Clarendon Lectures, Lecture 2

Implications of Directed Technical Change, Cross-Country Income Differences and Economic Divergence

Daron Acemoglu

October 23, 2007

Summary of Lecture 1

- Importance of directed technical change.
- Results on the equilibrium direction of technical change.
  - Factor Augmenting Theorem.
  - Weak Bias Theorem
  - Strong Bias Theorem
- Implications for the evolution of skill bias of technology and the nature of technological change.

This Lecture

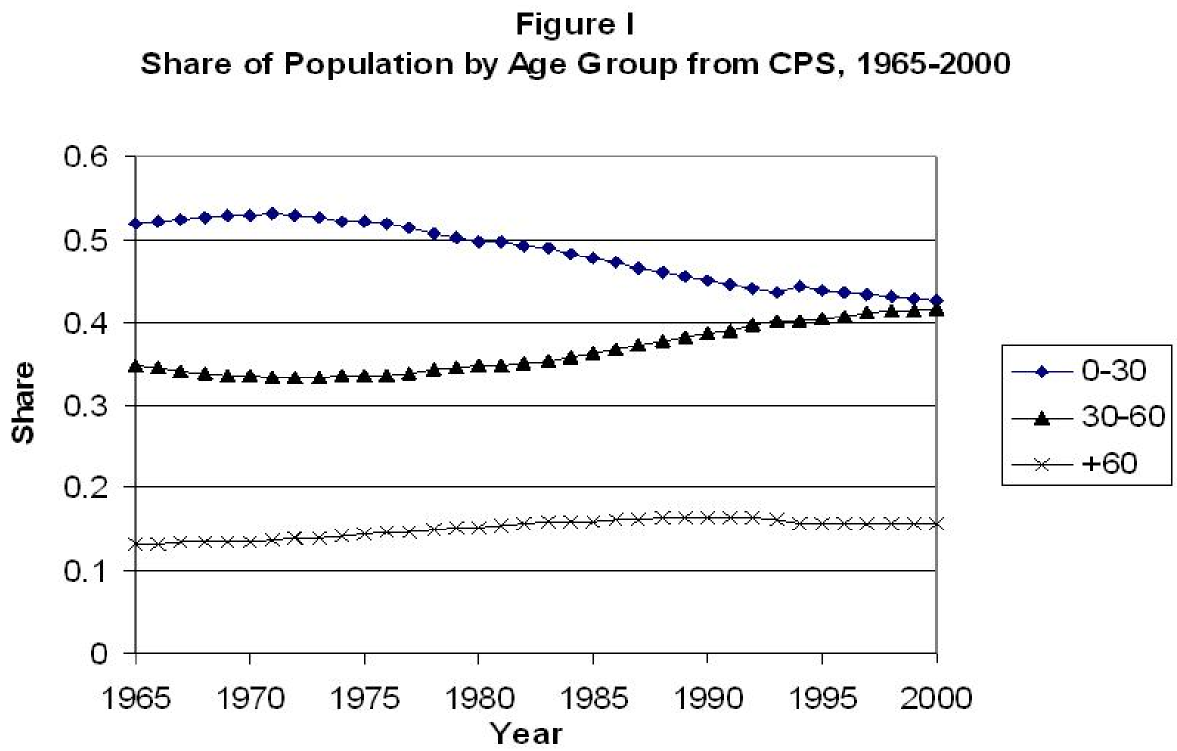
- Applications (with theory and evidence).
  1. Demographics and evolution on innovations in the pharmaceutical industry (joint work with Joshua Linn).
  2. A theory of cross-country income differences (joint work with Fabrizio Zilibotti).
  3. Possible perspectives on "lost decades" (joint work with Samuel Pienknagura).
  4. The effect of international trade on the nature of innovation and on cross-country income differences.
  5. Why should long-run technological change be labor augmenting?

Demographics and Innovation

- Pharmaceutical industry one of the most innovative sectors of the economy.
- With market research and competition, highly profit-driven.
- Consistent with the models of Lecture 1, large fixed costs and development and clinical trials of drugs.
- How should we expect the pharmaceutical industry to respond to the demographic changes due to the baby boom in the baby bust.

Demographic Changes

- Over the past 40 years large demographic changes.
- Different groups consume different types of drugs.



Motivating Theory: Environment

- Individual i has an endowment $y_i(t)$ at time t.
- A large number J of drugs, x_1, ..., x_J.
- Each drug has a potentially time-varying "quality", $q_1(t)$, ..., $q_J(t)$.
- These qualities are improved by research and development.
- Preferences

$$\int_0^{\infty} \exp(-rt) \left[c_i(t)^{1-\gamma} (q_j(t) x_{ji}(t))^{\gamma} \right] dt,$$

  for individual $i \in G_j$, i.e., individual who will consume this type of drug.
- One unit of the final good devoted to R&D for drug line j leads to a flow rate of $\delta_j > 0$ of discovering a new drug of this type, which is an improvement λ over the existing quality.
- Important feature: research directed.

Environment (continued)

- In equilibrium, limit prices (because of competition between different qualities of drugs):

$$p_j(t) = \lambda.$$

- Value of innovation in sector j with current quality q_j given by

$$rV_j(t \mid q_j) - \dot{V}_j(t \mid q_j) = \pi_j(q_j) - \delta_j z_j(t \mid q_j) V_j(t \mid q_j)$$

where $z_j(t \mid q_j)$ R&D effort or expenditure, and

$$\begin{aligned} \pi_j(q_j(t)) &= (\lambda - 1)\gamma \sum_{i \in G_j} y_i(t) \\ &= (\lambda - 1)\gamma Y_j(t) \end{aligned} \tag{1}$$

is flow profits and $Y_j(t) \equiv \sum_{i \in G_j} y_i(t)$ is **market size** for drug j.

Equilibrium

- Free entry requires

$$\text{if } z_j(t) > 0, \text{ then } \delta_j V_j(t \mid q_j) = 1.$$

- Unique equilibrium:

$$z_j(t) = \max\left\{\frac{\delta_j(\lambda-1)\gamma Y_j(t) - r}{\delta_j}; 0\right\},$$

- R&D effort depends on sector-specific technology δ_j and market size $Y_j(t)$.
- Important: no transitional dynamics.
- Because it is only worthwhile to invest in new drugs when the actual market size increases.

Anticipation Effects

- Modify the R&D technology such that one unit of final good spent for R&D in line j leads to the discovery of a better drug at the flow rate $\delta_j z_j \phi(z_j)$, where $\phi'(z) \leq 0$ for all z—external decreasing returns to research effort within a period.
- Also assume that $Y_j(t) = Y_j$ for all t.
- Equilibrium:

$$\frac{\dot{z}_j(t)}{z_j(t)} = \frac{1}{\varepsilon_\phi(z_j(t))}\left[r + \delta_j z_j(t)\phi(z_j(t)) - \delta_j \phi(z_j(t))(\lambda - 1)\gamma Y_j\right].$$

where $\varepsilon_\phi(z_j(t)) \equiv -\phi'(z_j(t)) z_j(t) / \phi(z_j(t))$ is the elasticity of the ϕ function.

