Technology Choice

Francesco Caselli

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1 Motivation

- All of the evidence and all of the models we have studied so far assume that cross-country technology differences are factor-neutral.

- But there is mounting evidence that technology differences may be non-neutral.

- We first review some of this evidence.

- We then turn to the implications of non-neutrality for explanations of world inequality.

- Non-neutrality gives rise to the notion of appropriate technology, and the implications of non-neutrality for income inequality depend on whether countries use appropriate or inappropriate technologies.

2 Evidence for Non-Neutrality

2.1 Generic observations

- Casual observation.
- Skilled biased technical change
- Papers from yesterday showing that capital composition is affected by country characteristics.

2.2 Caselli 2004 (forth. Handbook of Ec. Growth)

- Parametric production function allowing for non-neutrality.

$$y = [\alpha\,(A_k k)^{\sigma} + (1-\alpha)(A_h h)^{\sigma}]^{1/\sigma} \qquad \alpha \in (0,1),\ \sigma < 1.$$

  A_k and A_h are the efficiency units delivered by one unit of physical capital and quality-adjusted labor, respectively

- The elasticity of substitution is

$$\eta = 1/(1-\sigma).$$

- The Cobb-Douglas case is the limit for σ approaching 0 (η approaching 1). In this case, TFP A converges to $A_k^{\alpha} A_h^{1-\alpha}$. So factor neutrality is nested.

- Need a "second equation". Assume factor markets are everywhere competitive. Then,

$$\begin{aligned} r &= \alpha y^{1-\sigma} k^{\sigma-1} A_k^{\sigma} \\ w &= (1-\alpha) y^{1-\sigma} h^{\sigma-1} A_h^{\sigma}. \end{aligned}$$

- Rearranging

$$\begin{aligned} A_k &= \left(\frac{S_k}{\alpha}\right)^{1/\sigma} \frac{y}{k} \\ A_h &= \left(\frac{S_h}{1-\alpha}\right)^{1/\sigma} \frac{y}{h}, \end{aligned}$$

where $S_k = rk/y$ and $S_h = wh/y = 1 - S_k$.

