The Macroeconomics of Innovation:

Models of Economic Growth - Endogenous technology growth

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Economics of innovation

Exogenous technology growth

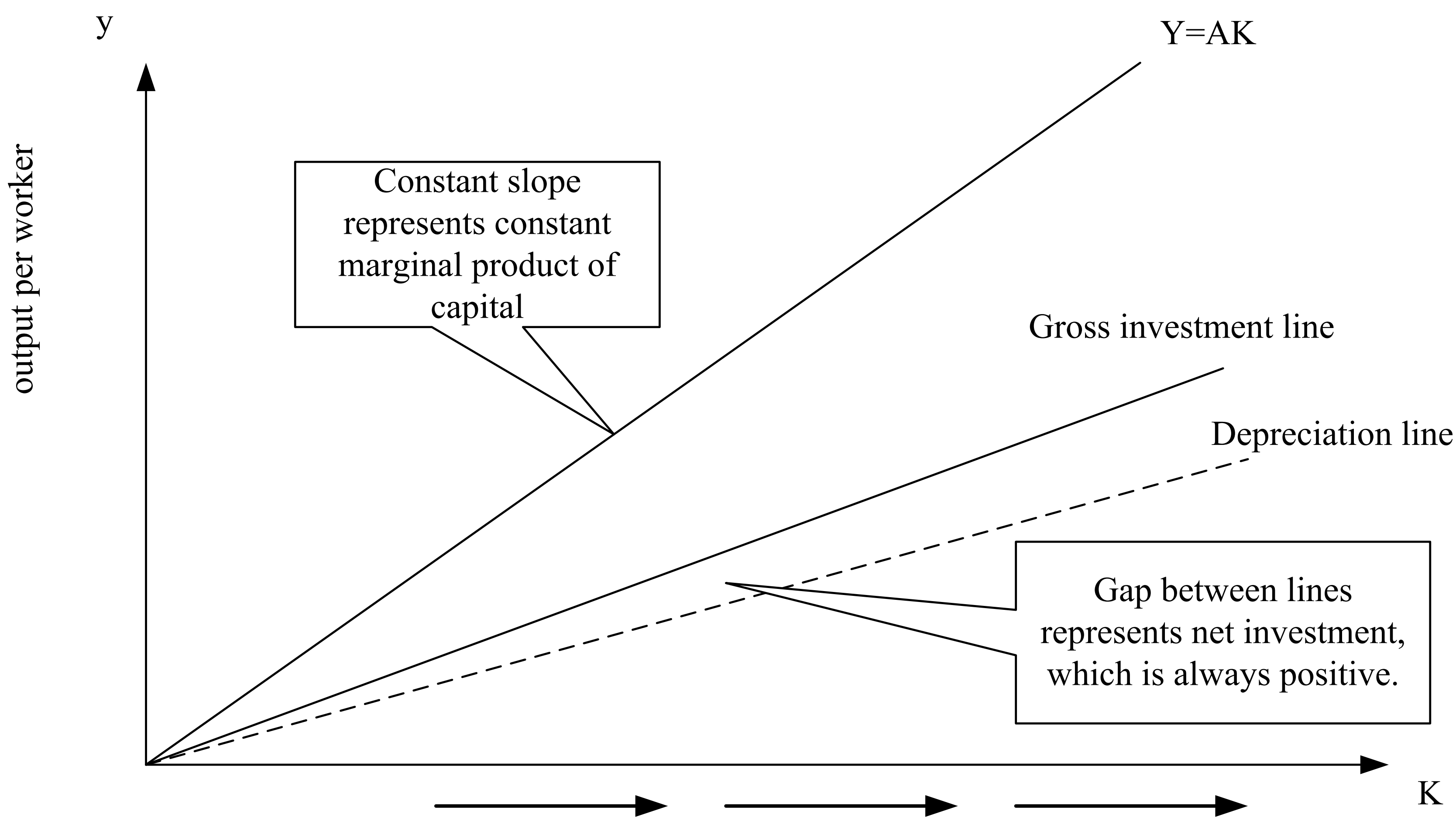
- Solow (and Swan) models show that technological change drives growth
- But growth of technology is not determined within the model (it is **exogenous**)
- Note that it does not show that capital investment is unimportant ($A\uparrow \Rightarrow \uparrow y$ and $\uparrow MP_k$, hence $\uparrow k$)
- In words …. better technology raises output, but also creates new capital investment opportunities
- Endogenous growth models try to make **endogenous** the driving force(s) of growth
- Can be technology or other factors like learning by workers