Anticipation Effects (continued)

- Steady-state equilibrium similar to before

$$z_j^S = \frac{\delta_j \phi\left(z_j^S\right)(\lambda - 1)\gamma Y_j - r}{\delta_j \phi\left(z_j^S\right)}$$

- No transitional dynamics in equilibrium.
- Response to anticipated changes in market size, but limited—intuition same as before.

From Theory to Estimation

- R&D success: "major new drugs" entitled new molecular entities.
- Here success rate is $n_j(t) = \delta_j z_j(t)$, with $n_j(t) = \delta_j(\lambda - 1)\gamma Y_j(t) - r \equiv \delta_j m_j(t)$, where. $m_j(t) =$market size.
- As $r \longrightarrow 0$:

$$n_j(t) = \text{constant} \times \delta_j \times m_j(t),$$

- Allowing for other determinants and time effects yields the Poisson model:

$$E\left[N_{ct} \mid \zeta_c, \bar{X}_c\right] = \exp(\alpha \cdot \log M_{ct} + X'_{ct} \cdot \beta + \zeta_c + \mu_t),$$

- N_{ct}: number of new molecular entities in drug category c; M_{ct}: our measure of demographically-driven potential market size; $\bar{X}_c$ denotes the vector of all (strictly) exogenous variables from $t = 1, ..., T$.

Estimation

- Poisson model with fixed effects $\longrightarrow$ inconsistent estimates.
- Use the Hausman, Hall and Griliches conditional logit transformation to eliminate fixed effects and apply quasi-ML.

$$E\left[N_{ct} \mid \zeta_c, \bar{X}_c, \bar{N}_c\right] = \frac{\exp(\alpha \cdot \log M_{ct} + X'_{ct} \cdot \beta + \mu_t)}{\sum_{\tau=1}^{T} \exp(\alpha \cdot \log M_{c\tau} + X'_{c\tau} \cdot \beta + \mu_\tau)} \bar{N}_c, \quad (2)$$

- Consistent under relatively weak assumptions.

Data

- Data on new molecular entities on 33 drug categories.
- Key variable: potential market size:

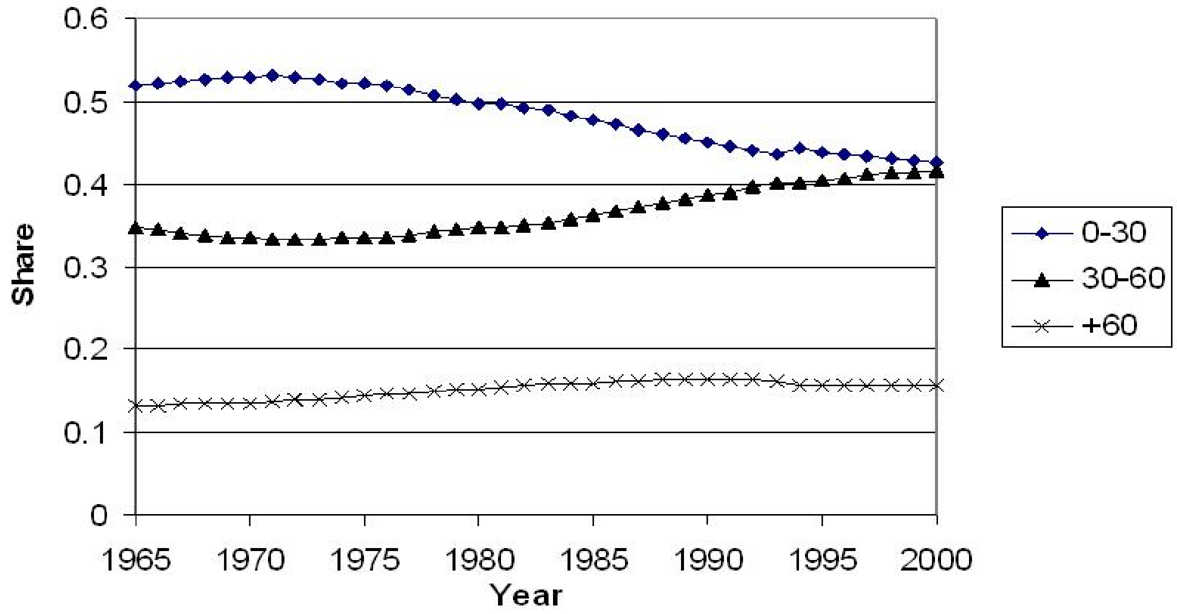
$$M_{ct} = \sum_a u_{ca} \cdot i_{at}, \tag{3}$$

  where i_{at} is the U.S. income at time t that is in age category a, and u_{ca} is the expenditure share of drug category c in the incomes of those in age group a (five-year age bins).

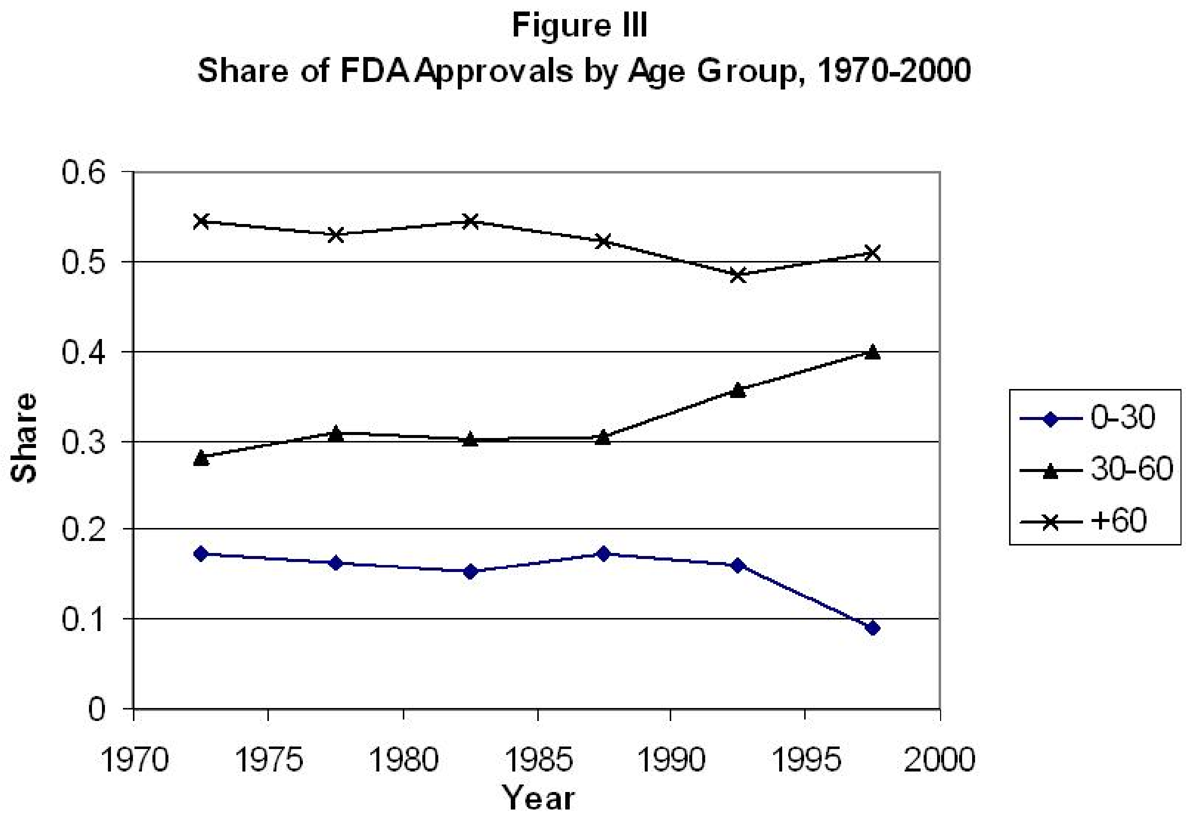
- Note u_{ca} time invariant, so all variation in potential market size from aggregate demographic and income changes.
- Five-year age groups, 0-4,..., 90+; five-year time periods.
- Sample: 1970-2000.

