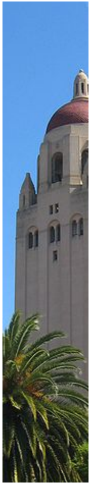


Artificial Intelligence and Economic Growth

Chad Jones

Maekyung-KAEA Forum

January 4, 2025

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
- Catastrophic risks from A.I.?

Talk based on material from several papers

- Aghion, B. Jones, and C. Jones (2019) “Artificial Intelligence and Economic Growth”

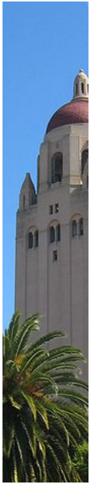
- Jones (2024 AER Insights) “The A.I. Dilemma: Growth versus Existential Risk”

- Jones (2025) “How much should we spend to reduce A.I.’s existential risk?”

Two Main Themes (Aghion, B. Jones, and C. Jones, 2019)

- 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



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

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

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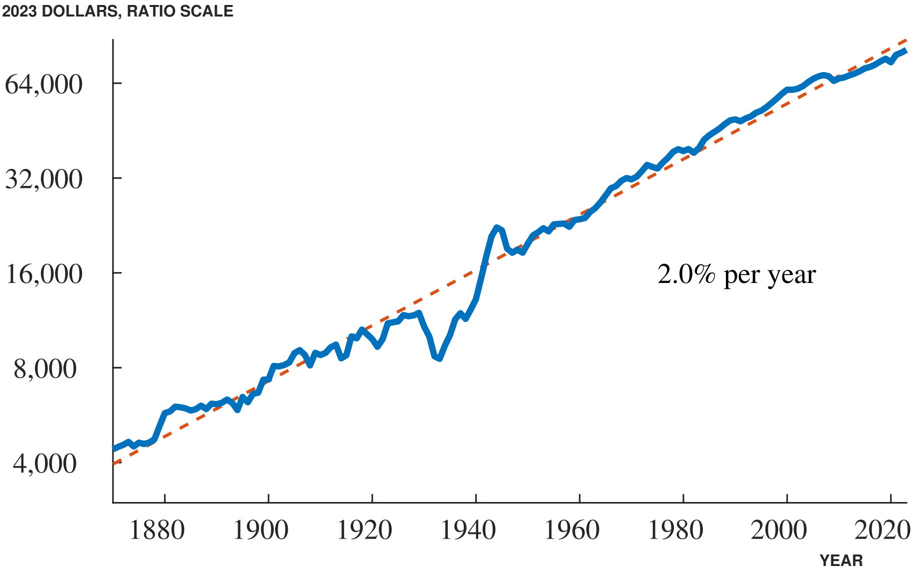
- Comments:
  - α reflects the *fraction* of tasks that are automated
  - Embed in neoclassical growth model $\Rightarrow$

$$g_y = \frac{g_A}{1-\alpha} \quad \text{where} \quad y_t \equiv Y_t/L_t$$

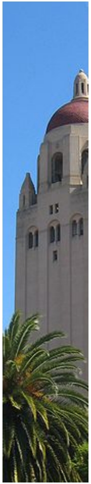
- Automation: $\uparrow \alpha$ raises both capital share and LR growth
  - Hard to reconcile with 20th century
  - Substantial automation but stable growth and capital shares

Average income per person in the U.S.



Recent papers

- Acemoglu and Restrepo (2017, 2018, 2019, 2020, 2021, 2022, 2023)
  - Foundational work in this literature
  - Old tasks are gradually automated as new (labor) tasks are created
  - Fraction automated can then be steady
  - Rich framework, with endogenous innovation and automation
  - Acemoglu-Restrepo (2022 ECMA): Rising automation can explain 60% of changes in the U.S. wage distribution since 1980
- Hemous and Olson (2016), B. Jones and Liu (2024)



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!
  - Automation tends to raise the capital share
  - But bottlenecks and Baumol effects tend to raise the labor share
    Labor is the scarce factor that cannot be accumulated easily

AJJ Economic Environment

Final good	$Y_t = \left(\int_0^1 y_{it}^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}}$ where $\sigma < 1$ **(Baumol effect)**
Tasks	$y_{it} = \begin{cases} K_{it} & \text{if automated } i \in [0, \beta_t] \\ L_{it} & \text{if not automated } i \in [\beta_t, 1] \end{cases}$
Capital accumulation	$\dot{K}_t = I_t - \delta K_t$
Resource constraint (K)	$\int_0^1 K_{it} di = K_t$
Resource constraint (L)	$\int_0^1 L_{it} di = L$
Resource constraint (Y)	$Y_t = C_t + I_t$
Allocation	$I = \bar{s}_K Y$