The AK model

- The '*AK* model' is sometimes termed an 'endogenous growth model'
- The model has $Y = AK$

  where *K* can be thought of as some composite 'capital and labour' input
- Clearly this has **constant marginal product of capital** ($MP_k = dY/dK=A$), hence long run growth is possible
- Thus, the 'AK model' is a simple way of illustrating endogenous growth concept
- However, it is very simple! 'A' is poorly defined, yet critical to growth rate
- Also composite 'K' is unappealing

The AK model in a diagram



Endogenous technology growth

- Suppose that technology depends on past investment (i.e. the process of investment generates new ideas, knowledge and learning).

$$A = g(K) \qquad \text{where} \quad \frac{dA}{dK} > 0$$

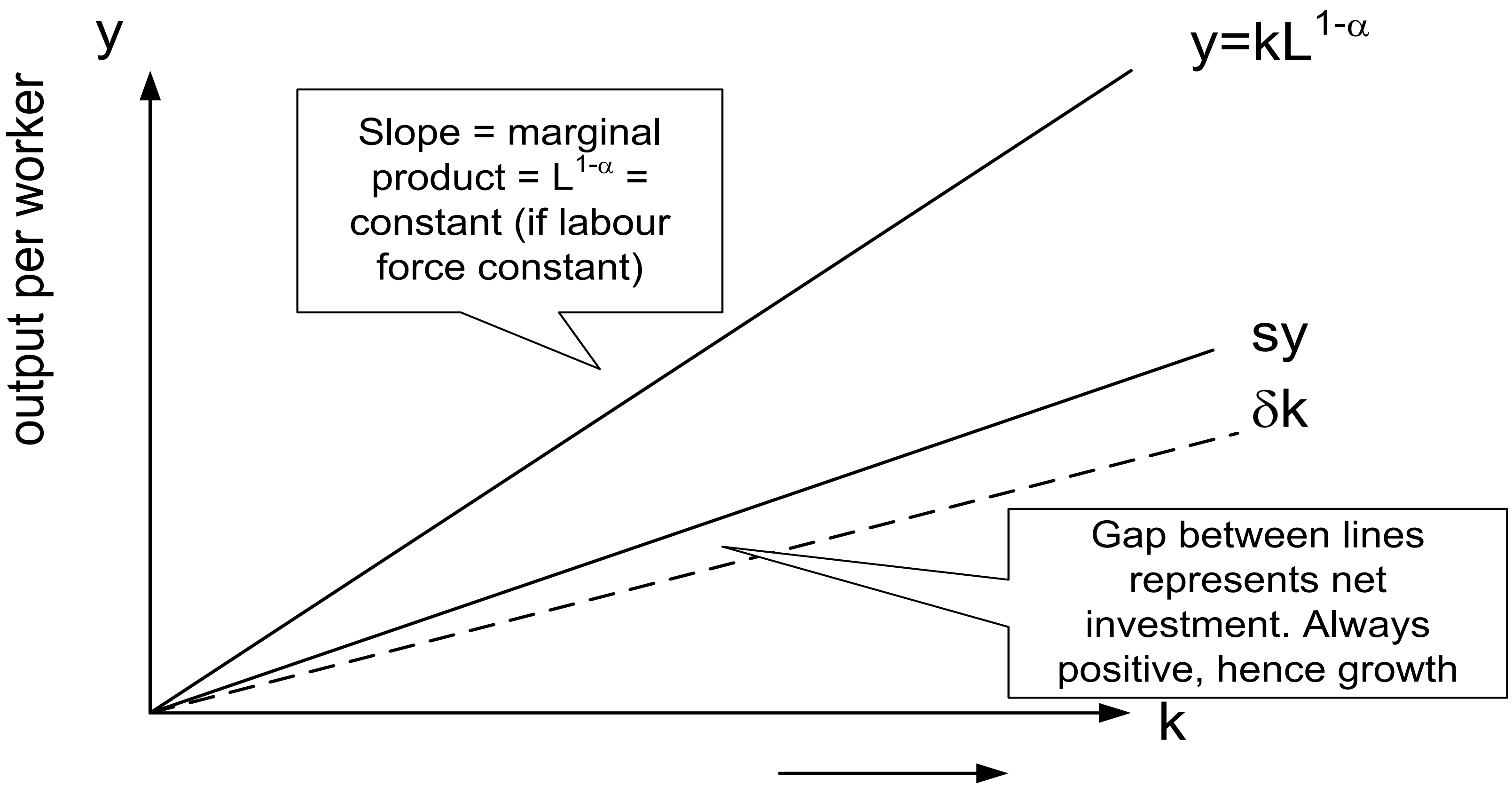
$$\text{Specifically, let} \quad A = K^{\beta} \qquad \beta > 0$$