Broad Patterns in the Data

Figure I
Share of Population by Age Group from CPS, 1965-2000



Broad Patterns in the Data (continued)



Summary of Results

- Positive and significant effect of market size on entry of new drugs.
- Generally, a 1 percent increase in potential market size associated with approximately a 3-4 percent increase in the entry of new molecular entities.
- No evidence of a response to lagged market size.

Some Details

- Results from quasi-maximum likelihood estimation of the model:

QML for Poisson model

Dependent Variable: Count of new molecular entities

Market size	3.54	5.79	-1.38	
	(1.19)	(6.66)	(5.16)	
Lag market size		-1.99		
		(5.28)		
Lead market size			7.35	5.75
			(5.11)	(2.37)

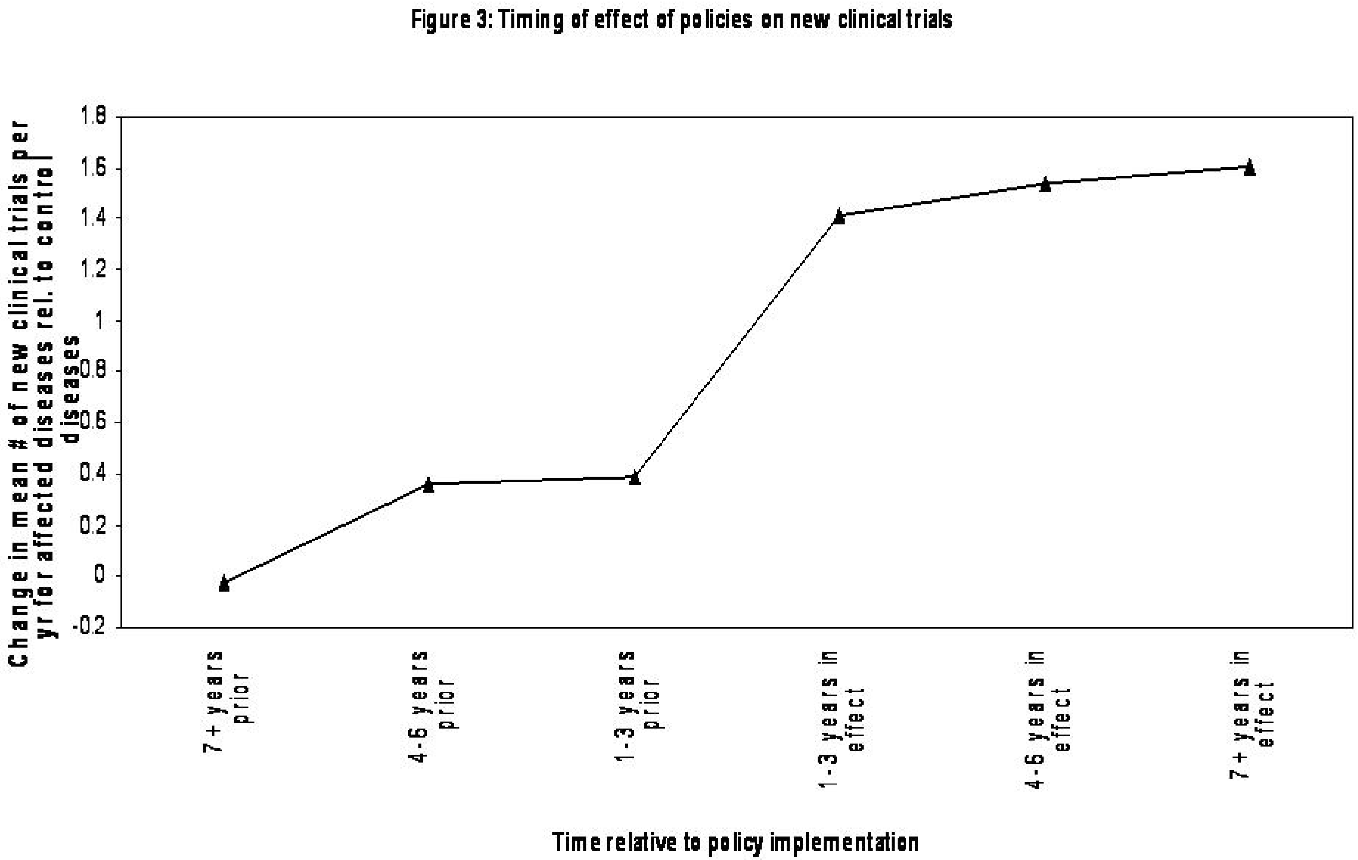
Table 1: Huber-White robust standard errors are reported in parentheses.

Conclusion and Other Research

- Consistent with the ideas of directed technical change, very strong response to changes in market size driven by exogenous demographics.
- Similar results from policy changes.
- Finkelstein (2004): increased subsidies to certain types of vaccines $\Rightarrow$ greater clinical trials for developing these vaccines.

Conclusion and Other Research (continued)

- The increase in the number of clinical trials for vaccines receiving greater subsidies:



Cross-Country Income Differences

- Directed technical change $\Rightarrow$ new theory of cross-country income differences.
- Key idea: directed technical change $\Rightarrow$ major technologies inappropriate for initially poor economies.

