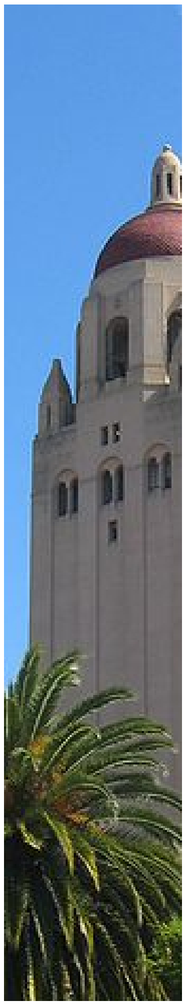

The Direction of Technical Change

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Uzawa's Theorem

Suppose a NGM with $Y_t = F(K_t, L_t, t)$ exhibits a BGP with $\frac{\dot{y}_t}{y_t} = g > 0$ starting at date 0. Then $\forall t > 0$,

$$Y_t = F(K_t, A_t L_t, 0)$$

where $\frac{\dot{A}_t}{A_t} = g$.

- If a NGM exhibits a BGP, then technical change must be "labor augmenting" along that path.
- Intuition: By CRS,

$$1 = F\left(\frac{K_t}{Y_t}, \frac{L_t}{Y_t}, t\right)$$

K_t/Y_t constant, so technical change must exactly neutralize the fall in L_t/Y_t.

The Direction of Technical Change: Why?

- Why in a NGM should technical change be labor augmenting? (Acemoglu 2003)
- To understand changes in the ratio of wages for college graduates to high school graduates, Katz and Murphy (1992) and a huge follow-on literature invoke skill-biased technical change (SBTC). Why should it be this way? (Acemoglu 1998)
- How do environmental problems and resource depletion affect the direction of technical change, sustainability, and growth? (Acemoglu, Aghion, Bursztyn, and Hemous).

Key Properties of CES Production Functions

$$Y_t = F(M_t K_t, N_t L_t) = (\alpha(M_t K_t)^\rho + (1-\alpha)(N_t L_t)^\rho)^{1/\rho}$$

	ρ	$EofS = \frac{1}{1-\rho}$
Cobb-Douglas	0	1
Leontief: min(K,L)	$-\infty$	0
Perfect Subst: Y=K+L	1	∞
Low EofS	$\rho < 0$	$EofS < 1$
High EofS	$0 < \rho < 1$	$EofS > 1$
	$-\infty < \rho < 1$	$0 < \sigma < \infty$

- Isoquants – K,L that produce a fixed amount of Y.

CES Properties (continued)

- Simple way to compute marginal products (memorize)