- State of knowledge about S_k

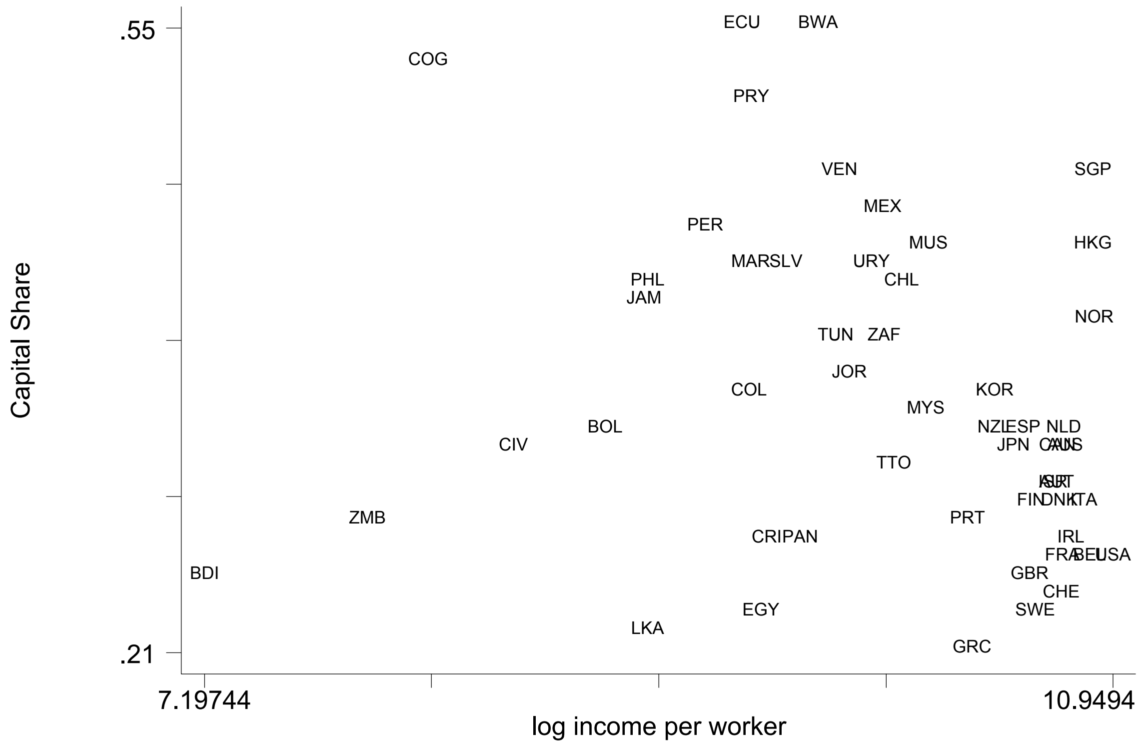


Figure 1: Distribution of S_k

- Patterns of y/k and y/h

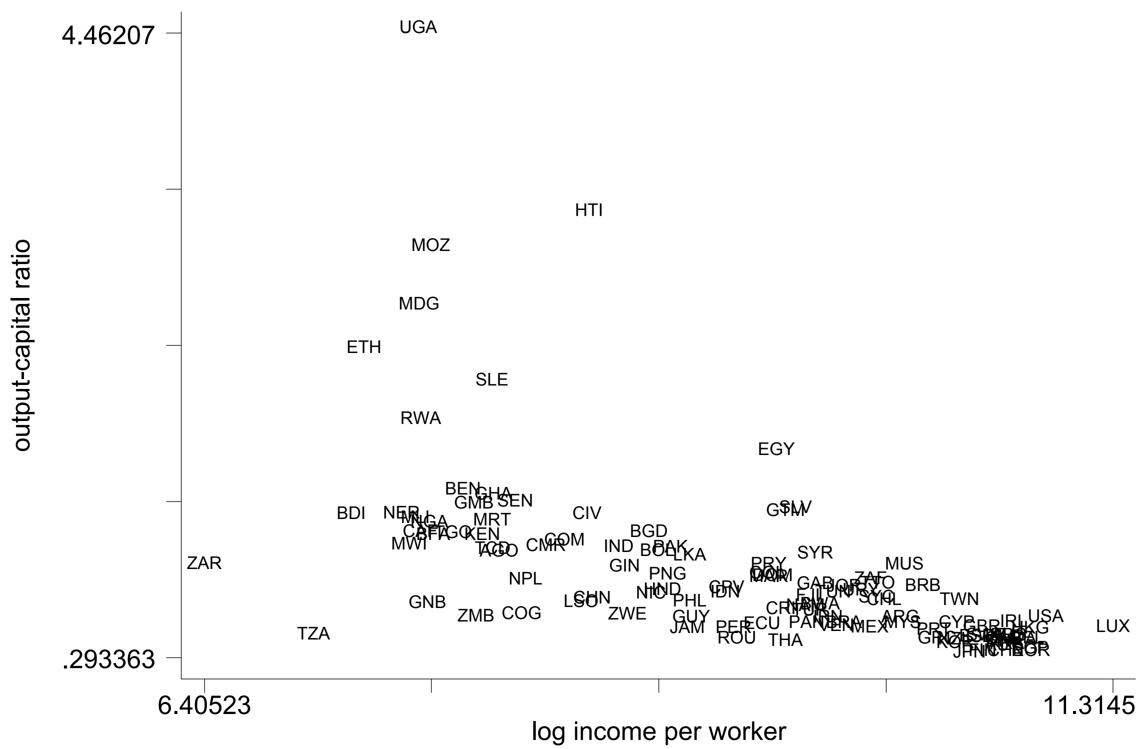


Figure 2: Distribution of y/k

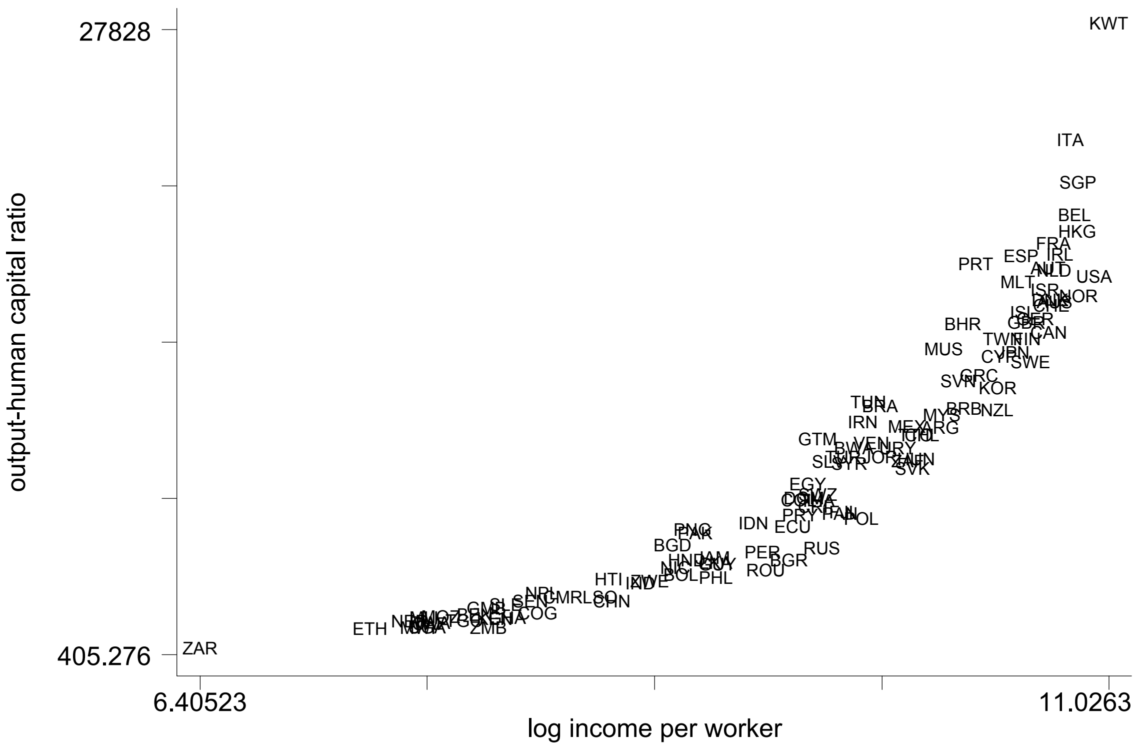


Figure 3: Distribution of y/h

- Using observed S_k and S_h

Table 1: Regressions of $log(A_k)$ and $log(A_h)$ on $log(y)$

Dep. Var.	$\eta = .1$	$\eta = .5$	$\eta = .9$	$\eta = 1.1$	$\eta = 1.5$	$\eta = 2$	$\eta = 50$
log(A_k)	-.32 (5.98)	-.27 (4.01)	.15 (.39)	-.89 (1.99)	-.48 (3.62)	-.43 (4.44)	-.37 (5.67)
log(A_s)	.80 (28.41)	.74 (17.56)	.20 (.81)	1.55 (5.33)	1.01 (12.72)	.95 (17.18)	.88 (25.47)

- Conclusion: virtually impossible to argue that cross-country technology differences are factor neutral.

2.3 Caselli and Coleman 2005 (forth. AER)

- Similar exercise but focusing on skilled- and unskilled- labor: labor literature tells us they are not perfect substitutes. Hence h construct problematic.

- Production function:

$$y = k^{\alpha} \left[(A_u L_u)^{\sigma} + (A_s L_s)^{\sigma} \right]^{\frac{1-\alpha}{\sigma}}$$

- Skill premium

$$\frac{w_s}{w_u} = \frac{A_s^{\sigma} {L_s}^{\sigma-1}}{A_u^{\sigma} L_u^{\sigma-1}}$$

- Two equations in two unknowns

- Data
  - y, k – From Summers and Heston (via Hall and Jones)
  - L_s, L_u – From Barro and Lee
    - Three partions
      - (i) $L_s =$ primary completed and above
      - (ii) $L_s =$ secondary completed and above
      - (iii) $L_s =$ college completed and above
    - Partition (i) "preferred"

- Data (cont.)
  - $\frac{w_s}{w_u} = \exp(\beta n)$

    $\beta =$ Mincerian coefficient (from Bils and Klenow)

    $n =$ schooling years of skilled worker (from Barro and Lee)
  - 53 countries

– L_s, L_u details

$$L_s = \sum_i E_i L_{s,i},$$

$$E_i = \exp(\beta n_{s,i})$$

$n_{s,i}$ extra years of sub-group (s,i) relative to lowest sub-group in L_s

- Calibration
  - Capital share: $\alpha = 0.33$ (standard - comparability)
  - Elasticity of substitution: $\frac{1}{1-\sigma}$
    - $\in (1, 2)$ [Autor, Katz, and Krueger (1998)]
    - Preferred value 1.4 [Katz and Murphy (1992)]

- Cross-country technology patterns

Table 2: Regression coefficients of A_s and A_u on y

	Literacy			High School			College		
$1/(1-\sigma)$	A_s	A_u	diff	A_s	A_u	diff	A_s	A_u	diff
1.1	3.45	-5.26	*	4.62	-1.13	*	3.90	.55	*
1.4	1.41	-.70	*	1.62	.33	*	1.35	.75	
1.7	1.12	-.05	*	1.19	.54	*	.99	.78	
2	1.00	.21	*	1.02	.62	*	.84	.78	