Theory of Inappropriate Technology

- Consider the framework from Lecture 1.
  - Possible to develop the same points in richer models
- Suppose that all technology invented and developed in OECD economies.
- Also weak intellectual property rights in the rest of the world, so the main market size for these technologies the OECD.
- Let us focus on the two factors as unskilled and skilled labor $(Z = H)$.

Reprise on Equilibrium

- Recall that with the structure in Lecture 1, BGP technology is

$$\left(\frac{N_Z}{N_L}\right)^* = \eta^\sigma \gamma^\varepsilon \left(\frac{Z}{L}\right)^{\sigma-1},$$

- Now because $Z = H$ and only supplies in the OECD are relevant, we have

$$\left(\frac{N_H}{N_L}\right)^* = \eta^\sigma \gamma^\varepsilon \left(\frac{H^U}{L^U}\right)^{\sigma-1},$$

  where H^U number of skilled workers in the US or the OECD, and L^U number of unskilled workers.

- Implication: technological change **directed** at supplies in the US or the OECD.

Implications for LDCs

- Previously poor economies, LDCs, import these technologies.
- The main theory of technological convergence across countries relies on flows of technology from advanced economies to less advanced ones.
- But the of the LDCs will have to use these technologies with their own factor supplies.
- Potential source of inappropriateness.
- For example: consider the case where $L^U = 0$ and for LDCs $H^S = 0$.

Some Theoretical Results

- Define net output in country j as:

$$NY_j \equiv Y_j - X_j,$$

where $j = U$ for the US are OECD and $j = S$ for the LDCs.

- Income per capita and income per effective unit of labor in different countries:

$$y_j \equiv \frac{Y_j}{L_j + H_j} \text{ and } y_j^{eff} \equiv \frac{Y_j}{L_j + \omega H_j}.$$

- All of these quantities are functions of labor supplies and of relative technologies, N_H / N_L.

Some Theoretical Results (continued)

Proposition: With directed technical change and weak intellectual property rights in the LDCs, the world equilibrium is such that the BGP technology ratio N_H^*/N_L^* achieves the unique maximum of net output in the OECD for given $N_H + N_L$ (as a function of relative technology N_H/N_L).

Moreover, given the BGP technology ratio N_H^*/N_L^*, we have

$$y_U > y_S$$

and

$$y_U^{eff} > y_S^{eff}.$$

Implications

- Incomes and productivity will be endogenously higher in the OECD than the LDCs because technology is appropriate to the OECD, but not to the LDCs.
- It can be verified that this effect can be theoretically very large.
- How large is it for empirically plausible specifications?

Case Study for Inappropriate Technology

- Production of diesel engines in Japan and India.
- During the early 1960s, the same leading manufacture Cummins Engine Co., opened plants in India and Japan to produce the same truck engine.
- Outcomes very different: within a few years the Japanese plant was "producing the Cummins engine with 80 to 90 percent local content and of a quality that equaled international standards." The Indian plant was a failure (Baranson, 1967, 1972).
- Main reason: the Indian workers did not possess the "high degree of technical skill...required to convert techniques and produce the new technical drawings and manufacturing specifications." (Baranson, 1972, pp. 58-59, 1967, pp. 80-81).
- General pattern: Chen (1983) "...technologies used by the parent firm are not introduced into its overseas subsidiary because of the lack of the required technical skill to cope with them."
- Particularly important: lack of experienced engineers and middle managers to operate modern technologies.

Appropriate Technology and the Lost Decades

- Could increased skill bias of technology over the past 30 years have contributed to the “lost decades,” whereby the convergence of many countries in Latin America and Asia to the richest nations slowed down or reversed?

- Basic idea: greater skill bias of frontier technologies creates a further disadvantage in technological catch-up.

- To investigate the extent of this issue, let us consider a simple “calibration of the model”.

- Also supplement this with estimation.

Taking the Model the Data

- Strategy: anchor the model to elasticities of substitution from US labor market and evolution of relative prices and relative supplies in the US market to estimate bias of technology.
- Given these inputs, we can compute:
  - how much of the changes in the world income distribution the standard neoclassical growth model accounts for;
  - how introducing notions of inappropriate technology contributes to differential evolution of incomes.

Taking the Model the Data

- To provide a better fit to the data, extend the model, so that there are three types of workers, low-skill (less than high school education), medium-skill (high school equivalents) and high-skill (college equivalents).
- Output in country j:

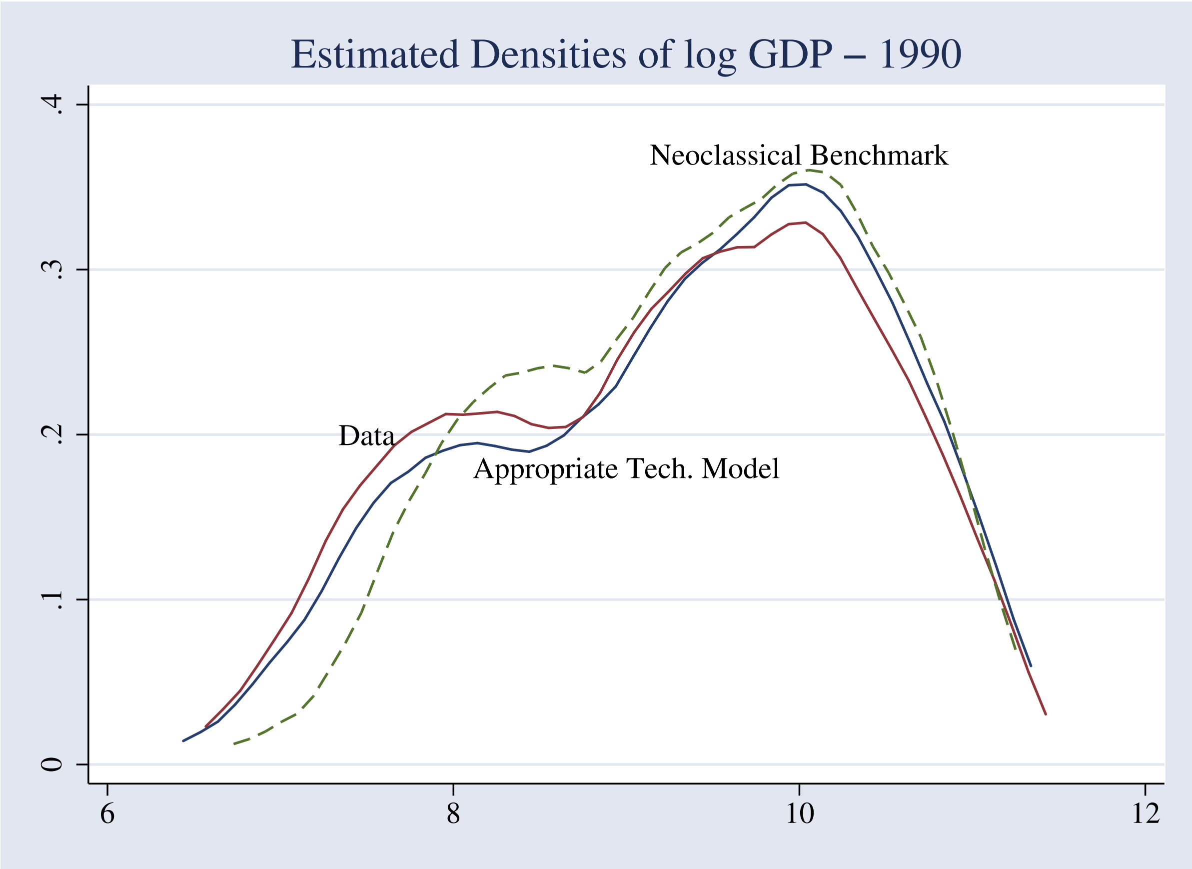
$$Y_j(t) = B_j \times \bar{B}(t) \times [K_j(t)]^{1-\alpha} \times$$
$$\left[\gamma_H \left(A_H(t)H_j(t)\right)^{\frac{\sigma-1}{\sigma}} + \gamma_M \left(A_M(t)M_j(t)\right)^{\frac{\sigma-1}{\sigma}} + \gamma_L \left(A_L(t)L_j(t)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\alpha\sigma}{\sigma-1}}$$