Automation and growth

- Combining equations

$$Y_t = \left[\beta_t \left(\frac{K_t}{\beta_t} \right)^{\frac{\sigma-1}{\sigma}} + (1-\beta_t) \left(\frac{L}{1-\beta_t} \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}$$

- How β interacts with K: two effects
  - β: what fraction of tasks have been automated
  - β: Dilution as $K/\beta \Rightarrow K$ spread over more tasks
- Same for labor: $L/(1-\beta_t)$ means given L concentrated on fewer tasks, raising "effective labor"

Rewriting in classic CES form

- Collecting the β terms into factor-augmenting form:

$$Y_t = F(B_t K_t, A_t L_t)$$

where

$$B_t = \left(\frac{1}{\beta_t}\right)^{\frac{1}{1-\sigma}} \text{ and } A_t = \left(\frac{1}{1-\beta_t}\right)^{\frac{1}{1-\sigma}}$$

- Effect of automation: $\uparrow \beta_t \;\Rightarrow\; \downarrow B_t$ and $\uparrow A_t$

Intuition: dilution effects just get magnified since $\sigma < 1$

Automation

- Suppose a constant fraction of non-automated tasks get automated every period:

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

$$\Rightarrow \quad \beta_t \rightarrow 1$$

- What happens to $1 - \beta_t =: m_t$?

$$\frac{\dot{m}_t}{m_t} = -\theta$$

The fraction of labor-tasks falls at a constant exponential rate

Putting it all together

$$Y_t = F(B_t K_t, A_t L_t) \text{ where } B_t = \left(\frac{1}{\beta_t}\right)^{\frac{1}{1-\sigma}} \text{ and } A_t = \left(\frac{1}{1-\beta_t}\right)^{\frac{1}{1-\sigma}}$$

- $\beta_t \to 1 \Rightarrow B_t \to 1$

- But A_t grows at a constant exponential rate!

$$\frac{\dot{A}_t}{A_t} = -\frac{1}{1-\sigma}\frac{\dot{m}_t}{m_t} = \frac{\theta}{1-\sigma}$$

- When a constant fraction of remaining goods get automated and $\sigma < 1$, the automation model features an asymptotic BGP that satisfies Uzawa

$$\alpha_{Kt} \equiv \frac{F_K K}{Y} = \beta_t^{\frac{1}{\sigma}} \left(\frac{K_t}{Y_t}\right)^{\frac{\sigma-1}{\sigma}} \to \left(\frac{\bar{s}_K}{g_Y + \delta}\right)^{\frac{\sigma-1}{\sigma}} < 1$$

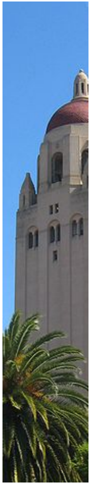
Intuition for AJJ result

- Why does automation lead to balanced growth and satisfy Uzawa?
  - $\beta_t \to 1$ so the KATC piece "ends" eventually
  - Labor per task: $L/(1-\beta_t)$ rises exponentially over time!
  - Constant population, but concentrated on an exponentially shrinking set of goods $\Rightarrow$ exponential growth in "effective" labor
- Labor earns 2/3 of GDP even though labor tasks are vanishing
  - Baumol: these are the tasks that are scarce and essential, so they demand a high share of GDP
- Limitation
  - An asymptotic result
  - Only occurs as $\beta_t \to 1$, so unclear if relevant for U.S. or other modern economies

B. Jones and Liu (AER 2024)

- BGP can occur "today" with $\beta_t < 1$, not asymptotically
  - Adds capital-augmenting technical change ("faster computers") = Z_t
  - Capital share is $\alpha_{Kt} = \beta_t \,/\, Z_t$
  - Might describe modern economies

- Automation and KATC coexist along the BGP with stable factor shares



A.I. and Ideas

A.I. in the Idea Production Function

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

$$\dot{A}_t = A_t^{\phi} \left(\int_0^1 X_{it}^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}}, \ \sigma < 1$$

- Assume fraction β_t of tasks are automated by date t. Then:

$$\dot{A}_t = A_t^{\phi} F(B_t K_t, C_t S_t) \text{ where } B_t = \left(\frac{1}{\beta_t} \right)^{\frac{1}{1-\sigma}} \text{ and } C_t = \left(\frac{1}{1-\beta_t} \right)^{\frac{1}{1-\sigma}}$$

- This is like before...