- TFP with standard approach

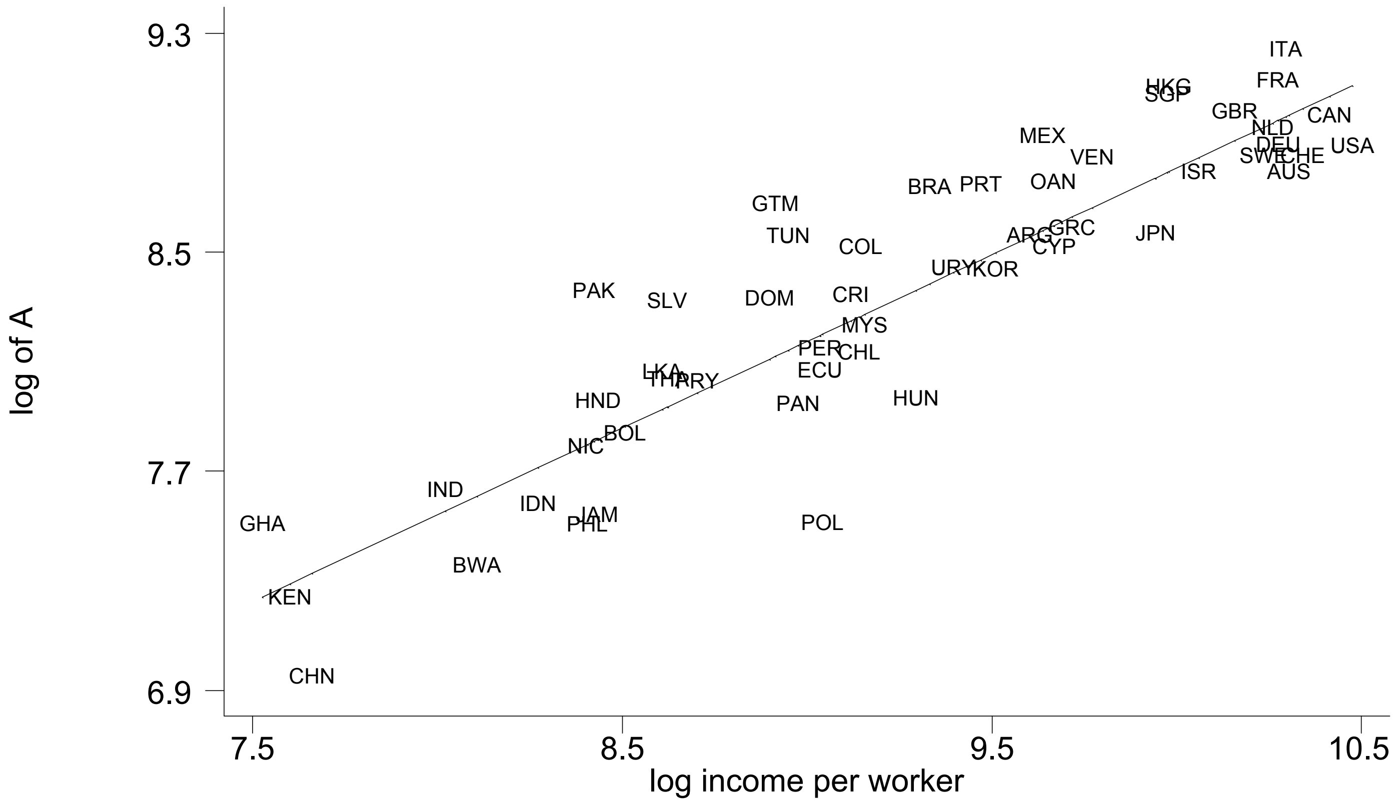


Figure 4: TFP in development accounting

A_s in preferred case

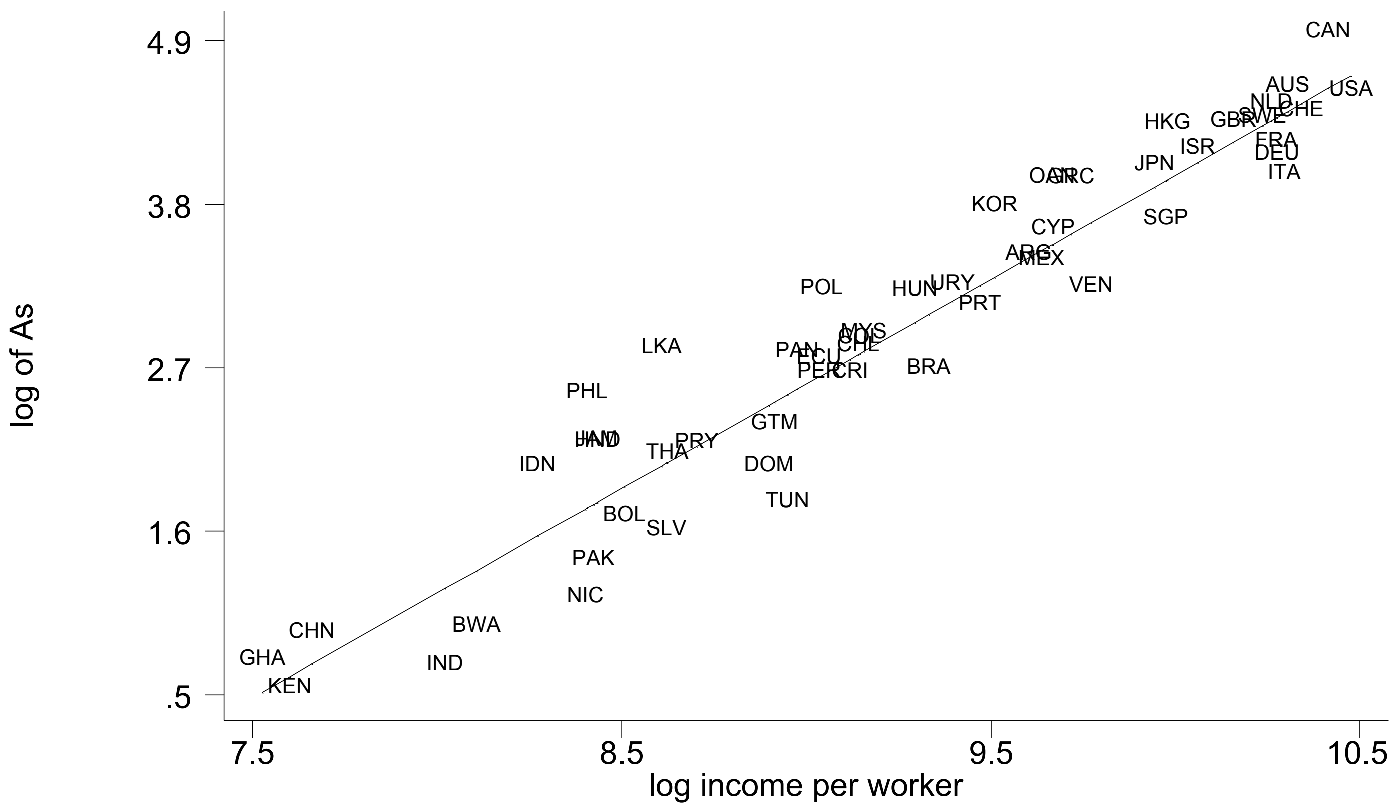


Figure 5: Efficiency of skilled labor

A_u in preferred case

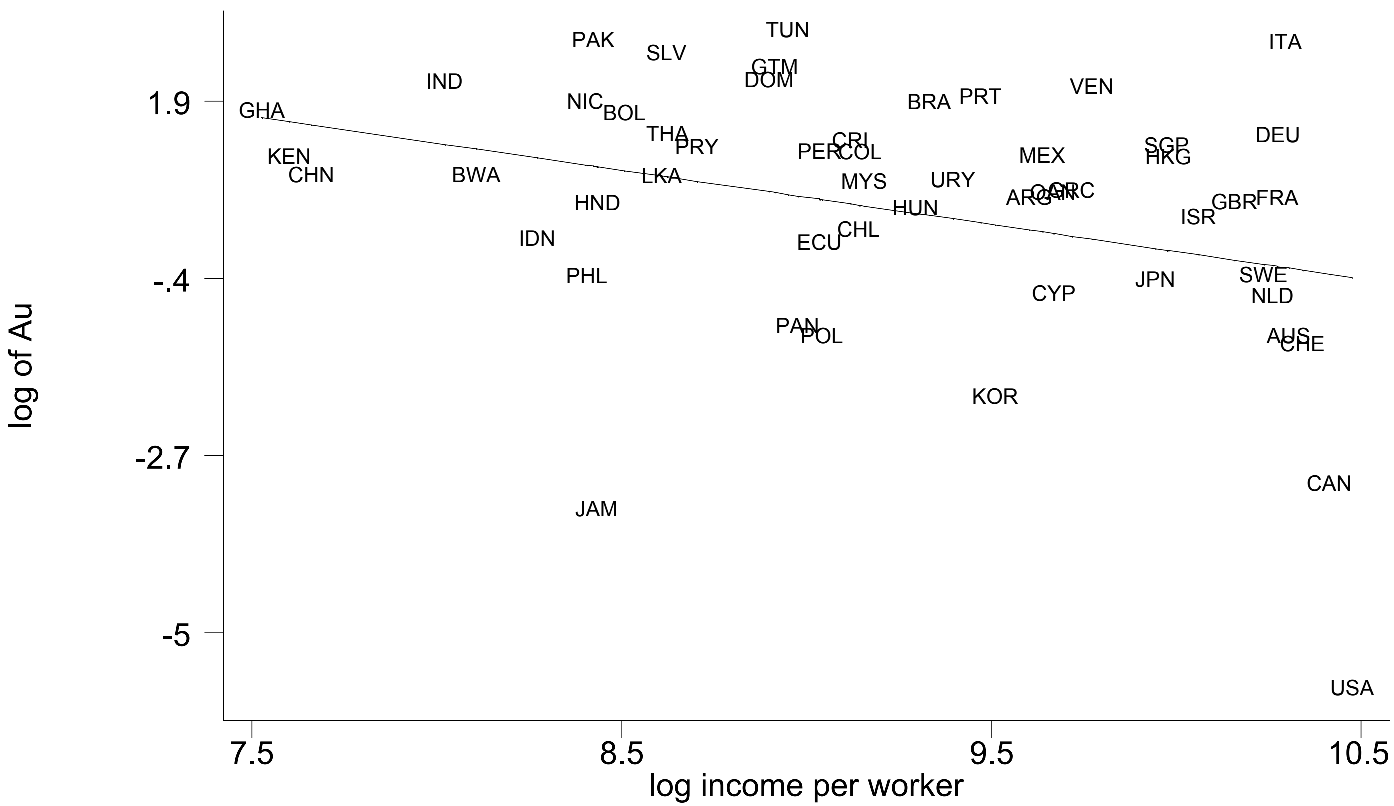


Figure 6: Efficiency of unskilled labor

- Deconstructing result:

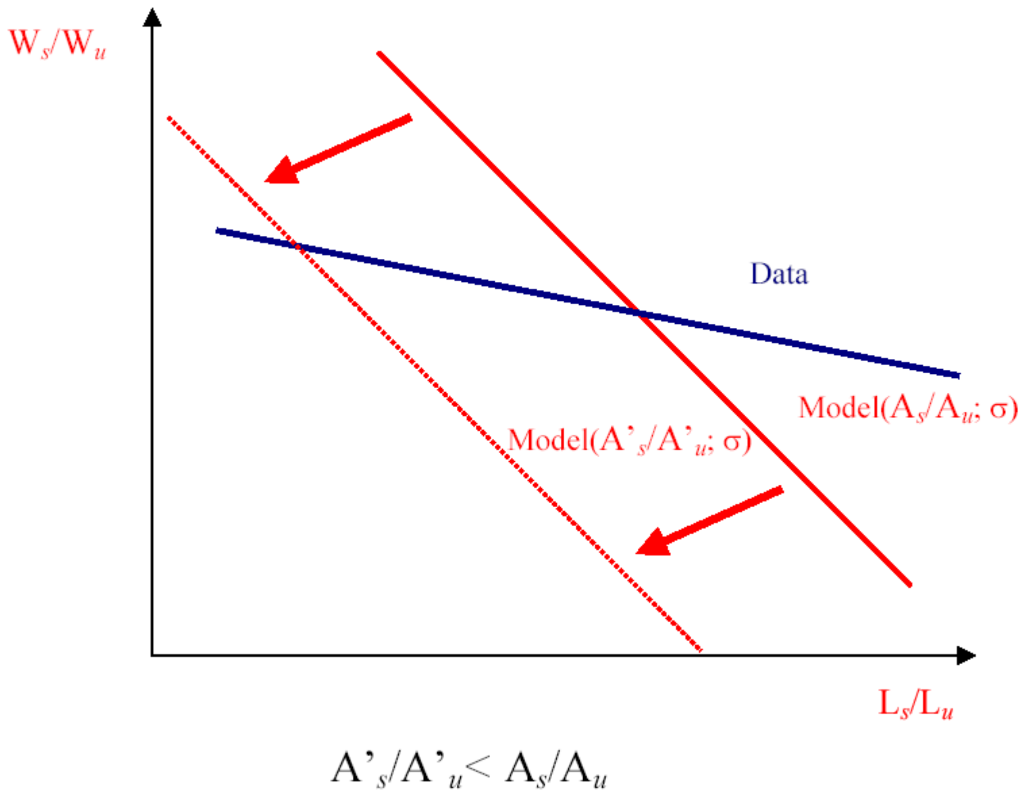


Figure 7:

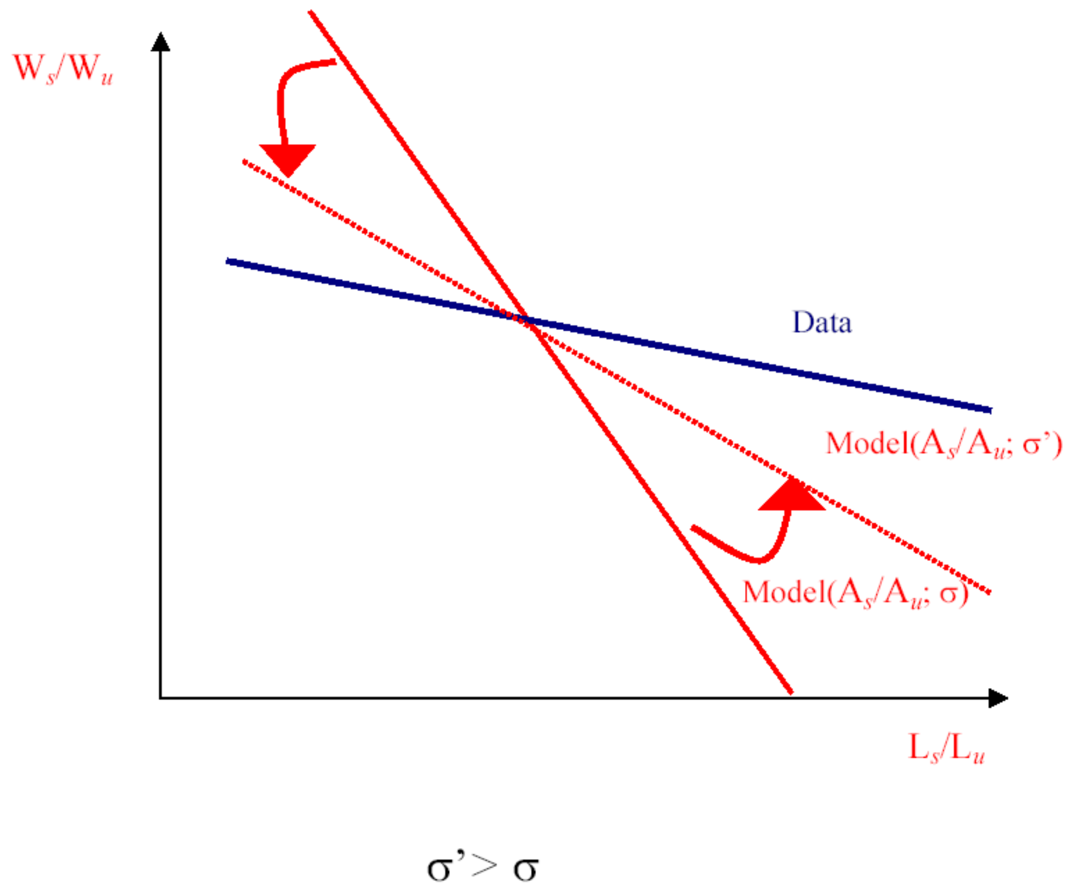


Figure 8:

- Bottom line: with $F(A_k K, A_h L)$ strong evidence that A_k/A_h varies across country (non-neutral technology differences)

- with $KF(A_s L_s, A_u L_u)$ strong evidence that A_s/A_u varies across country (non-neutral technology differences)

- [We also did $F(A_k K, A_u L_u, A_s L_s)$]

2.4 Kumar and Russell (AER 2002)

- Data Envelope Analysis: World Production Frontier in 1990.

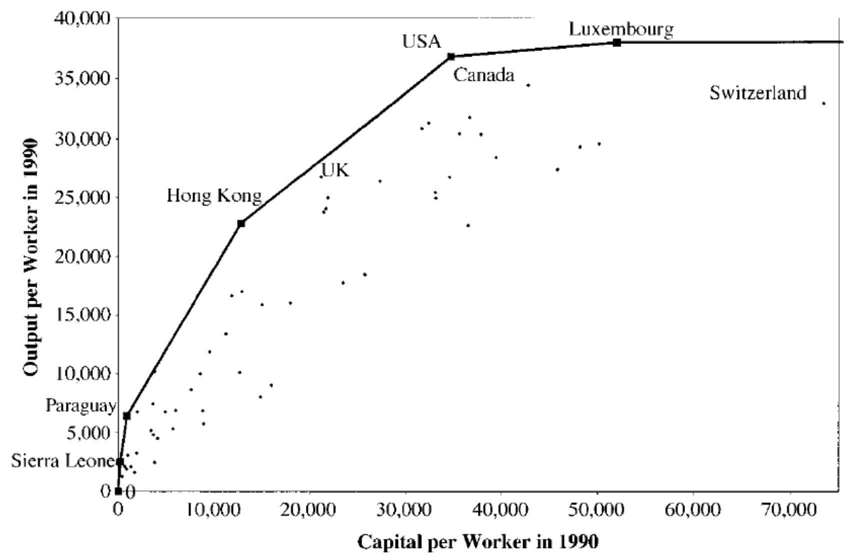


FIGURE 6. 1990 WORLD PRODUCTION FRONTIER

Figure 9:

- Distance from frontier is efficiency gap. Nice to have a non-parametric measure of efficiency differences. If all countries were on frontier all income differences would be explained by factors.