Taking the Model the Data (continued)

- Here $H_j(t)$, $M_j(t)$ and $L_j(t)$ supplies of high, middle and low skill workers in country j at time t.
- $K_j(t)$: capital (computed by perpetual inventory).
- $A_L(t)$, $A_M(t)$ and $A_H(t)$ technology terms "developed in the US" and used in all countries.
- B_j: fixed cross-country differences capturing other factors.
- The effects potentially larger if there is costly decision to adopt new technologies.
- Choose $\alpha = 2/3$ and $\sigma = 2$ consistent with US and international evidence.
- The rest of parameters (in particular B_j, $\bar{B}(t)$, $A_L(t)$, $A_M(t)$ and $A_H(t)$) chosen to match the 1970 world income distribution, evolution of the US income per capita, and evolution of US labor market prices.

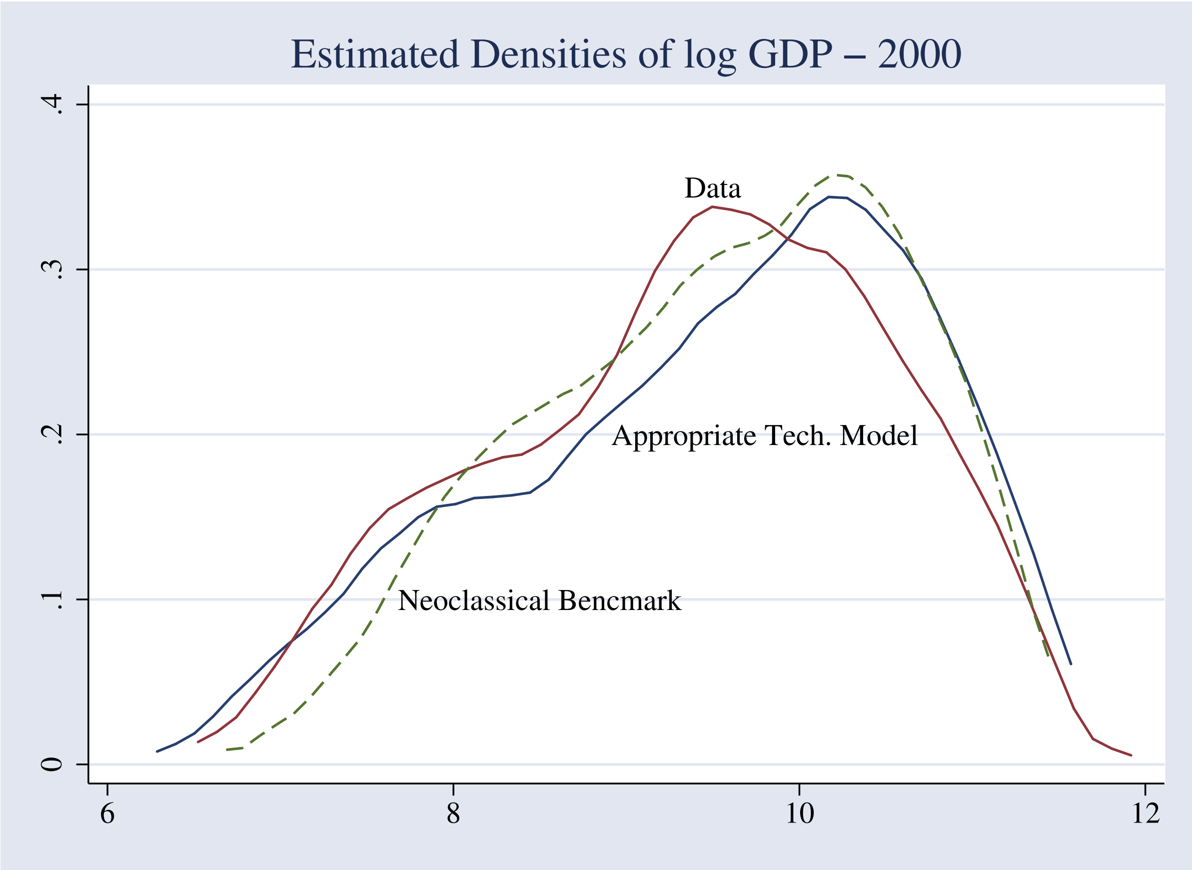
Results at a Glance

- Evolution the world income distribution
- Data, neoclassical benchmark and model of (in)appropriate technology.



