j')$ needed to move *across* sectors/occupations j, j'.

Key Feature #2, contd.

- Intermediate sector produces education:

$$y_e = f_e(k_e, \ell_e(h_e, r_e))$$

Human Capital Return: $\dfrac{w_{j'} - w_j}{e(j, j')p_e}$, where $p_e =$ endogenous education price.

- Infinitely many occupations:

Scope for unbounded human capital accumulation (though in different form)

Other Features

- No other restrictions on technology: functional form, elasticity of substitution, even curvature.
- Perfect competition: can extend easily to monopolistic competition with constant markup rates.
- Infinitely lived households: allocate resources between current consumption, further education and financial investments, subject to borrowing constraints.
- Household heterogeneity: impatience, tastes, initial wealth and occupation, borrowing constraint

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$$\lim_{\eta \to 0} c_r(\eta, 1/\nu_r) < 1.$$

where:

- c_r is unit cost function of producing robot services,
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where:

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- $\nu_r \equiv \ell_j(0, r_j)/r_j$ is average productivity of robots under full automation.
- Holds if k-ℓ elasticity of substitution in r sector is at least one:
- more generally if it exceeds a bound below 1.

Automation and the Long-Run Labor Share

Theorem 1

- *Assume SRC, and enough patience for some households. Then as $t \to \infty$:*

[I] ***Growth***: *per capita income grows without bound.*

[II] ***Automation***: *every growing sector j is asymptotically automated: $h_j/r_j \to 0$.*

[III] ***Distribution***: *if preferences of patient households are asymptotically homothetic, the share of human wages in national income converges to 0*

Intuition for (I) and (II) of Theorem

- SRC $\Rightarrow$ full automation of robot production economically viable, if machine capital is sufficiently cheap
- Nonsubstitution Theorem: Robots produced by capital and robots: robot price bounded (relative to capital) if capital sufficiently cheap.

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- Capital *does* becomes arbitrarily cheap relative to human labor, owing to indefinite capital accumulation (in turn owing to household patience):
  - induces asymptotic automation sequentially in sectors.
- Economy released from human scarcity: "aggregate production function" is asymptotically Ak, leading to long run growth given sufficient hh patience

Intuition for (III) of Theorem

- Asymptotic automation of sector j implies that:
  - Share of human wage bill in sector j value-added $\downarrow 0$.
- Humans can move to sectors/occupations that are YTBA (yet to be automated, owing to relative efficiency of humans)
  - Set of YTBA sectors could be nonempty at every finite t, but will keep shrinking with t.

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  - Set of YTBA sectors could be nonempty at every finite t, but will keep shrinking with t.
- Asymptotic homotheticity of demand implies that:
  - expenditure share of YTBA set will converge to 0

Long Run Wages

- Wages could also grow without bound, (though slower than returns to capital, by Theorem 1)
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Proposition 2

If the conditions for Theorem 1 hold, and there is a sequence of sectors j where relative efficiency of robots tends to 0:

(a) the highest human wage grows without bound

(b) every human wage grows without bound, if sector-switching $e(j, j')$ education requirements are bounded

Extensions

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- **Proposition 3** shows (under mild additional conditions) that the asymptotic human share in national income is bounded away from zero.

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- **Proposition 3** shows (under mild additional conditions) that the asymptotic human share in national income is bounded away from zero.

2. What if unbounded skills can be acquired within occupations?

- **Proposition 4** shows Theorem 1 extends if marginal costs of such accumulation are unbounded above.

3. Extensions, contd.

What if there are protected sectors where humans are technologically essential?

- e.g., live music
- Must become infinitely expensive relative to other sectors:
- So Theorem 1 extends if expenditure share of infinitely expensive goods tends to zero (**Proposition 5**)

3. Extensions, contd.

What if there are protected sectors where humans are technologically essential?

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- Must become infinitely expensive relative to other sectors:
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4. What about technical progress?

- Theorem 1 extends if R&D is ex ante unbiased in favor of humans relative to robots or machines, unlike Acemoglu-Restrepo (2018) (**Theorem 2**)

Relation to Literature

Contrast to existing literature on growth and automation:

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  - but is merely a transversality condition fully consistent with balanced growth.
- More loosely, Piketty emphasizes role of capital accumulation;
  - But to explain declining labor share, k-ℓ substitution elasticity must exceed one;
  - At odds with empirical evidence for most industries (Chirinko-Mallick 2014).

Relation to Literature, contd.

Contrast also to theories of declining labor share:

- Rising *human* relative to physical capital accumulation, owing to (exogenous) slowing of technical progress (Grossman et al (2020))

- Rising markups (concentration), decline in unions and labor bargaining power (Neary 2003, Gutiérrez and Philippon 2017, Azar and Vives 2018, Eggertsson, Robbins, and Wold 2018, Kaplan and Zoch (2020))

Last Word

- The relative importance of different explanations for the falling labor share is ultimately an empirical question

- Potential role of our theory is indicated by evidence of Karabarbounis and Neiman 2014: half the decline in labor share world-wide explained by decline in capital good prices, *even after controlling for (capital augmenting) technical progress, markup rates and skill composition of the labor force*