- Previous picture perfectly consistent with neutral technological change and efficiency gaps being TFP differences. Model $\log(y) = \log(A) + \alpha \log(k)$ would fit data fairly well.

- But now compare 1990 with 1960.

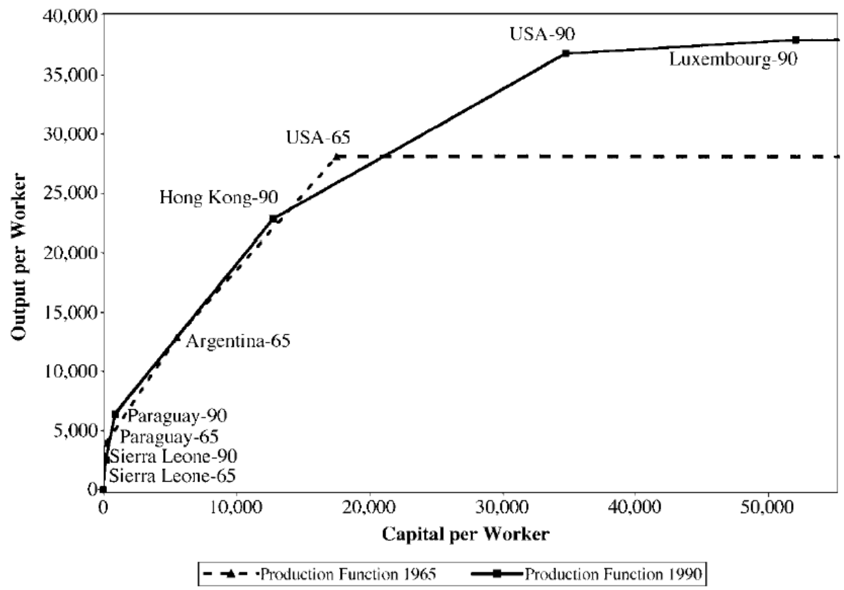


FIGURE 7. 1965 AND 1990 WORLD PRODUCTION FRONTIERS

Figure 10:

- Not consistent with factor-neutral technical change: frontier moved out only at high capital-labor ratios!

- Nice, but:

  – "Frontier" may have shifted for everyone, but "efficiency" of Paraguay and Sierra Leone may not have kept up. (Or rich countries in 1965 may have been far below frontier). Point is that disentangling "frontier" from "efficiency" is hard. Ultimately, not sure amounts to saying much more than TFP growth was faster in rich countries.

  – Omission of human capital. Could explain pattern if h grew faster in rich countries (which I don't think was the case), or if human capital became more important (which would bring us back to non-neutral technology – see Berman paper in reading list on this point). Would be interesting to see pictures with k/h on horixontal axis.

  – Calculation of k in 1965. Believable?

  – Literature review and general connection with growth literature disastrous.

3 Implications of Non Neutrality: Appropriate Technology

3.1 Atkinson-Stiglitz (EJ 1969)

- 5 pages that contain most of the relevant points.

- Technical progress in the advanced countries – directed towards the factors that are abundant there – may not help the poor countries. What is needed is R&D directed towards the factors that are abundant there. This may imply that poor countries should engage in R&D in their own right.

- Suppose that there is *learning by doing*, and that factor endowments are time varying (e.g. capital accumulation). Then a firm may want to use an inappropriate technology (in a static sense) if it expects that technology to become appropriate in the future. If the benefits of learning by doing are external, governments may want to subsidize adoption of said technology.

- Similarly, R&D must be directed towards the factors that will be plentiful in the future.

- Learning by doing and induced R&D may also lead to *path dependence*: initial endowments dictate the future path of technical change, and hence output. This could not happen in “standard” models.

3.2 Diwan and Rodrik (JIE 1991)

- Implications for IPR protection. Common wisdom is that poor countries should free ride on rich countries. This is because they are too small to really affect incentives. With AT, however, collectively poor countries have incentive to protect IPRs. This is true even if all R&D is performed in rich countries.

- The optimal degree of IPR protection depends on the degree of AT-ness of technologies.

- (But there is still the problem of free riding *among poor countries*, which presumably provides a rationalization for putting IPRs in the WTO).

- One implication is that increased IPR protection in poor countries may not necessarily be good for the rich countries, if different technologies compete for R&D resources.

- (Even without AT, another argument for IPR protection being beneficial to poor countries is *re-import* of the unprotected product to the rich countries. This effectively makes the market-size argument irrelevant).

3.3 Basu and Weil (QJE 1998)

- Formalizes some of the implications of learning by doing in a model of appropriate technology. It's a nice model, so we look at it.

- Output in country i:

$$Y_i = A(K_i, t)B_i K_i^{\alpha}$$

  - Efficiency of capital-labor ratio K_i can differ from efficiency of capital-labor ratio K_j. In other words each K_i has a different A. Implicit there is an optimal choice among a menu of many technologies, and $A(K_i, t)$ corresponds to the optimal choice given K_i (that may differ from the optimal choice given K_j).

  - Efficiency of capital-labor ratio K_i at time t can differ from efficiency at time t'. In other words each of these appropriate-technologies is subject to technological progress.

  - B_i unexplained component of productivity differences.

- Evolution of A (technological change):
  - $A^*(j) \equiv$ maximum attainable level for $A(j,t)$.
  - $k = \log(K)$.
  - Learning by doing *cum* spillovers:

    $$\dot{A}(j,t) = \beta\,[A^*(j) - A(j,t)] \sum_i I(k_i - \gamma < j < k_i + \gamma).$$

    In other words, the more countries have capital-labor ratios in a neighborhood of j, the more the world learns to use the technology that is optimal for capital-labor ratio j.
  - $A(j, 0) = 0$ for all j greater than some $x > k_0$..
  - Maximum technology increases with K:

    $$A^*(K) = K^{1-\alpha}$$

    so more capital-intensive technologies have greater *potential*.

- Evolution of K and Y:

$$\dot{K}_i = s_i Y_i - \delta K_i$$

  (no capital mobility).

  - Define $R(j,t) \equiv A(j,t)/A^*(j)$. Then:

$$\begin{aligned}
\dot{k}_i &= \frac{\dot{K}_i}{K_i} = s_i \frac{A(K_i,t)B_i K_i^{\alpha}}{K_i} - \delta \\
&= s_i R(K_i,t) A^*(K_i) B_i K_i^{\alpha-1} - \delta \\
&= s_i R(K_i,t) B_i - \delta
\end{aligned}$$

  - Also:

$$Y_i = R(K_i,t)A^*(K_i)B_i K_i^{\alpha} = R(K_i,t)B_i K_i$$

  - so:

$$\frac{\dot{Y}_i}{Y_i} = \frac{\dot{R}(K_i,t)}{R(K_i,t)} + \frac{\dot{K}_i}{K_i}$$

- *Two-country* model, where $s_1 B_1 > s_2 B_2$.

– There is a steady state with constant g_1, g_2, R_1 and R_2. $g_i = \frac{\dot{Y}_i}{Y_i} = \frac{\dot{K}_i}{K_i} = s_i R_i B_i - \delta$.

– $R_1 < R_2$. This is because learning spillovers benefit the backward country more.

– Depending on parameters, two possible steady states:

– If $s_1 B_1$ not too large relative to $s_2 B_2$, $g_1 = g_2 = g$, and

$$\begin{aligned} R_1 &= 1 - e^{-\beta(2\gamma - d)/g} \\ R_2 &= 1 - e^{-\beta(2\gamma + d)/g}. \end{aligned}$$

Where $d = k_1 - k_2$. So decreasing in g (less time spent learning), increasing in γ (more cross-technology spillovers), and decreasing in d for leader but increasing for follower (asymmetry in cross-country spillovers).