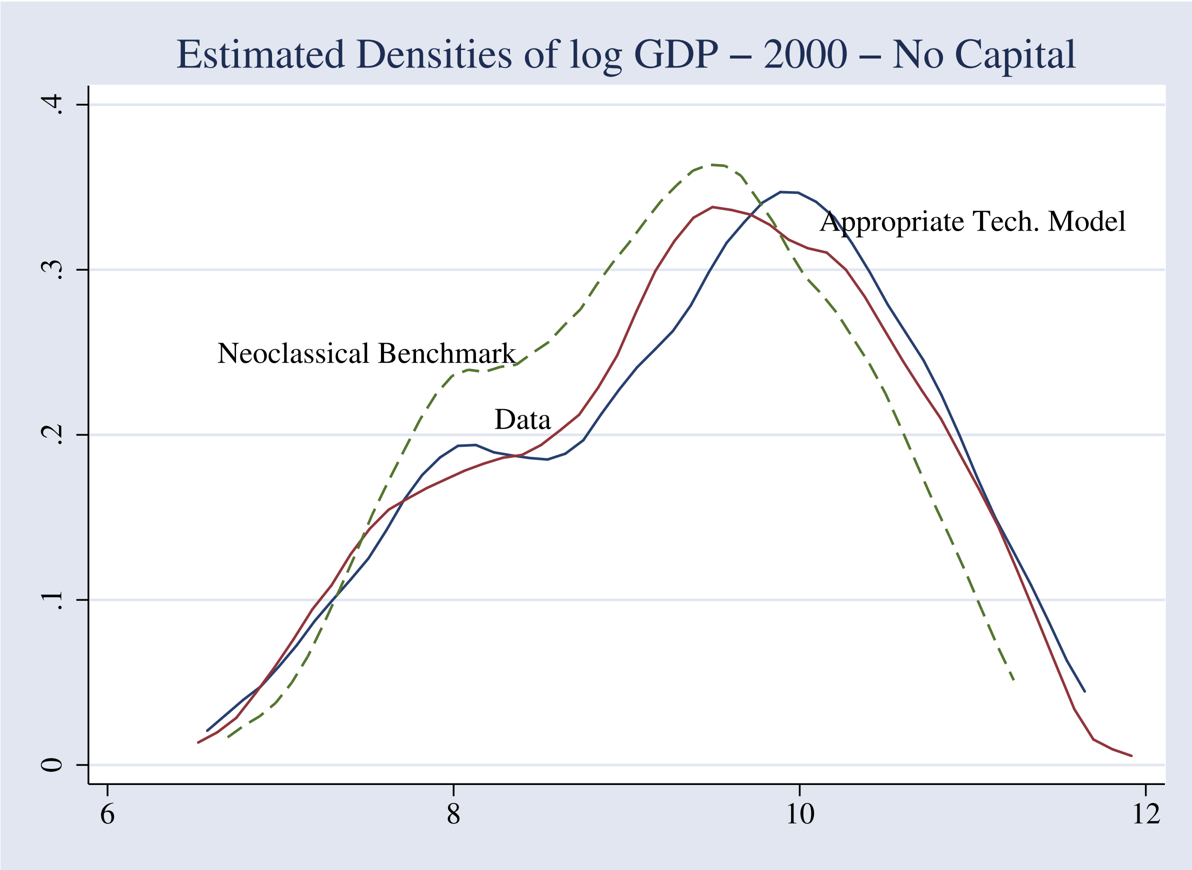
Results at a Glance (continued)

- By 2000, substantially more inequality among countries, better matched by the model of appropriate technology.



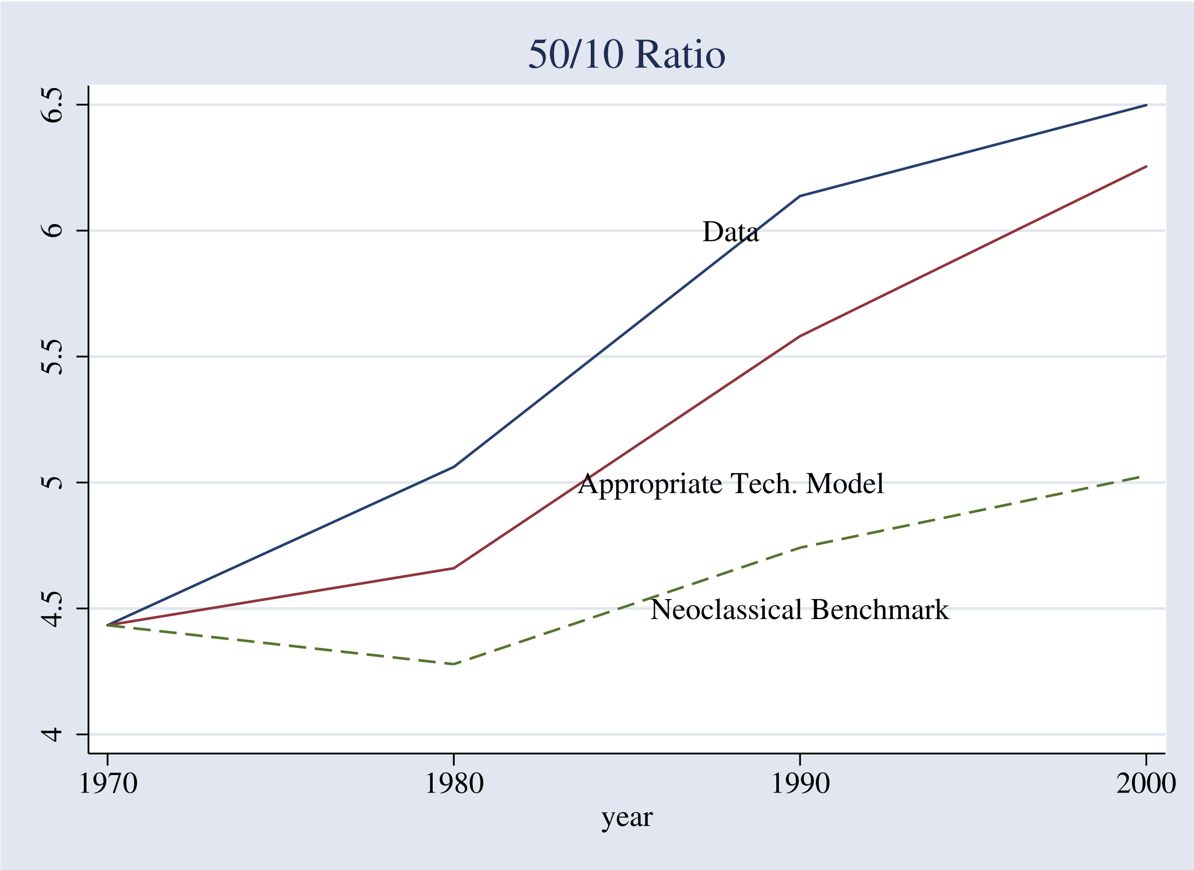
Results at a Glance (continued)

- Similar patterns if the rate of return on capital is supposed to be equalized across countries at each date.