Cobb-Douglas production function

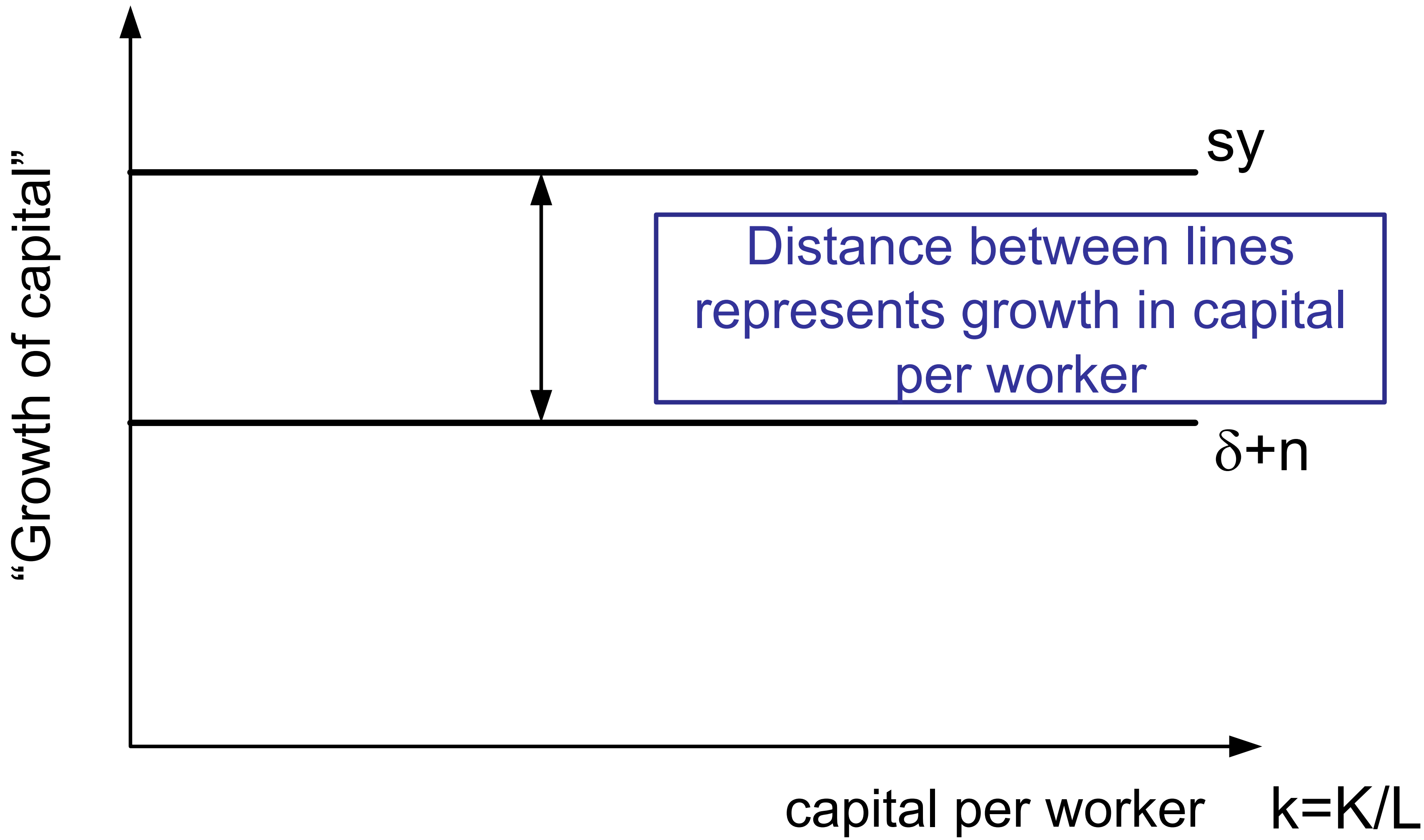
$$Y = AK^{\alpha}L^{1-\alpha} = [K^{\beta}]K^{\alpha}L^{1-\alpha} = K^{\alpha+\beta}L^{1-\alpha}$$

If $\alpha+\beta = 1$ then **marginal product of capital is constant** ($dY/dK = L^{1-\alpha}$).