– If $s_1 B_1 >> s_2 B_2$, $g_1 > g_2$,

$$\begin{aligned} R_1 &= 1 - e^{-\beta\gamma/g_1} \\ R_2 &= 1 - e^{-\beta(\gamma/g_2 + 2\gamma/g_1)}. \end{aligned}$$

Leader gets no cross-country spillovers.

- *Many countries.* The forward-backward spillovers imply the possibility of convergence clubs of countries growing at the same rate.

- One implication is that *miracles* – following an increased saving rate – only happen "from behind."

- The prediction $R_1 < R_2$ seems counterfactual. If we reinterpret K as $K^\alpha H^{1-\alpha}$, then we have $R = A$.

3.4 Acemoglu and Zilibotti (QJE 2001)

- State-of-the-art formalization of the idea that with AT rich-country R&D does not help poor countries. Uses endogenous growth models and focuses on skilled-vs-unskilled labor endowments.

- Scarce resources must be allocated towards improving efficiency of skilled labor or unskilled labor. Skilled labor is abundant in rich countries, and rich countries do all the R&D because of size effects and imperfect IPR protection in poor countries.

- Basic formula:

$$Y_j = \left[\int_0^{N_L} X_{L,j}(v)^{1-\beta} dv\right] L_j^{\beta} + \left[\int_0^{N_H} X_{Hj}(v)^{1-\beta} dv\right] H_j^{\beta} \qquad (1)$$

  - $N_L(N_H) =$ number of machine varieties that complement unskilled (skilled) labor;

  - $X_{Lj}(v)(X_{Hj}(v)) =$ quantity of machine v, complementary with unskilled (skilled) labor.

- L_j (H_j) = fixed endowment of unskilled (skilled) labor employed in producing good i
- Final goods produced in perfect competition.

- Comments:
  - Technical progress (and growth) will come through expansion in N_L and N_H.
  - Appropriate technology: countries with a lot of unskilled (skilled) labor would like lots of N_L (N_H).
  - L and H are, respectively, the markets for machines of the two types.

- Assume:
  - The inventor of a new variety gets patent protection only in own country.

- Constant cost of inventing new variety, same across two sectors.
- In each other country the new variety can be imitated at a *near-zero* entry cost ε.

- Then:
  - Profits from holding a patent for a z-complementary technology in country j are increasing in Zj.
  - Assume one country, n, is large (i.e. large L_n and large H_n) and all others are small.
  - All R&D is concentrated in country n.

- Properties of the steady state:

– Directed technical change (rather, induced innovation)*

$$\frac{N_H}{N_L} = \frac{H_n}{L_n}.$$

– Y_n, N_H, N_L all grow at constant rate g, *increasing in* $L_n + H_n$ (scale effect).

– Y_j also grows at rate g.

- Potentially bad for low H and high L countries. [Output is = constant × $LN_L + HN_H$.]

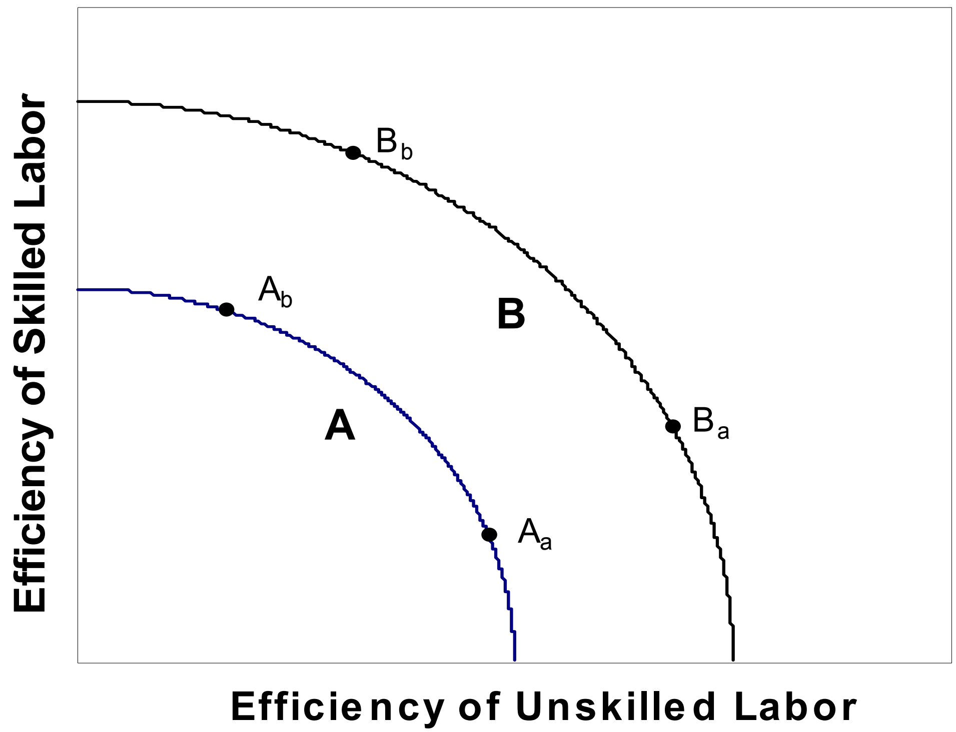
- Bottom line: idea that poor countries are "forced" to use "inappropriate" technologies appealing, but hard to reconcile with evidence in Caselli and Caselli and Coleman.

*This result holds assuming that $N_L(0)$ and $N_H(0)$ are initially sufficiently "low," in a sense that will become clear if you derive the results.

3.5 Back to Caselli and Coleman

- An appropriate technology model
- Firms choose among “blueprints”
- Each blueprint implies a certain combination of A_u and A_s
- Firms choose the appropriate blueprint given factor prices
- Skill-abundant countries adopt skill-biased technologies, and vice versa

Modelling strategy: technology frontiers



A (B) is the technology frontier of country A (B). A_a and B_a (A_b and B_b) are appropriate choices of technology for unskilled-labor (skilled-labor) rich countries.

Figure 11: Nesting Appropriateness and Barriers

The model

- Competitive firms maximize profits subject to

$$y = k^{\alpha}\left[(A_u L_u)^{\sigma} + (A_s L_s)^{\sigma}\right]^{\frac{1-\alpha}{\sigma}}$$

$$(A_s)^{\omega} + \gamma\,(A_u)^{\omega} \leq B$$

Choice variables: k,L_s,L_u, *and* A_u

- w_u, w_s, and r determined in competitive factors' markets

- k,L_s,L_u inelastically supplied

Equilibrium

- If $\omega > \sigma/(1-\sigma)$ equilibrium is symmetric (all in the middle)

- If $\omega < \sigma/(1-\sigma)$ equilibrium is asymmetric (all at the corners)

Properties of equilibrium

- Firms' choices

$$\frac{L_s}{L_u} = \left(\frac{w_s}{w_u}\right)^{\frac{\omega-\sigma}{\omega\sigma-(\omega-\sigma)}} \gamma^{\frac{\sigma}{(\omega-\sigma)-\omega\sigma}}$$
$$\frac{A_s}{A_u} = \left(\frac{w_s}{w_u}\right)^{\frac{\sigma}{\omega\sigma-(\omega-\sigma)}} \gamma^{\frac{1-\sigma}{(\omega-\sigma)-\omega\sigma}}$$

- Hence:

  $\frac{L_s}{L_u}$ decreasing in $\frac{w_s}{w_u}$

  if $\sigma > 0$, $\frac{A_s}{A_u}$ decreasing in $\frac{w_s}{w_u}$

  if $\sigma < 0$, $\frac{A_s}{A_u}$ increasing in $\frac{w_s}{w_u}$

Properties of equilibrium (cont.)