$$\boxed{\frac{F_K K}{Y} = \alpha \left(\frac{MK}{Y}\right)^{\rho}}$$

$$F_K = \alpha \frac{Y}{K} \cdot \left(\frac{MK}{Y}\right)^{\rho}$$

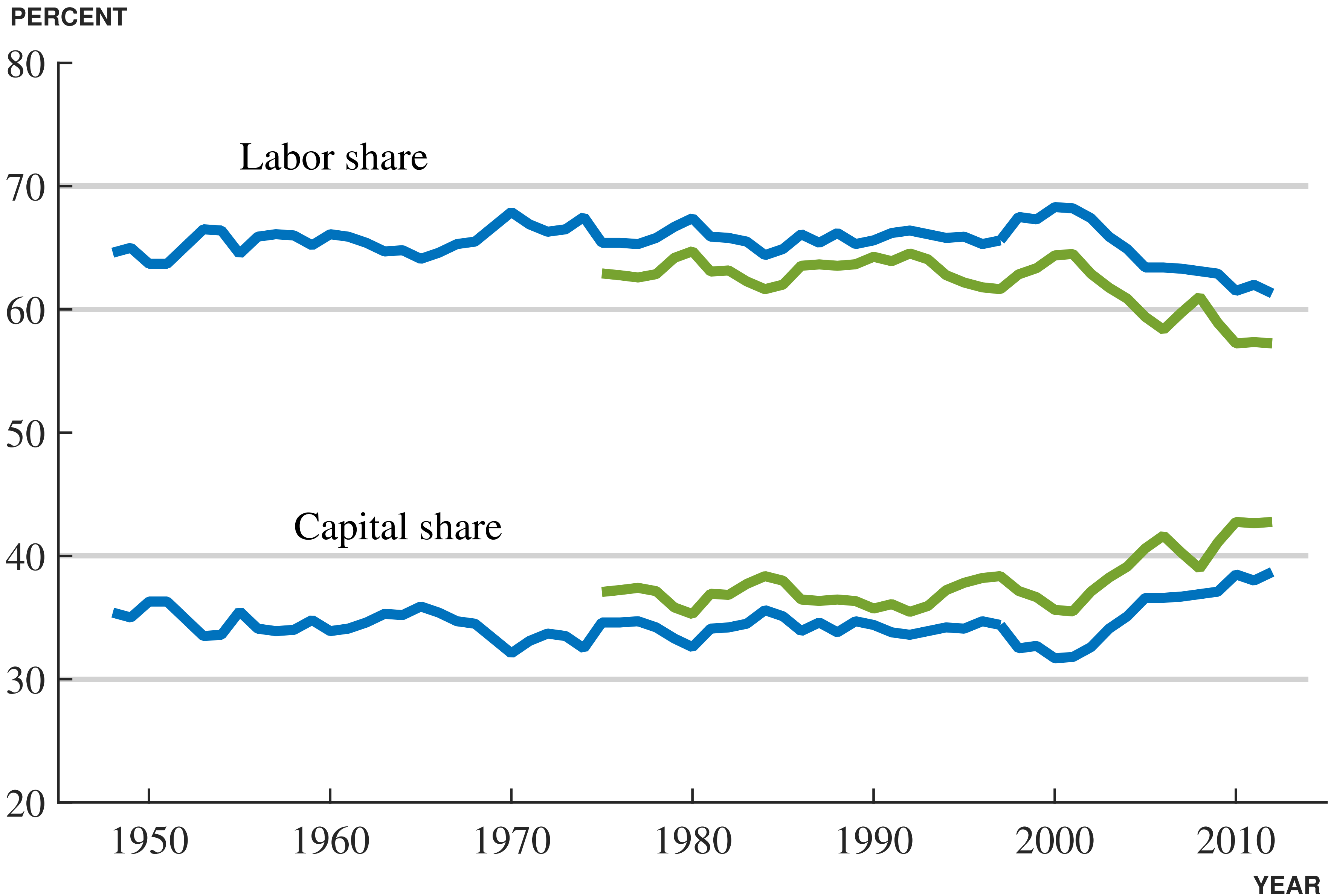
- Key applications of CES in growth models
  - Katz and Murpy (1992 QJE) Skill-biased tech. change
  - LJones and Manuelli (1990 JPE): AK behavior asympototically $\sigma > 1$
  - Acemoglu — various
  - Caselli and Coleman (2006 AER): Development accounting with CES.

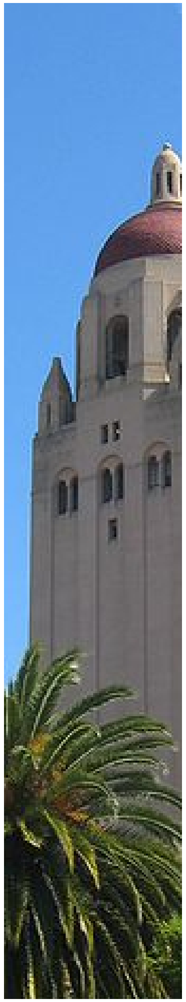
How Factor Shares Change with Scarcity

$$\boxed{\frac{F_K K}{Y} = \alpha \left(\frac{MK}{Y} \right)^{\rho}}$$

- $\sigma = 1$ $(\rho = 0)$: Cobb-Douglas, constant factor shares
- $\sigma < 1$ $(\rho < 0)$: Hard to substitute $\Rightarrow$ price changes more than quantity $\Rightarrow$ Scarcer factor gets rising share
- $\sigma > 1$ $(\rho > 0)$: Easy to substitute $\Rightarrow$ price changes less than quantity $\Rightarrow$ Plentiful factor gets rising share
    - Example: LJones and Manuelli: $\sigma > 1 \Rightarrow$ Capital share rises to one as capital accumulates $\Rightarrow$ asymptotically production is like $Y = MK$.

U.S. Factor Shares





Acemoglu (2003):

Labor- and Capital-Augmenting Technical Change

Overview

- Why should technical change be labor augmenting?
  - Study a two-dimensional Romer model, where $Y = F(MK, NL)$
  - R&D can raise M or N. What happens?
- Old literature in 1960s (Hicks, Samuelson, Kennedy, Fellner, Drandakis/Phelps).
  - Specify an frontier tradeoff $\frac{\dot{M}_t}{M_t}$ versus $\frac{\dot{N}_t}{N_t}$.
  - Maximize cost reduction instead of welfare
  - No true R&D model, no microfoundations
  - Sometimes got the Uzawa result