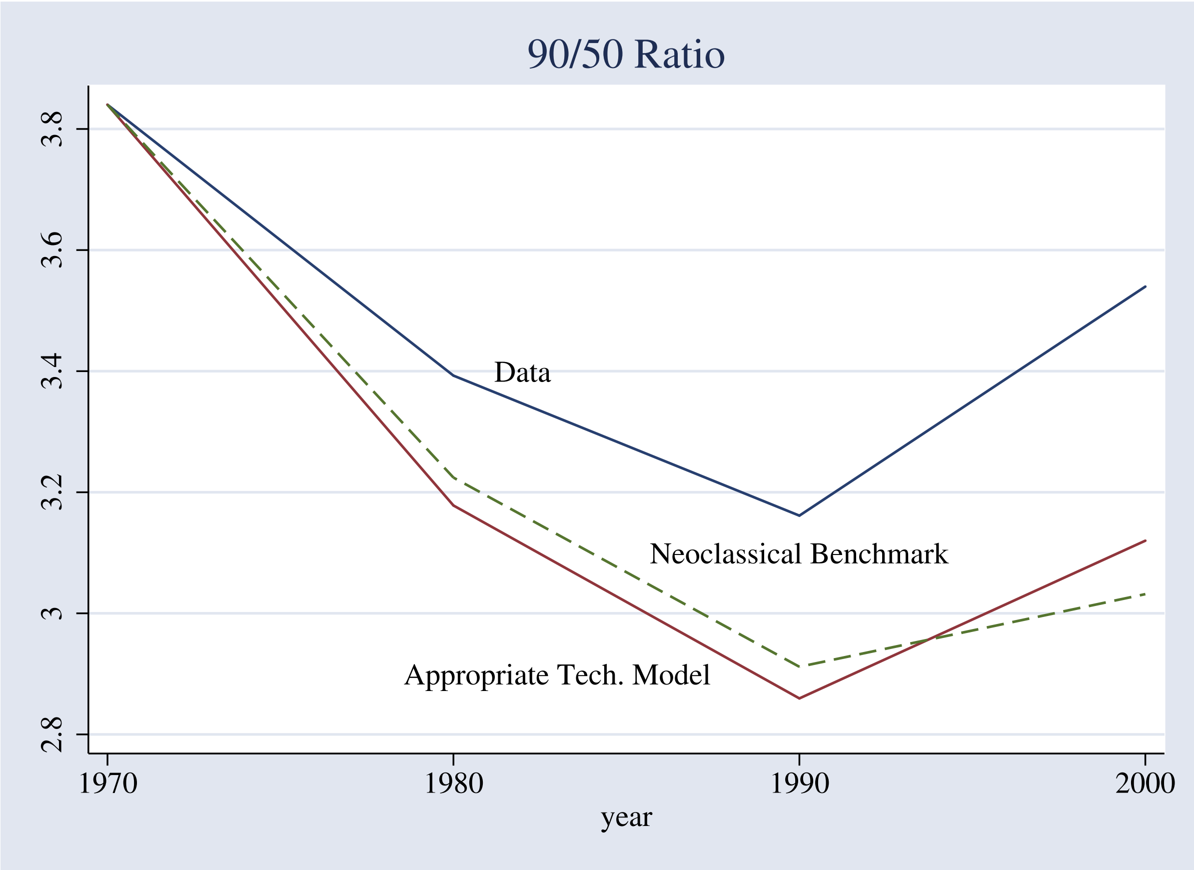
Evolution of Cross-Country Inequality at the Bottom

- The appropriate technology model much more successful in predicting the slowdown of convergence at the bottom.



Evolution of Cross-Country Inequality at the Top

- Both the neoclassical in the appropriate technology models not very successful in matching the convergence at the top.



Conclusions

- Directed technical change plus weak intellectual property rights potential barrier to technology flows across countries.
- The effects on cross-country income differences and productivity could be large.
- Potentially responsible for a significant part of the "lost decades" during which convergence of low-human capital LDCs to frontier economies slowed down.
- How much can we trust these results? Not clear, because based on a simple "calibration exercise".
- Nevertheless, direct estimation of the above production function on cross country panel on income and human capital distributions gives very similar results.

International Trade and Direction of Technical Change

- Now imagine that in the above-describe world, there is trade opening.
- But enforcement of intellectual property rights remains unchanged.
- What is the effect on direction of new technologies? What is the effect on cross-country income differences?

International Trade and Skill Biased Technical Change

- Recall the free entry equation, now written for OECD supplies:

$$\left(\frac{p_H}{p_L}\right)^{-\frac{1}{\beta}} = \eta \frac{H^U}{L^U}$$

- Trade opening: greater supply of L in the world economy (through import of labor-intensive products) $\Rightarrow p_H/p_L \downarrow$.
- How will equilibrium be restored?
- p_H/p_L needs to increase.

International Trade and Skill Biased Technical Change (continued)

- Recall that

$$\left(\frac{p_H}{p_L}\right) = \gamma^{\frac{\varepsilon\beta}{\sigma}} \left(\frac{N_H H}{N_L L}\right)^{-\frac{\beta}{\sigma}}$$

  where now H and L refer to world supplies.

- Therefore, p_H/p_L will increase with further **skill biased** technical change.

- As usual, if $\sigma > 1$, $N_H/N_L \uparrow$, and if $\sigma < 1$, $N_H/N_L \downarrow$.

- Intuition: price effect on the direction of technical change.

  - Market sizes for different technologies unchanged; trade affects product prices.

- Potentially much larger effects of trade opening on inequality in OECD than in standard theory.

International Trade and Cross-Country Income Differences

- Implications for cross-country inequality.
- Before trade opening, technology is already "too skill biased" for the LDCs.
- Trade opening leads to further skill biased technological change, thus opening the gap between OECD and LDCs.
- Trade is beneficial for LDCs, but increases cross-country inequality.

More on Labor-Augmenting Technological Change

- Why should technological change be labor augmenting in the long run?
- Let us consider a generalization of the baseline model of directed technical change.
- Main change: knowledge spillovers across sectors.
- Why knowledge spillovers?
- Endogenous technological change models normally rely on such spillovers.
- If research uses scarce factors (such as labor or scientists), sustained growth only possible with such spillovers.
- So far avoided by using the lab equipment specification.

Directed Technical Change with Knowledge Spillovers

- The lab equipment specification of the innovation possibilities frontier does not allow for state dependence.
- Assume that R&D is carried out by scientists and that there is a constant supply of scientists equal to S
- With only one sector, sustained endogenous growth requires $\dot{N}/N$ to be proportional to S (Romer's original formulation).
- With two sectors, there is a variety of specifications with different degrees of state dependence, because productivity in each sector can depend on the state of knowledge in both sectors.

Directed Technical Change with Knowledge Spillovers (continued)

- A flexible formulation is

$$\begin{aligned} \dot{N}_L(t) &= \eta_L N_L(t)^{(1+\delta)/2} N_Z(t)^{(1-\delta)/2} S_L(t) \\ \text{and } \dot{N}_Z(t) &= \eta_Z N_L(t)^{(1-\delta)/2} N_Z(t)^{(1+\delta)/2} S_Z(t), \end{aligned}$$

  where $\delta \leq 1$ is the extent of state dependence.

- Scientists introduced for simplicity (alternatively labor or some other scarce factor with give equivalent results).

- In general, both N_L and N_H create spillovers for current research in both sectors.

