Artificial Intelligence and Economic Growth

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What are the implications of A.I. for economic growth?

- Build some growth models with A.I.
  - A.I. helps to make goods
  - A.I. helps to make ideas

- Implications
  - Long-run growth
  - Share of GDP paid to labor vs capital
  - Firms and organizations

- Singularity?
Two Main Themes

• A.I. modeled as a continuation of automation
  ○ Automation = replace labor in particular tasks with machines and algorithms
  ○ Past: textile looms, steam engines, electric power, computers
  ○ Future: driverless cars, paralegals, pathologists, maybe researchers, maybe everyone?

• A.I. may be limited by Baumol’s cost disease
  ○ Baumol: growth constrained not by what we do well but rather by what is essential and yet hard to improve
Outline

• Basic model: automating tasks in production

• A.I. and the production of new ideas

• Singularity?

• Some facts

• Organization of firms and wage inequality
The Zeira 1998 Model
Simple Model of Automation (Zeira 1998)

- Production uses \( n \) tasks/goods:

\[
Y = AX_1^{\alpha_1}X_2^{\alpha_2} \cdot \ldots \cdot X_n^{\alpha_n},
\]

where \( \sum_{i=1}^{n} \alpha_i = 1 \) and

\[
X_{it} = \begin{cases} 
L_{it} & \text{if not automated} \\
K_{it} & \text{if automated}
\end{cases}
\]

- Substituting gives

\[
Y_t = A_t K_t^\alpha L_t^{1-\alpha}
\]
\[ Y_t = A_t K_t^\alpha L_t^{1-\alpha} \]

- **Comments:**
  - \( \alpha \) reflects the *fraction* of tasks that are automated
  - Embed in neoclassical growth model \( \Rightarrow \)
    \[ g_y = \frac{g_A}{1 - \alpha} \text{ where } y_t \equiv Y_t/L_t \]

- **Automation:** \( \uparrow \alpha \) raises both capital share and LR growth
  - Hard to reconcile with 20th century
  - Substantial automation but stable growth and capital shares
Subsequent Work

- Acemoglu and Restrepo (2017)
  - Old tasks are gradually automated as new (labor) tasks are created
  - Fraction automated can then be steady
  - Rich framework, with endogenous innovation and automation, all cases worked out in great detail

- Peretto and Seater (2013), Hemous and Olson (2016), Agrawal, McHale, and Oettl (2017)
Automation and Baumol’s Cost Disease
Baumol’s Cost Disease and the Kaldor Facts

- Baumol: Agriculture and manufacturing have rapid growth and declining shares of GDP
  - ... but also rising automation

- Aggregate capital share could reflect a balance
  - Rises within agriculture and manufacturing
  - But falls as these sectors decline

- Maybe this is a general feature of the economy!
  - First agriculture, then manufacturing, then services
Model

• Production is CES in tasks, with EofS < 1 (complements)

\[ Y_t = A_t \left( \int_0^1 X_{it}^\rho \, di \right)^{1/\rho} \text{ where } \rho < 0 \] (Baumol)

• Let \( \beta_t \) = fraction of tasks automated by date \( t \):

\[ Y_t = A_t \left[ \beta_t \left( \frac{K_t}{\beta_t} \right)^\rho + (1 - \beta_t) \left( \frac{L}{1 - \beta_t} \right)^\rho \right]^{1/\rho} \]

\[ \implies Y_t = A_t ((B_tK_t)^\rho + (C_tL)^\rho)^{1/\rho} \]

where \( B_t = \beta_t^{\rho - 1} \) and \( C_t = (1 - \beta_t)^{\rho - 1} \)

• Note: increased automation \( \Rightarrow \downarrow B_t \) and \( \uparrow C_t \) since \( \rho < 0 \).
  (e.g. a given amount of capital is spread over more tasks.)
Factor Shares of Income

- Ratio of capital share to labor share:

\[
\frac{\alpha_K}{\alpha_L} = \left( \frac{\beta_t}{1 - \beta_t} \right)^{1-\rho} \left( \frac{K_t}{L_t} \right)^\rho
\]

- Two offsetting effects ($\rho < 0$):
  - $\uparrow \beta_t$ raises the capital share
  - $\uparrow K_t/L_t$ lowers the capital share

*If these balance, constant factor shares are possible*
Automation and Asymptotic Balanced Growth

- Suppose a constant fraction of non-automated tasks become automated each period:

\[ \dot{\beta}_t = \theta (1 - \beta_t) \]

Then \( \beta_t \to 1 \) and \( C_t \) grows at a constant rate!

