Discussion of: Artificial Intelligence and Economic Growth
by

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An agenda for the field

- Explore the growth Implications of:
  - AI as increasing automation in production
    - Capital replacing labor at an increasing range of production tasks
  - AI as augmenting idea creation
    - Capital replacing researchers in an increasing array of idea generating tasks
- Formally: modify and extend Zeira (1998, QJE) model

Disciplining this exercise

- Squaring model implications with the Kaldor facts
  - Reasoning: Automation in this form going on since at least the Industrial Revolution
  - Any model we write down projecting what will/might happen shouldn't do a great deal of violence to these basic facts
    - Growth rates/factor shares relatively stable
- Does the model makes sense?
  - Does shoe-horning it to these facts lead to other things which don't?
- Are there fundamental economic forces that would push it towards matching the Kaldor facts?

Alternatively

- Another view: Historic growth experiences are no reliable guide.
- This is a game changer, and as such we don't have to worry about Kaldor facts.
    - Then ask, what might happen in such an "untethered" world?
    - Almost a Sci Fi world: "superintelligence", "futurists", the "singularity community",
- AJJ provide a way of structuring our speculation about these possibilities.

Zeira Model

$$Y = AX_1^{\alpha_1} X_2^{\alpha_2} \cdot \ldots \cdot X_n^{\alpha_n} \quad \text{where} \sum_{i=1}^{n} \alpha_i = 1.$$

$$X_i = \begin{cases} L_i & \text{if not automated} \\ K_i & \text{if automated} \end{cases}$$

$$Y = AK^{\alpha} L^{1-\alpha}$$

- Embed in neo-classical growth model with constant *I* rate.
- Increasing automation increases capital share (α)

$$g_y = \frac{g}{1-\alpha},$$

Problem (Kaldor)

- Growth rates and factor shares are relatively stable
  - Seemingly something wrong with this simple formulation.
- How do we formulate this process so as not to fly in the face of facts?

One Resolution: Acemoglu Restrepo (2016)

- Allow set of tasks automated to expand.
  - Automation displaces labor from some tasks but new tasks (not yet automated) are constantly invented too.
    - Can keep α constant along BGP
    - Can Keep growth/factor shares constant on BGP

AJJ Resolution

$$Y_t = A_t \left(\int_0^1 Y_{it}^{\rho} di \right)^{1/\rho} \quad \text{where } \sigma \equiv \frac{1}{1-\rho} < 1$$

$$A_t = A_0 e^{gt}$$

- GDP a CES combination of goods.
  - Elasticity of substitution less than 1.

$$Y_{it} = \begin{cases} L_{it} & \text{if not automated} \\ K_{it} & \text{if automated} \end{cases}$$

Closing the Model

$$Y_t = C_t + I_t$$

$$\dot{K}_t = I_t - \delta K_t$$

$$\int_0^1 K_{it} di = K_t$$

$$\int_0^1 L_{it} di = L$$

And a constant investment rate (exogenous).

Surprisingly

- Reduces to :

$$Y_t = A_t F(B_t K_t, C_t L_t) \text{ where } B_t \equiv \beta_t^{\frac{1-\rho}{\rho}} \text{ and } C_t \equiv (1-\beta)^{\frac{1-\rho}{\rho}}.$$

  - where β_t is the share of goods that have been automated by time *t*

- With ρ < 0, (σ < 1):

  - Increasing automation, increases β_t, lowers *B* and increases *C*

  - Automation is capital diluting and labor augmenting!!!

Baumol's Cost Disease

- $\rho < 0$: low substitutability across sectors
- Automation generates an income effect
- Spend progressively more of real wealth on sectors NOT subject to automation.
  - Protracted relative price increase of non-automated goods sectors
- Two counteracting forces:
  - 1 labor employed in fewer sectors — lowering factor share,
  - 2 labor continues to work in sectors with increasing relative prices — raising factor share,

Squaring with facts?

- Structural Transformation
  - Mechanization of agriculture in the West:
    - Ag share (employment) in US: 1930s ~30% —> Today~ 1-2%
  - Increased mechanization of manufacturing:
    - Manufacturing employment share falling
- So a possible explanation for relatively balanced factor shares:
  - Automation increases capital shares in automated sectors but nonhomotheticities lower these sectors' GDP shares.

Additional Insights

- 1. **Holding A fixed**.
  - There exists a rate of automation growth than can yield stable growth rate
    - Featuring an increasing capital share (asymptoting at a constant)
    - And structural transformations along the increasing path
  - — **requires a constant fraction of un-automated sectors to become automated through time**.
  - In the limit, automation almost stops

Additional Insights

- 2. Constant factor shares along the path permanently also possible
  - With A increasing and K/L growing over time, need the rate of automation (beta) growth to decline in a correspondingly off-setting manner.
  - This causes GDP to grow at an increasing rate
- Understanding this:
- balanced growth requires gY = gK but here we have $g_{Yt} = g_A + \beta_t g_{Kt}.$
  - With gA > 0 then balanced growth requires gY=gK (always), but then as beta rises gY will have to rise.