A.I. in the Idea Production Function

- Intuition: with $\sigma < 1$ the scarce factor comes to dominate

$$F(B_tK_t, C_tS_t) = C_tS_t\, F\left(\frac{B_tK_t}{C_tS_t}, 1\right) \rightarrow \text{Constant} \cdot C_tS_t$$

- So, with continuous automation

$$\dot{A}_t \rightarrow A_t^{\phi} C_t S_t$$

- And asymptotic balanced growth path becomes

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

- We get a "boost" from continued automation (g_C)

Theory: A.I. can raise growth

- Automation (computers, internet, etc.) has been ongoing for decades
  - Recall $g_C = \frac{1}{1-\sigma} \cdot \theta$
  - where θ is the fraction of remaining labor tasks that get automated each year

    $\Rightarrow$ continued automation by itself may not raise growth

- However, an increase in the rate of automation via A.I. $\uparrow \theta$ could raise growth
  - Rapid advances in reasoning models (OpenAI's o1-pro, o3) suggest possible!

- Extreme version: If all research tasks are automated, then

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

and a growth explosion is possible (e.g. if $\phi > 0$)

What would A.I. accelerating economic growth look like?

- Near-term productivity boosts from A.I.
  - Software: 25% productivity improvements already
  - In the next decade: A.I. agents that can automate most coding?
  - Virtuous circle: code up even better A.I. agents
- With Moore's Law price decreases $\Rightarrow$ millions($\uparrow$) of virtual research assistants
  - Automate cognitive tasks $\Rightarrow$ invent new ideas
  - E.g. better chips, better robots, medical technologies, etc.
  - A.I. + robots for physical tasks
- Potential to raise growth rates substantially over the next two decades?

Bottlenecks and Baumol Effects

- Economic history $\Rightarrow$ may take longer than we expect
  - Electricity and computers changed the economy over 50 years
- Automation has been going on for 150 years with no speed up in growth
  - Electricity, engines, semiconductors, the internet, smartphones
  - Yet growth always 2% per year
- Maybe those great ideas are what *kept* growth from slowing
  - Perhaps A.I. = latest great idea letting us maintain 2% growth for a while longer. (pessimistic view, but possible)

The Labor Market, Jobs, and Meaningful Work

- The world where A.I. “changes everything” is a world where GDP is incredibly high
  - The size of the pie available for redistribution is enormous
  - Transition could be hard
- As we get richer, we naturally work less
  - Rising leisure, lower retirement ages. This is a good thing!
  - “Work” is a bad in most of our models
- But there is also good work, meaningful work
  - Chess more popular than ever despite iPhone $>$ Magnus Carlsen
  - We may choose to value experiences involving people (arts, music, sports) Keeps labor share high?

A.I. and Existential Risk: A Thought Experiment (Jones, 2024 AERI)

- More impressive than electricity, but more dangerous than nuclear weapons?
- The Oppenheimer Question:
  - If nothing goes wrong, A.I. accelerates growth to 10% per year
  - But a one-time small chance that A.I. kills everyone
  - Use it or not? What risk are you willing to take: 1%? 10%?

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- Two findings:
  1. High living standards and diminishing returns $\Rightarrow$ only take small risk
  2. But 10% growth $\Rightarrow$ cure cancer, heart disease

     Willing to take large risks (25%) to cut mortality rates in half

We do not need a 4th flat screen TV or a 3rd iphone.

Need more years of life to enjoy already high living standards.

How much should we spend to reduce A.I.'s catastrophic risk? (Jones 2025)

- Covid pandemic: "spent" 4% of GDP to mitigate a mortality risk of 0.3%
  - A.I. risk is at least this large ⇒ spend at least this much?
  - Are we massively underinvesting in mitigating this risk?

- Better intuition
  - VSL = $10 million
  - To avoid a mortality risk of 1% ⇒ WTP = $1\% \times \$10$ million $= \$100,000$
  - This is more than 100% of a year's per capita GDP
  - Xrisk over two decades ⇒ **annual investment of 5% of GDP**
  - Large investments worthwhile, even with no value on future generations

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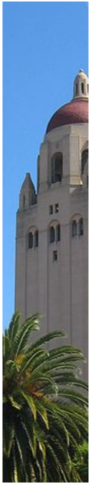
Incomplete: ignores the "effectiveness" of mitigation

but intuition is correct; see paper.



Final Thoughts

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- How much did the internet change the world between 1990 and 2020?
  - How much will A.I. change things between 2015 and 2045? More or less?
  - I believe the answer is much more
  - Just because changes take 30 years instead of 5 years does not mean that the ultimate effects will not be large
- Are we massively underinvesting in mitigating risks?
  - Exernalities and race dynamics: A.I. labs do not internalize the risks to all of us
  - Should we tax GPUs and use the revenue to subsidize safety?

Thank you!

These slides

Chad’s web page