- Assuming *A*=g(*K*) is Ken Arrow's (1962) learning-by-doing paper
- Intuition is that learning about technology prevents marginal product declining



Situation on growth diagram



Increasing returns to scale

$$Y = K^{\alpha+\beta} L^{1-\alpha} \quad \text{with } \alpha + \beta = 1$$

- "Problem" with $Y = K^1 L^{1-\alpha}$ is that it exhibits **increasing returns to scale** (doubling *K* and *L*, more than doubles *Y*)
- IRS $\Rightarrow$ large firms dominate, no perfect competition (no P=MC, no first welfare theorem)
- …. solution, assume feedback from investment to *A* is external to firms (note this is positive externality, or spillover, from microeconomics)

Knowledge externalities

A firm's production function is $Y_i = A_i K_i^{\alpha} L_i^{1-\alpha}$
but A_i depends on aggregate capital
(hence firm does not 'control' increasing returns)

- Romer (1986) paper formally proves such a model has a competitive equilibrium
- However, the importance of externalities in knowledge (R&D, technology) long recognised
- Endogenous growth theory combines IRS, knowledge externalities and competitive behaviour in (dynamic optimising) models

Knowledge externalities

Knowledge spillovers occur between firms, hence the economy-level production function is different from the firm-level production function.

This basic result turns out to have very important implications. The model suggests that:

1) the competitive growth rate is below the socially optimal growth rate (due to the presence of knowledge externalities);
2) shocks and policies may have permanent effects on a country's growth rate;
3) large countries may grow faster (a scale effect).

More formal endogenous growth models

- Romer (1990), Jones (1995) and others use a model of profit-seeking firms investing in R&D
- A firm's R&D raises its profits, but also has a **positive externality** on other firms' R&D productivity (can have competitive behaviour at firm-level, but IRS overall)
- Assume $\boldsymbol{Y = K^{\alpha}(AL_Y)^{1-\alpha}}$
- Labour used either to produce output (L_Y) or technology (L_A)
- As before, *A* is technology (also called 'ideas' or 'knowledge')
- Note total labour supply is $L = L_Y + L_A$

Romer model

Assume $\frac{dA}{dt} = \delta L_A{}^{\lambda} A^{\phi}$ $\delta > 0$

This is differential equation. Can A have constant growth rate?

Answer: depends on parameters ϕ and λ and growth of L_A

Romer (1990) assumed: $\lambda = 1, \phi = 1$

hence $\frac{dA}{dt} = \delta L_A A$

$\Rightarrow \frac{dA}{dt} / A = \delta L_A$ (>0 if some labour allocated to research)

If A has positive growth, this will give long run growth in GDP *p.w.*

Note that there is a 'scale effect' from L_A

Note ‘**knife edge**’ property of ϕ=1. If ϕ>1, growth rate will accelerate over time; if ϕ<1, growth rate falls.

Jones model (semi-endogenous)

$\lambda > 0, \phi < 1$ (Jones, 1995)

Now $\dfrac{dA}{dt} = \delta L_A^{\lambda} A^{\phi} \quad \Rightarrow \quad \dfrac{dA}{dt} / A = \dfrac{\dot{A}}{A} = \dfrac{\delta L_A^{\lambda} A^{\phi}}{A} = \dfrac{\delta L_A^{\lambda}}{A^{1-\phi}}$

Can only have positive long run growth if far right term is constant

This only when $\lambda \dfrac{\dot{L}_A}{L_A} = (1-\phi)\dfrac{\dot{A}}{A}$ or $\dfrac{\dot{A}}{A} = \dfrac{\lambda}{(1-\phi)} \dfrac{\dot{L}_A}{L_A}$

In words: growth of technology = constant $\times$ labour growth

- No scale effects, no ‘knife edge’ property, but requires (exogenous) labour force growth hence “semi-endogenous” (see Jones (1999) for discussion)

Human capital – the Lucas model

- Lucas defines human capital as the skill embodied in workers
- Constant number of workers in economy is N
- Each one has a human capital level of h
- Human capital can be used either to produce output (proportion *u*)
- Or to accumulate new human capital (proportion *1-u*)
- Human capital grows at a constant rate

$$dh/dt = h(1-u)$$

Lucas model in detail

- The production of output (Y) is given by

  $$Y = AK^{\alpha} (uhN)^{1-\alpha} h_a^{\gamma}$$

  where $0 < \alpha < 1$ and $\gamma \geq 0$
- Lucas assumed that technology (A) was constant
- Note the presence of the extra term h_a^{γ} - this is defined as the 'average human capital level'
- This allows for external effect of human capital that can also influence other firms, e.g. higher average skills allow workers to communicate better
- Main driver of growth - As h grows the effect is to scale up the input of workers N, so raising output Y and raising marginal product of capital K