Economic Environment

Final output	$Y = \left(\gamma Y_L^{\frac{1-\epsilon}{\epsilon}} + (1-\gamma) Y_K^{\frac{1-\epsilon}{\epsilon}}\right)^{\frac{\epsilon}{1-\epsilon}}$
Capital	$\dot{K} = I$
Labor goods	$Y_L = \left(\int_0^n y_\ell(i)^\beta di\right)^{1/\beta}, \ 0 < \beta < 1$
Capital goods	$Y_K = \left(\int_0^m y_k(i)^\beta di\right)^{1/\beta}$
Production	$y_\ell(i) = \ell(i), \ \ y_k(i) = k(i)$
Resource constraints	$\int_0^n \ell(i) di = L, \ \int_0^m k(i) di = K,$
Idea PF	$\frac{\dot{n}_t}{n_t} = b_\ell S_\ell - \delta, \ \frac{\dot{m}_t}{m_t} = b_k S_k - \delta$
Resource constraint	$S_\ell + S_k = \bar{S}$
Preferences	$\int_0^\infty \frac{C_t^{1-1/\sigma}}{1-1/\sigma} e^{-\rho t} dt$

Social Planner Allocation

Symmetry: $Y_L = NL,\ Y_K = MK,\ N \equiv n^{1/\beta - 1},\ M \equiv m^{1/\beta - 1}$

$$\max_{\{C_t, v_t\}} \int_0^\infty u(C_t) e^{-\rho t} \ \ s.t.$$

$$Y_t = (\gamma (M_t K_t)^\eta + (1-\gamma)(N_t L_t)^\eta)^{1/\eta}$$

$$\dot{K}_t = Y_t - C_t$$

$$\frac{\dot{N}_t}{N_t} = b_n v_t \bar{S} - \delta$$

$$\frac{\dot{M}_t}{M_t} = b_m (1 - v_t) \bar{S} - \delta$$

Hamiltonian

$$H = u(C_t) + \lambda_t(Y_t - C_t) + \mu_{nt}(b_n v_t \bar{S} N_t - \delta N_t) + \mu_{mt}(b_m(1 - v_t)\bar{S} M_t - \delta M_t)$$

FOC:

(1) $H_c = 0$: $$u'(C_t) = \lambda_t$$

(2) $H_v = 0$: $$\mu_{nt} b_n \bar{S} N_t = \mu_{mt} b_m \bar{S} M_t$$

(3) Arbitrage(N): $$\rho = \frac{\dot{\mu_{n\,t}}}{\mu_{n\,t}} + \frac{1}{\mu_n}\left[\lambda_t \frac{\partial Y_t}{\partial N_t} + \mu_{nt}\frac{\dot{N}_t}{N_t}\right]$$

(4) Arbitrage(M): $$\rho = \frac{\dot{\mu_{m\,t}}}{\mu_{m\,t}} + \frac{1}{\mu_m}\left[\lambda_t \frac{\partial Y_t}{\partial M_t} + \mu_{mt}\frac{\dot{M}_t}{M_t}\right]$$

(5) Arbitrage(K): $$\rho = \frac{\dot{\lambda}_t}{\lambda_t} + \frac{1}{\lambda_t}\left[\lambda_t \frac{\partial Y_t}{\partial K_t}\right]$$

and transversality conditions.

Solving for BGP

- (1) + (5) $\Rightarrow \frac{\dot{C}_t}{C_t} = \sigma\left(\frac{\partial Y}{\partial K} - \rho\right) \Rightarrow \frac{\partial Y}{\partial K}$ constant
- $Y = C + I$ and $\dot{K} = I \Rightarrow g_Y = g_C = g_I = g_K$ along BGP.
- What is $\frac{\partial Y}{\partial K}$?

$$\frac{\partial Y}{\partial K} = (1-\gamma)\left(\frac{MK}{Y}\right)^{\eta}\frac{Y}{K}$$

$\Rightarrow M_t$ must be constant along a BGP!

BGP (continued)

- Now, solve rest of model to make sure a constant M is okay
- $\frac{\dot{M}_t}{M_t} = 0 \;\Rightarrow\; b_m(1 - v_t)\bar{S} = \delta \;\Rightarrow$

$$v^* = 1 - \frac{\delta}{b_m \bar{S}}$$

- Growth: $g_Y = g_C = g_K = g_I = g_N$

$$\boxed{g_N = b_n v^* \bar{S} - \delta}$$

as long as b_n is sufficiently large.

- Great! Acemoglu provides microfoundations where researchers endogenously choose LATC.

‘Lab Equipment’ Version?