- General equilibrium

$$\left(\frac{A_s}{A_u}\right)^{\omega-\sigma} = \gamma\left(\frac{L_s}{L_u}\right)^{\sigma}$$

- Hence:

  if $\sigma > 0$, $\frac{A_s}{A_u}$ increasing in $\frac{L_s}{L_u}$, or *relative skill bias*

  if $\sigma < 0$, $\frac{A_s}{A_u}$ decreasing in $\frac{L_s}{L_u}$

General equilibrium (cont.)

$$
\begin{aligned}
A_s &= \left(\frac{B}{1 + \gamma^{\sigma/(\sigma-\omega)} (L_s/L_u)^{\omega\sigma/(\sigma-\omega)}} \right)^{1/\omega} \\
A_u &= \left(\frac{B/\gamma}{1 + \gamma^{\sigma/(\omega-\sigma)} (L_s/L_u)^{\omega\sigma/(\omega-\sigma)}} \right)^{1/\omega}
\end{aligned}
$$

With $\sigma > 0$,

A_s increasing in both B and L_s/L_u

A_u increasing in B but decreasing in L_s/L_u

$\Rightarrow$ potential for *absolute skill bias*

Quantitative Implications

Backing out the Frontiers

- Each country's frontier depends on B, γ, and ω

- From model's solution we have

$$\log\left(\frac{A_s^i}{A_u^i}\right) = \frac{\sigma}{\omega-\sigma}\log\left(\frac{L_s^i}{L_u^i}\right) + \frac{1}{\omega-\sigma}\log\gamma^i$$

- Estimate by OLS. Back out ω from coefficient, and γ from error term

- Plug into

$$(A_s^i)^\omega + \gamma^i\left(A_u^i\right)^\omega = B^i$$

and back out B

Here they are

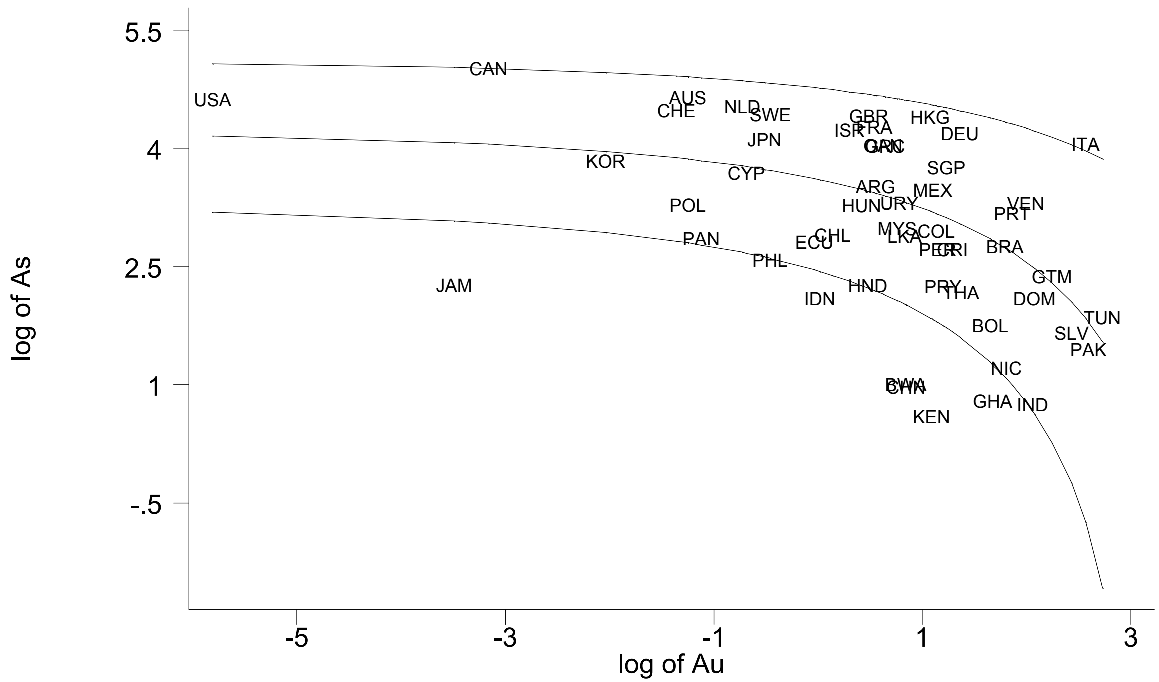


Figure 12: Technology frontiers of Italy (top), Argentina (middle), and India

The world technology frontier

- Is the “highest” frontier
- The highest frontier is Italy’s

Counterfactual incomes (i)

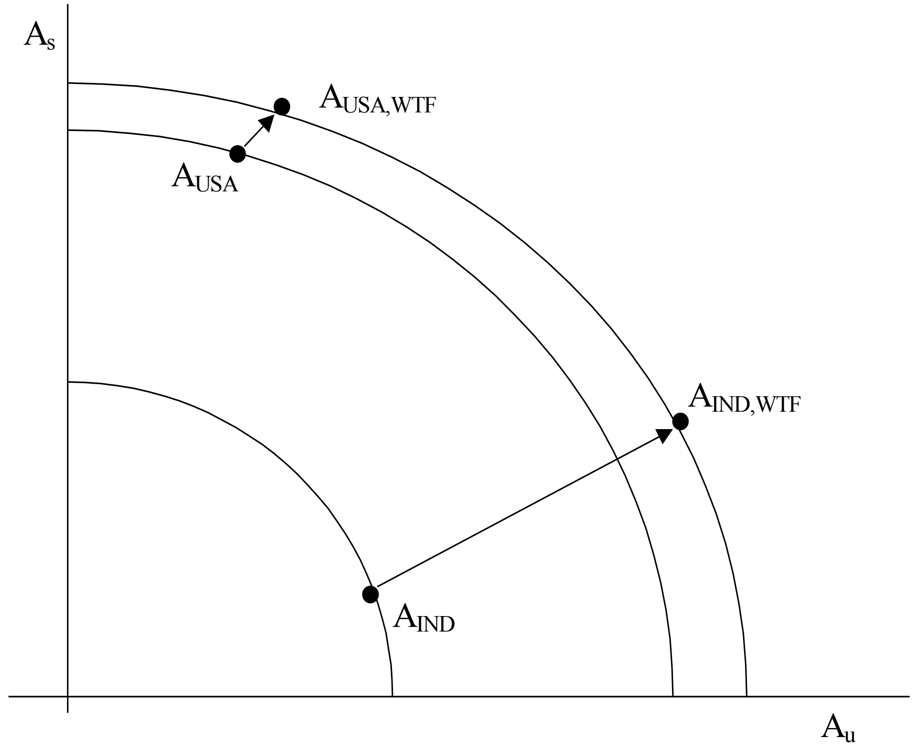


Figure 13: Technology choices on world technology frontier

- Cost of inappropriateness: $y_{IND}\left(A_{USA,WTF}\right)/y_{IND}\left(A_{IND,WTF}\right)$