- With \( Y_t = F(B_tK_t, C_tL_t) \), balanced growth as \( t \to \infty \):
  - All tasks eventually become automated
  - Agr/Mfg shrink as a share of the economy...
  - Labor still gets 2/3 of GDP! Vanishing share of tasks, but all else is cheap (Baumol)
Simulation: Automation and Asymptotic Balanced Growth

Growth Rate of GDP

YEAR

Growth Rate of GDP

0% 1% 2% 3%
Simulation: Capital Share and Automation Fraction

Fraction automated, $\beta_t$

Capital share $\alpha_K$

(also automated share of GDP)
Constant Factor Shares?

- Consider $g_A > 0$ — technical change beyond just automation

- Alternatively, factor shares can be constant if automation follows

$$g_{\beta t} = (1 - \beta_t) \left( \frac{-\rho}{1 - \rho} \right) g_{kt},$$

- Knife-edge condition...

- Surprise: growth rates increase not decrease. Why?
  Requires

$$g_{Yt} = g_A + \beta_t g_{Kt}.$$ 

- $g_A = 0$ means zero growth. $g_A > 0$ means growth rises
Simulation: Constant Capital Share

Fraction automated, $\beta_t$

Capital share $\alpha_K$
Simulation: Constant Capital Share

GROWTH RATE OF GDP

YEAR
Simulation: Switching regimes...
Simulation: Switching regimes...

Fraction automated, $\beta_t$

Capital share $\alpha_K$
A.I. and Ideas
AI in the Ideas Production Function

- Let production of goods and services be $Y_t = A_tL_t$
- Let idea production be:

  \[
  \dot{A}_t = A_t^\phi \left( \int_0^1 X_{it}^\rho \, di \right)^{1/\rho}, \rho < 0
  \]

- Assume fraction $\beta_t$ of tasks are automated by date $t$. Then:

  \[
  \dot{A}_t = A_t^\phi F(B_t K_t, C_t S_t)
  \]

  where

  \[
  B_t \equiv \beta_t^{\frac{1-\rho}{\rho}}; C_t \equiv (1 - \beta_t)^{\frac{1-\rho}{\rho}}
  \]

- This is like before...
AI in the Ideas Production Function

- Intuition: with $\rho < 0$ the scarce factor comes to dominate

$$F(B_tK_t, C_tS_t) = C_tS_t F\left(\frac{B_tK_t}{C_tS_t}, 1\right) \to C_tS_t$$

- So, with continuous automation

$$\dot{A}_t \to A^\phi_t C_tS_t$$

- And asymptotic balanced growth path becomes

$$g_A = \frac{g_C + g_S}{1 - \phi}$$

- We get a “boost” from continued automation ($g_C$)
Can automation replace population growth?

• Maybe! Suppose $S$ is constant, $g_s = 0$
  ○ Intuition: Fixed $S$ is spread among exponentially-declining measure of tasks
  ○ So researchers per task is growing exponentially!

• However
  ○ This setup takes automation as exogenous and at “just the right rate”
  ○ What if automation is endogenized?
  ○ Is population growth required to drive automation?
  ○ Could a smart/growing AI entirely replace humans?
Singularities
Singularities

• Now we become more radical and consider what happens when we go “all the way” and allow AI to take over all tasks.