Creative destruction and firm-level activity

- many endogenous growth models assume profit-seeking firms invest in R&D (ideas, knowledge)
  - **Incentives**: expected **monopoly** profits on new product or process. This depends on probability of inventing and, if successful, expected length of monopoly (strength of intellectual property rights e.g. patents)
  - **Cost**: expected labour cost (note that 'cost' depends on productivity, which depends on extent of spillovers)
- models are 'monopolistic competitive' i.e. free entry into R&D $\Rightarrow$ zero profits (fixed cost of R&D=monopoly profits). 'Creative destruction' since new inventions destroy markets of (some) existing products.
- without 'knowledge spillovers' such firms run into diminishing returns
- such models have **three** potential market failures, which make policy implications unclear

Market failures in R&D growth models

1. Appropriability effect (monopoly profits of a new innovation < consumer surplus) $\Rightarrow$ **too little R&D**
2. Creative-destruction, or business stealing, effect (new innovation destroys profits of existing firms), which private innovator ignores $\Rightarrow$ **too much R&D**
3. Knowledge spillover effect (each firm's R&D helps reduce costs of others innovations; positive externality) $\Rightarrow$ **too little R&D**

The overall outcome depends on parameters and functional form of model

What do we learn from such models?

- Growth of technology via ‘knowledge spillovers’ vital for economic growth
- Competitive profit-seeking firms can generate investment & growth, but can be market failures (‘social planner’ wants to invest more since spillovers not part of private optimisation)
- Spillovers, clusters, networks, business-university links all potentially vital
- But models too generalised to offer specific policy guidance

Competition and growth

- Endogenous growth models imply greater competition, lower profits, lower incentive to do R&D and lower growth (R&D line shifts down)
- But this conflicts with economists' basic belief that competition is 'good'!
- Theoretical solution
  - Build models that have optimal 'competition'
  - Aghion-Howitt model describes three sector model ("escape from competition" idea)
- Intuitive idea is that 'monopolies' don't innovate

Do ‘scale effects’ exist

- Romer model implies countries that have more ‘labour’ in knowledge-sector (e.g. R&D) should grow faster
- Jones argues this not the case (since researchers in US $\uparrow$ 5x (1950-90) but growth still $\approx$2% p.a.
- Hence, Jones claims his semi-endogenous model better fits the ‘facts’, BUT
  - measurement issues (formal R&D labs increasingly used)
  - ‘scale effects’ occur via knowledge externalities (these may be regional-, industry-, or network-specific)
  - Kremer (1993) suggests higher population (scale) does increase growth rates over last 1000+ years
- anyhow…. both models show ϕ (the ‘knowledge spillover’ parameter) is important

Convergence debate: Do poorer countries grow faster?

Two common ways to assess convergence

1. Beta (β) convergence
2. Sigma (σ) convergence

<u>β-convergence</u> (use regression analysis)

$$growth_i = constant + \beta\ (initial\ GDP\ p.w.)_i$$

(i stands for a country. Test on sample of 60+)

If **β<0**, poorer countries, on average, grow faster

<u>σ-convergence</u>

measure **dispersion** (variance) of GDP per worker across countries in a given year. If dispersion **falls** over time can say countries 'converging'.

Problems and other evidence

- There are more than 110 countries (UN 191). The poorest countries often don’t have data. Hence above result could be mis-leading.
- L Pritchett (1997) “**Divergence, Big Time**”.
  - 1870-1990, rich countries got much richer
  - 9/1 ratio in 1870; 45/1 ratio in 1990
- Some view the 1960s-80s as good decades for poorer countries – normally divergence
- “Conditional convergence”.
  - If regression analysis controls for other factors (e.g. investment), poorer countries do grow faster.
  - Not very surprising …. what are other factors?

What are mechanisms driving ‘convergence’?

- Important to understand basic data, but real issue is mechanisms
- Consider some ‘theory’ initially
  - open economy growth models
  - models of technological catch-up
- Note: this ‘convergence’ is not ‘Solow-Swan convergence to steady state’
  - can consider country convergence in S-S model but must assume technology common to all countries

Conclusions

Sigma (σ) convergence

- Using unweighted measures, cross-country evidence suggests 'divergence'
- Weighted measures ⇒ convergence over last 30 years due to performance of China
- However, most recent 'world inequality' measures based on within and across country data, ⇒ divergence

Beta (β) convergence

- No unconditional convergence
- There is conditional convergence (poorer countries grow faster if you control for other factors)
- Expect this (basic closed economy Solow and endogenous growth models predict this)