- Suppose idea PF uses K and L as inputs, not just labor (Rivera-Batiz and Romer, 1991)
- New economic environment:

$$C + I + R_m + R_n = Y$$

$$\dot{N} = b_n s_n Y - \delta N, \quad R_{nt} = s_{nt} Y_t$$

$$\dot{M} = b_m s_m Y - \delta M, \quad R_{mt} = s_{mt} Y_t$$

Hamiltonian

$H = u(C) + \lambda((1 - s_n - s_m)Y - C) + \mu_n(b_n s_n Y - \delta N) + \mu_m(b_m s_m M - \delta M)$

FOC: (use (2) and (3) to simply arbitrage results)

(1) $H_c = 0$: $$u'(C) = \lambda$$

(2) $H_{s_n} = 0$: $$\lambda Y = \mu_n b_n Y$$

(3) $H_{s_m} = 0$: $$\lambda Y = \mu_m b_m Y$$

(3) Arbitrage(N): $$\rho = \frac{\dot{\mu_n}}{\mu_n} + \frac{\lambda}{\mu_n}\frac{\partial Y}{\partial N} - \delta$$

(4) Arbitrage(M): $$\rho = \frac{\dot{\mu_m}}{\mu_m} + \frac{\lambda}{\mu_m}\frac{\partial Y}{\partial M} - \delta$$

(5) Arbitrage(K): $$\rho = \frac{\dot{\lambda}}{\lambda} + \frac{\partial Y}{\partial K}$$

and transversality conditions.

Solving for BGP

- As before Euler eqn $\Rightarrow$ MPK constant $\Rightarrow$ M constant. But now, this will pose problems!
- FOC (2) and (3) $\Rightarrow \frac{\mu_n}{\mu_m} = \frac{b_m}{b_n}$ constant. (Why?)
- But (4) and (5) $\Rightarrow$

$$\mu_n = \frac{\lambda \frac{\partial Y}{\partial N}}{\rho - g_{\mu_n} + \delta}, \quad \mu_m = \frac{\lambda \frac{\partial Y}{\partial M}}{\rho - g_{\mu_m} + \delta}$$

- Therefore $\frac{\mu_n}{\mu_m}$ constant $\Rightarrow \frac{\partial Y / \partial N}{\partial Y / \partial M}$ constant

$$\boxed{\frac{\partial Y / \partial N}{\partial Y / \partial M} = \frac{\gamma}{1-\gamma} \left(\frac{LN}{MK} \right)^{\eta} \frac{M}{N}}$$

- So $\frac{\partial Y / \partial N}{\partial Y / \partial M}$ falls at rate g_N $\Rightarrow$ No BGP!

Comparing the models

- In both, MPK constant $\Rightarrow M$ constant.
- Moreover, the benefit of creating ideas depends on

$$\frac{\partial Y/\partial N}{\partial Y/\partial M} = \frac{\gamma}{1-\gamma}\left(\frac{LN}{MK}\right)^{\eta}\frac{M}{N}$$

  which falls at rate g_N.
- Therefore, for a BGP to exist, the relative cost of creating ideas must fall at rate g_N as well...

Comparing the models (continued)

Does the relative cost of creating N versus M fall at rate g_N?

Model 1:

$$\dot{N} = b_n S_\ell N - \delta N$$

$$\dot{M} = b_m S_k M - \delta M$$

Model 2:

$$\dot{N} = b_n v Y - \delta N$$

$$\dot{M} = b_m (1 - v) Y - \delta M$$

Model 3:

$$\dot{N} = b_n S_\ell^\lambda N^\phi - \delta N$$

$$\dot{M} = b_m S_k^\lambda M^\phi - \delta M$$

Model 4:

$$\dot{N} = b_n S_\ell N^\alpha M^\beta - \delta N$$

$$\dot{M} = b_m S_k N^\lambda M^\theta - \delta M$$

Comments

- Great idea for a paper!
- One can write down a model with microfoundations that leads to the LATC result and a BGP
- However, that model is quite fragile.
- This paper offers an intriguing possibility, but in general there's no real reason here to think that economic forces will lead to LATC.

Additional Work

- Jones (2005 QJE): Houthakker + Kortum =
  - Exponential growth
  - Cobb-Douglas (global) production function
  - Labor-augmenting technical change.
- Karabarbounis and Neiman (2014 QJE)
  - “Declining Labor Shares and the Global Rise of Corporate Savings”
  - Great data on labor shares in 51 countries
  - Many show declines
- Robots? Agriculture?
  - Acemoglu and Restrepo, “The Race between Man and Machine...” in progress

Further Directions after AABH

- Dell, Jones, Olken (2011) “Temperature Shocks and Economic Growth: Evidence from the Last Half Century”
- Per Krusell, Tony Smith, John Hassler, Golosov, Tsyvinski — recent papers on climate, pollution, and growth.
- Acemoglu, Akcigit, Hanley, and Kerr (JPE forthcoming), “Transition to Clean Technology” — Estimates AABH. $\Rightarrow$ carbon taxes and research subsidies.
- Aghion et al (Hemous/JVR), (2015 JPE) “Carbon taxes, path dependency and directed technical change: evidence from the auto industry”
- How to move the model closer to empirics — wide range of outcomes are optimal in current setup. ϵ, ψ?
- Apply to developing countries (China, India)?