Additional Insights

- 3. **Alternating between two regimes in this model can match the data.**
  - Can have phases where capital share is constant or rising and growth will accelerate,
  - phases where capital share is declining when growth will decelerate
- UZAWA: since we do not in general have purely labor-augmenting technical change, this setting will not lead to balanced growth
  - **Either the capital share or the growth rate of GDP will increase over time. Or both.**

Comment 1

- What is precise relationship with Acemoglu & Restrepo (2016)?
  - Models differ slightly
    - A&R unit measure of tasks to produce final good
    - Tasks produced by combining labor or capital with a task specific intermediate (made from final good)
      - Newer tasks have higher labor productivity
  - Similarly, automation allows labor input to be perfectly substituted by capital input

Comment 1

- Are these differences substantive?
  - A & R rule out strong forms of non-homotheticity by restricting the degree of substitutability between factors and intermediates
  - A & R fn. 11 "…strong substitution creates **implausible features**. For example, automation which increases the productivity of capital, may end up raising the demand for labor more than the demand for capital."
  - Is this the analog of $\rho < 0$?

Comment 2

- Why not endogenize the allocation of research effort to automation?
  - Answer:“But it is relatively clear that depending on exactly how one specifies this technology, $\frac{\beta_t}{1-\beta_t}$ can rise faster or slower than $(K_t/L_t)^{\rho}$ declines. That is, the result would depend on detailed assumptions related to automation, and we do not have strong priors on how to make these assumptions….”

Comment 2

- I think this sells the framework short.
  - It is a relatively simple model to work with — and can be easily exploited to explore this
  - Agreed we know little about the automation production function
  - But such an exercise has the potential to be useful for helping us think about fundamental economic forces that might push us towards or away from balance.

Comment 3

- A & R (2016) fruitfully follow this path
  - Identify forces (associated with directed technical change)
  - Pushing towards balance between the rate of task automation and the rate at which tasks expand
- In AJJ this is left hanging,
  - Worryingly it seems that fundamental forces would tend to push the model away from balance and a match with the Kaldor facts.

Comment 3

- Non-homotheticities in AJJ framework force growth towards balance
  - More automated sectors, each commanding smaller shares of the total pie
  - Essentially lower the relative price and expenditure share of automated sectors

Comment 3

- So innovation in non-automated sectors progressively becoming more valuable
  - Given research resources progressively becoming more focused on a smaller number of more important sectors.
  - Suggests something opposite to what was built into the scale invariant endogenous growth models — Aghion-Howitt, Young, Peretto, Dinopolous-Thompson
  - Should make growth accelerate
- So if only to dispel such (perhaps wrong) intuition, this should be explored

Comment 4: AI and Business Stealing

- AJJ claim that AI similar to IT in its effects on knowledge flows
  - Focus on two competing forces, Following Baslandze (2016)
    - IT increases knowledge diffusion
      - a positive effect — rapid learning, dissemination
      - a negative (business stealing) effect — competitors gain knowledge more quickly

Comment 4: AI and Business Stealing

- This analogy between IT and AI should be elaborated on further.
- In fact, this goes against my (perhaps naive) intuitions.
  - IT increases knowledge flows directly, and as such would tend to directly lead to more capacity for business stealing
  - But AI, as modelled here — replacing workers in production or research tasks with machines — would seem to do the opposite
    - If I invent a machine, I control its building/use then I control the rents from it.
      - Intellectual property is of course imperfect.

Comment 4: AI and Business Stealing

- Compare it with other forms of knowledge creation: e.g. an innovation that uses labor
  - labor can see it, work with it, learn it….
  - Can walk away, start up their own firms using the same idea, or work for my competitors
- Intellectual property rights of course should, in principle also protect the inventor from that
- But surely protecting the intellectual property embodied in a machine is easier than in other forms.

A lot more…

- Haven't touched on much of the paper
  - AI and Firms
  - Automation in ideas production
    - Singularities
    - Superintelligence
    - Potential Bottlenecks

The End

AI and Firms

- Leave out of discussion

Automation in ideas production

- An equally compelling effect of AI: idea production.
    - Introspectively: math, dissemination, data, retrieval etc.
    - So apply (similar) task based automation model to ideas production.
- Approximate previous model with a production function for ideas
    - F(Automated Tasks, Researchers)

Automation in ideas production

- Consider One off changes in beta (level of automation)
  - Elasticity of substitution in F < 1: Increasing automation leads to a level effect and no growth effect phi < 1, or growth rate effect phi = 1 (a la Jones style semi-endogenous growth model).
  - Elasticity of substitution in F = 1. Then growth rises. Accumulable factor in production becomes more important for idea creation…growth will rise.
  - Elasticity of substitution in F > 1. Explosive growth (incomes infinite in finite time). …but true even without automation as capital accumulates and makes research more productive through time without bound….so exclude this case.

Continuous Change

- continuous changes in beta
  - consider analogous change to earlier — newly automated tasks are a constant fraction of previously unautomated tasks.
  - so even in the phi < 1 case we can have exponential growth as “effective” research effort is rising faster than the number of researchers. number of new ideas produced by researchers an increasing function of the stock of ideas but at a decreasing rate.

singularities

- Explosive growth
  - 1. growth increasing without bound but remaining finite
  - 2. infinite output in finite time
- With complete automation in goods production
  - AK production function with A increasing over time….(type 1 explosion)
- With complete automation in ideas production
  - Full automation of non-rivalrous factor (ideas), increasing returns to accumulable factor (runaway growth, type 2 explosion)
- Increased but incomplete automation
- Superintelligence
- This is heady stuff.

bottlenecks

- Automation limits (some things not automable)
- Search limits (getting faster at searching but less to find in the pond)
- Baumol tasks and natural laws
  - some things hard to improve
  - rho<0 output and growth end up being determined not by what we are good at but by what is hard to improve (but essential and unsubstitutable)