- Market clearing for scientists requires that

$$S_L(t) + S_H(t) \leq S.$$

Directed Technical Change with Knowledge Spillovers (continued)

- If $\delta = 0$, results presented so far apply exactly because no state-dependence:

$$\left(\partial \dot{N}_Z / \partial S_Z\right) / \left(\partial \dot{N}_L / \partial S_L\right) = \eta$$

is constant regardless of the levels of N_L and N_Z.

- $\delta = 1$. Extreme state-dependence:

$$\left(\partial \dot{N}_Z / \partial S_Z\right) / \left(\partial \dot{N}_L / \partial S_L\right) = \eta N_Z / N_L$$

- In this case, an increase in the stock of L-augmenting machines today makes future labor-complementary innovations cheaper, but has no effect on the cost of Z -augmenting innovations.

Equilibrium with Knowledge Spillovers

- State dependence adds another layer of "increasing returns," this time not for the entire economy, but for specific technology lines.
- Free entry conditions:

$$\begin{aligned} \eta_L N_L(t)^{(1+\delta)/2} N_Z(t)^{(1-\delta)/2} V_L(t) &\leq w_S(t) \\ \text{and } \eta_L N_L(t)^{(1+\delta)/2} N_Z(t)^{(1-\delta)/2} V_L(t) &= w_S(t) \text{ if } S_L(t) > 0. \end{aligned}$$

and

$$\begin{aligned} \eta_Z N_L(t)^{(1-\delta)/2} N_Z(t)^{(1+\delta)/2} V_Z(t) &\leq w_S(t) \\ \text{and } \eta_Z N_L(t)^{(1-\delta)/2} N_Z(t)^{(1+\delta)/2} V_Z(t) &= w_S(t) \text{ if } S_Z(t) > 0, \end{aligned}$$

where $w_S(t)$ denotes the wage of a scientist at time t.

Equilibrium with Knowledge Spillovers (continued)

- When both of these free entry conditions hold, BGP free entry implies:

$$\eta_L N_L (t)^{\delta} \pi_L = \eta_Z N_Z (t)^{\delta} \pi_Z ,$$

- Therefore:

$$\left(\frac{N_Z}{N_L}\right)^{*} = \eta^{\frac{\sigma}{1-\delta\sigma}} \gamma^{\frac{\varepsilon}{1-\delta\sigma}} \left(\frac{Z}{L}\right)^{\frac{\sigma-1}{1-\delta\sigma}} . \qquad (4)$$

- Structure of equilibrium similar, but now the extent of state dependence will also influence equilibrium bias in its response to relative supplies.

Equilibrium with Knowledge Spillovers (continued)

- With state dependence, relative factor prices given by:

$$\omega^* \equiv \left(\frac{w_H}{w_L}\right)^* = \eta^{\frac{\sigma-1}{1-\delta\sigma}} \gamma^{\frac{(1-\delta)\varepsilon}{1-\delta\sigma}} \left(\frac{H}{L}\right)^{\frac{\sigma-2+\delta}{1-\delta\sigma}}. \tag{5}$$

- Again a unique BGP exists.
- Global stability is no longer guaranteed.
- Unique BGP globally stable if $\sigma < 1/\delta$.
- Otherwise, one of the sectors ultimately shuts down.

Weak and Strong Bias under Knowledge Spillovers

Proposition: In the equilibrium with knowledge spillovers there is always **weak equilibrium bias** in the sense that an increase in the supply of Z induces technological change biased towards Z.

Proposition: In the equilibrium there is **strong equilibrium bias** in the sense that the endogenous-technology relative demand curve is upper sloping if $\sigma > 2 - \delta$.

- Upward-sloping demand curves more likely because of within sector spillovers.

Labor Augmenting Technological Change

- Now take $Z = K$ and investigate whether technological change will be labor augmenting (in particular, "Harrod neutral" in the long run).
- Elasticity of substitution between capital and labor, $\sigma < 1$.
- Overwhelming evidence supporting $\sigma < 1$.
- Recall that this is the "short run elasticity".

Labor Augmenting Technological Change (continued)

- Key aspect: **capital deepening**. Suppose that in the long run:

$$\frac{\dot{K}(t)}{K(t)} = s_K > 0.$$

- First, encouraging result:

Proposition: Suppose that $\sigma < 1$. Then, in any directed technical change model, capital deepening implies technological change **more labor augmenting** than capital augmenting.

- Immediate implication of Factor Augmenting Theorem combined with $\sigma < 1$.

Labor Augmenting Technological Change (continued)

- Discouraging result:

Proposition: Consider the general model with potential state dependence. Then for any $\delta < 1$, technological change is **not purely labor augmenting**.

- Essentially, there is also some capital augmenting technological change in response to the increase in the supply of capital (because of the market size effect).

Labor Augmenting Technological Change (continued)

- What happens if $\delta = 1$ (extreme state dependence).

Proposition: Suppose that $\sigma < 1$ and δ =1. Then, there exists a unique constant growth path equilibrium, where all technological change is **purely labor augmenting** (Harrod neutral) in the long run. In the short run, there will be capital augmenting technological change as well. This constant growth path equilibrium is locally stable.

- Intuition with extreme state dependence

$$\frac{r(t)\,K(t)}{w_L(t)\,L} = \eta^{-1}.$$

- Technological change must move towards equalizing factor shares.

- When K/L is increasing, this is only possible by increasing the effective units of labor to offset this increase $\Rightarrow$Harrod neutral technological change.

Conclusion on Labor Augmenting Technological Change

- Most specifications do not generate purely labor augmenting technological change.
- But a fairly natural one, where spillovers are within sectors, does.
- If so, the first micro-founded reason for why technological change will take this special form and ensure balanced growth.
- The economy looks like the neoclassical growth model in the long run.
- But in the short run and in response to changes in policies or shocks, there will be capital-augmenting technological change.
- Application: Response of technology to wage push in continental Europe.

Back to Capital-Biased Technological Change in Continental Europe

- In light of this analysis, the framework also predicts a capital-biased technological change in response to a "wage push".
- Suppose there is an upward sloping supply of labor (or some labor market imperfections such as efficiency wages or search leading to an upward sloping wage-employment relationship).
- Wage push $\approx$ shift up of this schedule.
- This will reduce employment and with $\sigma < 1$, capital share will decrease.
- This will be accompanied by capital-biased technological change.
- When $\sigma < 1$, this will also further reduce employment.

  $\Rightarrow$ A simple theory of persistent unemployment in continental Europe.

Summary and Looking Ahead

- Implications of directed technical change for:
  1. Demographics and evolution on innovations in the pharmaceutical industry.
  2. A theory of cross-country income differences.
  3. Possible perspectives on "lost decades".
  4. The effect of international trade on the nature of innovation and on cross-country income differences.
  5. Long-run technological change.
- How general are the insights? Lecture 3.