The cost of inappropriateness

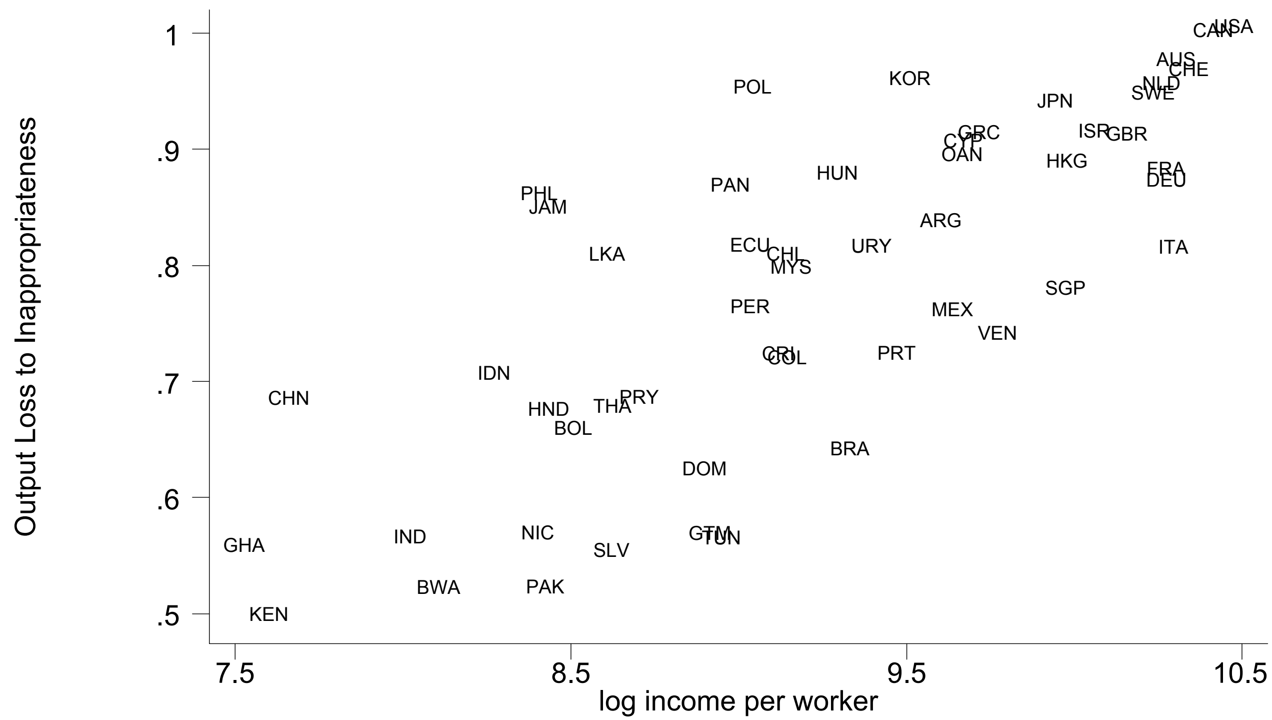


Figure 14: Output loss from using US-appropriate technology

Counterfactual incomes (ii)

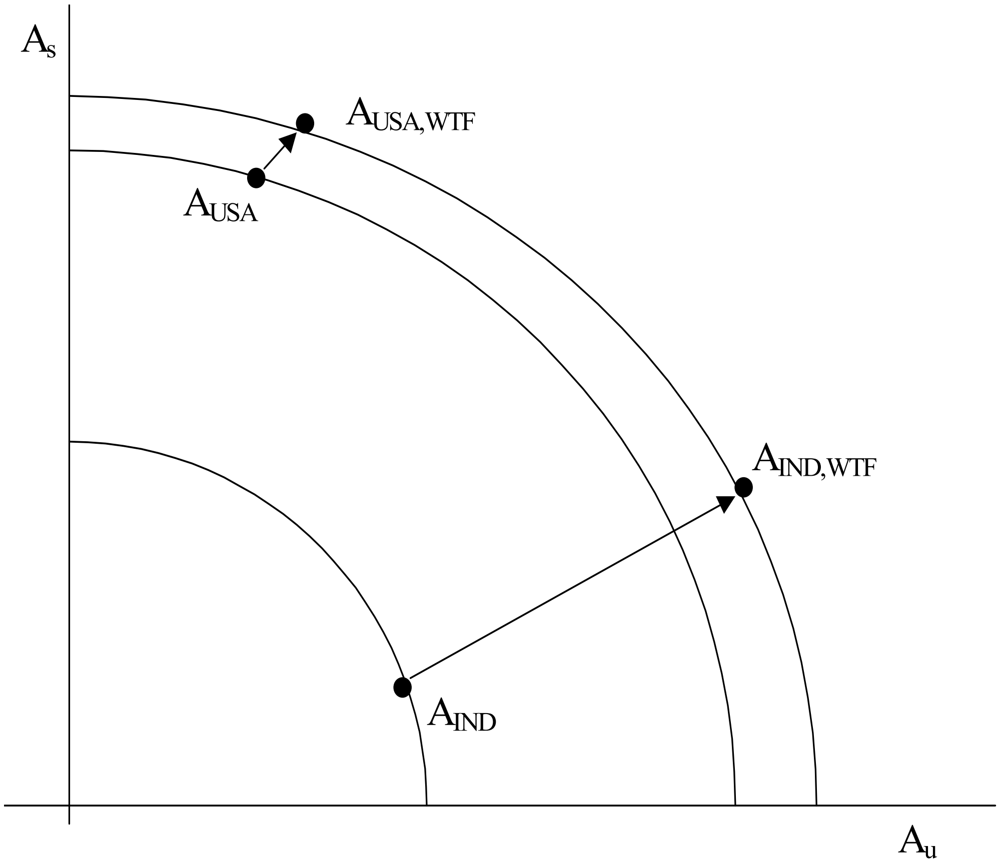


Figure 15: Technology choices on world technology frontier

- Cost of barriers: $y_{IND}\left(A_{IND,WTF}\right)/y_{IND}\left(A_{IND}\right)$

The cost of barriers

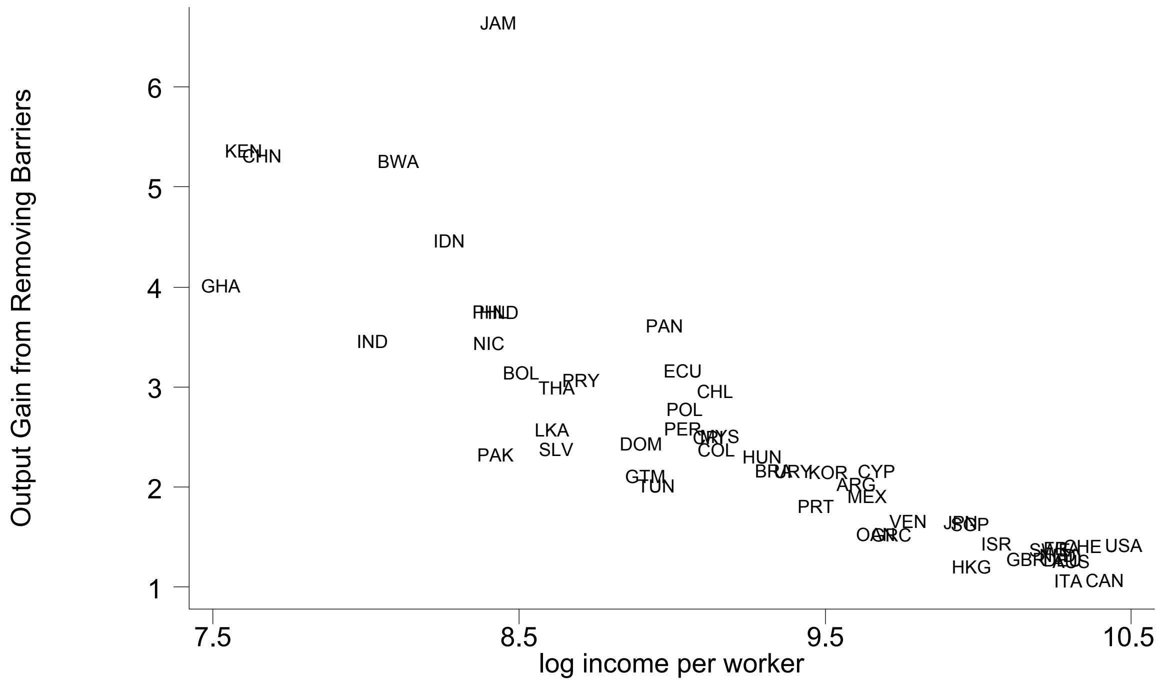


Figure 16: The Gain From Accessing the World Technology Frontier

Development accounting all over again

- With appropriate technology:

$$\frac{Var\{\text{log}[y_i(A_{i,WTF})]\}}{Var\{log[y_i]\}} = .5, \text{ or factors explain } 50\%$$

- With TFP approach factors explain 60%

Conclusions

$$y = k^{\alpha} \left[(A_u L_u)^{\sigma} + (A_s L_s)^{\sigma} \right]^{\frac{1-\alpha}{\sigma}}$$

Relative skill augmenting technical differences

Absolute unskilled reducing technical differences

Appropriateness+Barriers rationalizes findings

Appropriate technology quantitatively important

Role of barriers to adoption increases