• **Example 1:** Complete automation of goods and services production.

\[ Y_t = A_t K_t \]

→ Then growth rate can accelerate exponentially

\[ g_Y = g_A + sA_t - \delta \]

we call this a “Type I” growth explosion
Singularities: Example 2

- Complete automation in ideas production function

\[ \dot{A}_t = K_t A_t^\phi \]

- Intuitively, this idea production function acts like

\[ \dot{A}_t = A_t^{1+\phi} \]

- Solution:

\[ A_t = \left( \frac{1}{A_0^{-\phi} - \phi t} \right)^{1/\phi} \]

- Thus we can have a true **singularity** for \( \phi > 0 \). \( A_t \) exceeds any finite value before date \( t^* = \frac{1}{\phi A_0^\phi} \).
Singularities: Example 3 – Incomplete Automation

- Cobb-Douglas, $\alpha$ and $\beta$ are fraction automated, $S$ constant

$$\dot{K}_t = \bar{s}L A_t^\sigma K_t^\alpha - \delta K_t.$$

$$\dot{A}_t = K_t^\beta S^\lambda A_t^\phi$$

- Standard endogenous growth requires $\gamma = 1$:

$$\gamma := \frac{\sigma}{1 - \alpha} \cdot \frac{\beta}{1 - \phi}.$$ 

- If $\gamma > 1$, then growth explodes!
  - Can occur without full automation
  - Example: $\alpha = \beta = \phi = 1/2$ and $\sigma > 1/2$. 

Objections to singularities

1. Automation limits (no $\beta_t \to 1$)

2. Search limits

$$\dot{A}_t = A_t^{1+\phi}$$

but $\phi < 0$ (e.g., fishing out, burden of knowledge...)

3. Natural Laws

$$Y_t = \left( \int_0^1 (a_{it}Y_{it})^\rho \right)^{1/\rho} \text{ where } \rho < 0$$

now can have $a_{it} \to \infty$ for many tasks but no singularity (cf. Moore’s Law vs. Carnot’s Theorem)

- **Baumol theme**: growth determined not by what we are good at, but by what is essential yet hard to improve
Some Facts
Capital Shares in U.S. Industries

- Motor Vehicles
- Computers
- Chemicals
- Plastics
- Furniture
Capital Shares in U.S. Industries

Graph showing capital shares in various industries from 1940 to 2020:
- Movies
- Publishing
- Wholesale
- Retail
- Air Trans.
Capital Shares in U.S. Industries

Telecommunications

Federal Govt

Health (hospitals)

Health (ambulatory)

Education
Adoption of Robots and Change in Capital Share

Motor Vehicles = 56% of robot investment in 2014
Final Thoughts
Conclusion: A.I. in the Production of Goods and Services

- Introduced Baumol’s “cost disease” insight into Zeira’s model of automation
  - Automation can act like labor augmenting technology (surprise!)
  - Can get balanced growth with a constant capital share well below 100%, even with nearly full automation

- Considered effects on wage inequality and firm organization. More AI-intensive firms could:
  - Outsource a higher fraction of low-occupation tasks
  - Pay \( \uparrow \) premium to low-occupation workers they keep
Conclusion: A.I. in the Ideas Production Function

• Could A.I. obviate the role of population growth in generating exponential growth?

• Discussed possibility that A.I. could generate a singularity
  ○ Derived conditions under which the economy can achieve infinite income in finite time

• Discussed obstacles to such events
  ○ Automation limits, search limits, and/or natural laws (among others)
Extra Slides
AI, Organizations, and Wage Inequality

- Usual story: robots replace low-skill labor, hence ↑ skill premium (e.g., Krusell et al. 2000)
- But solving future problems, incl. advancing AI, might be increasingly hard, suggesting ↑ complementarities across workers, ↑ teamwork, and changing firm boundaries (Garicano 2000, Jones 2009)
- Aghion et al. (2017) find evidence along these lines
  - outsource higher fraction of low-skill workers
  - pay *increased* premium to low-skill workers kept
AI, Organizations, and Wage Inequality

![Graph showing the relationship between log wage relative to labor market mean and In R&D intensity.](image)

*kernel = epanechnikov, degree = 0, bandwidth = .31, pwidth = .47*
AI, Skills, and Wage Inequality

![Graph showing the relationship between log wage relative to labor market mean and In R&D intensity for low, medium, and high skill levels.](image)