

# Growth and Distribution

by

Danny Quah

dquah@econ.lse.ac.uk

<http://econ.lse.ac.uk/~dquah/>

Economics Department LSE

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## 1 ISSUES AND FACTS

### Basic questions

1. “Why some are so rich and some so poor”
  - Income level differences: Across economies, across people
  - Growth rates to levels: Doubling time
2. Dynamics of cross-section income distributions
3. Away from just “great ratios”

Lucas (1988):

“By the problem of economic development I mean simply the problem of accounting for the observed pattern, across countries and across time, in levels and rates of growth of per capita income.”

Stiglitz and Uzawa (1969):

“The primary objective of the modern theory of economic growth is to explain, on the one hand, the movements in the output, employment, and capital stock of a growing economy and the inter-relations among these variables, and on the other hand, to explain the movements in the distribution of income among the factors of production.”

## Organizing principles (Otherwise survey of surveys)

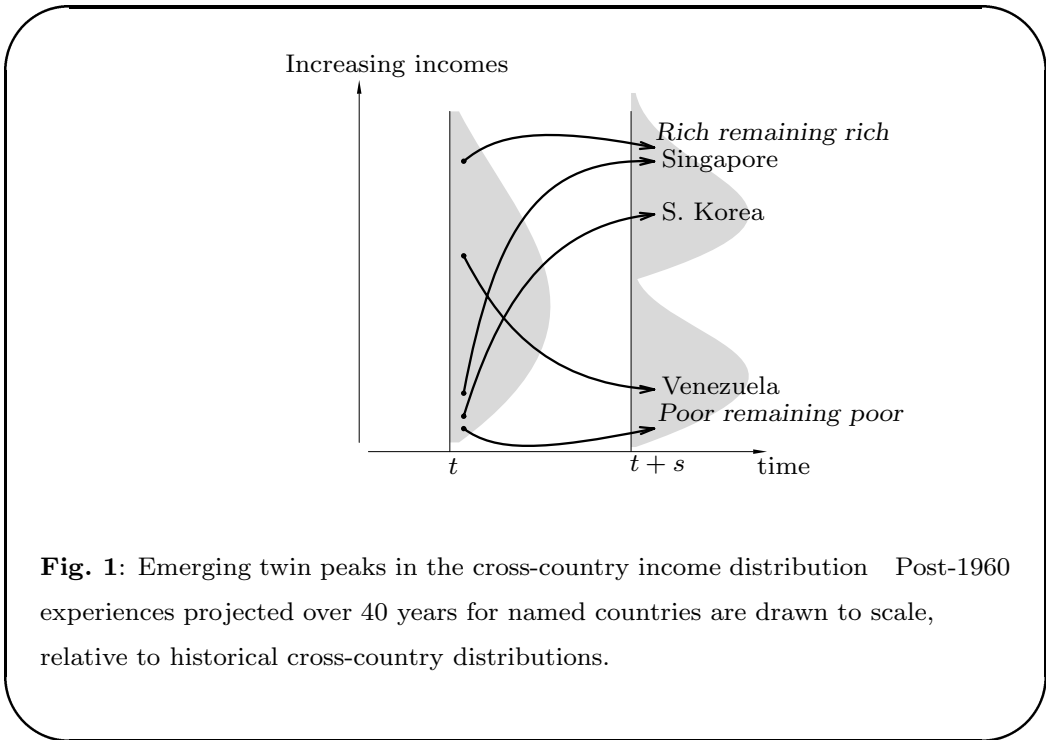
*Cross-section variation of direct interest*

- Not just a statistical device for averaging out over a panel
- Hence “distribution”, even though slight misnomer

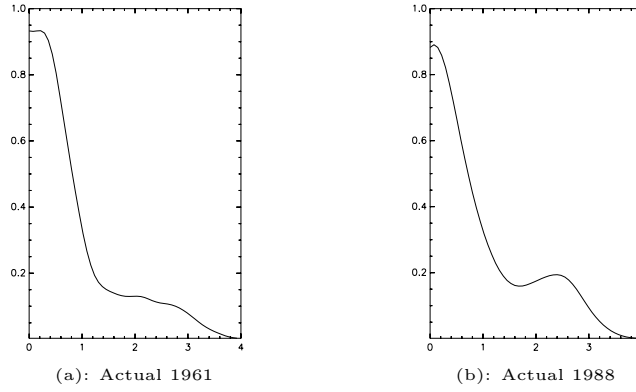
*Themes*

1. Importance of technology: Just a fact
2. Models of technology dissemination: Distribution dynamics
3. Symmetric treatment for growth and inequality: Overwhelming importance of growth

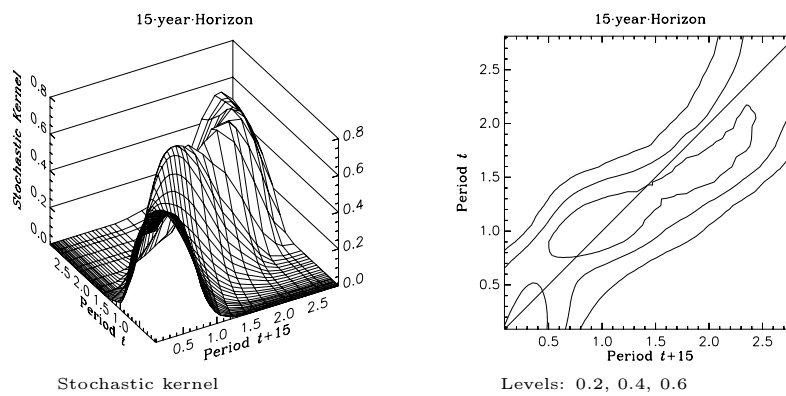
	1960	1989
World per capita income	$\nearrow$ 2.25% p.a.	
	times world per capita income	
Per capita income in national economies	1960–64	1985–89
10th %-ile	0.22 × (26.0% world popn.)	0.15 × (3.3% world popn.)
90th %-ile	2.70 × (12.5% world popn.)	3.08 × (9.3% world popn.)
(25th-15th) %-iles	0.13 ×	0.06 ×
(95th-85th) %-iles	0.98 ×	0.59 ×



**Fig. 1:** Emerging twin peaks in the cross-country income distribution Post-1960 experiences projected over 40 years for named countries are drawn to scale, relative to historical cross-country distributions.



**Fig. 2:** Distributions across 98 countries (Densities of relative output per worker)



**Fig. 3:** Distribution dynamics across countries (Relative output per worker) The right panel contains contour plots of the 15-year stochastic kernel in the left panel.

## 2 CROSS-COUNTRY GROWTH AS DISTRIBUTION DYNAMICS

### 2.1 Standard growth model

$$y \stackrel{\text{def}}{=} Y/N \quad k \stackrel{\text{def}}{=} K/N \quad (1)$$

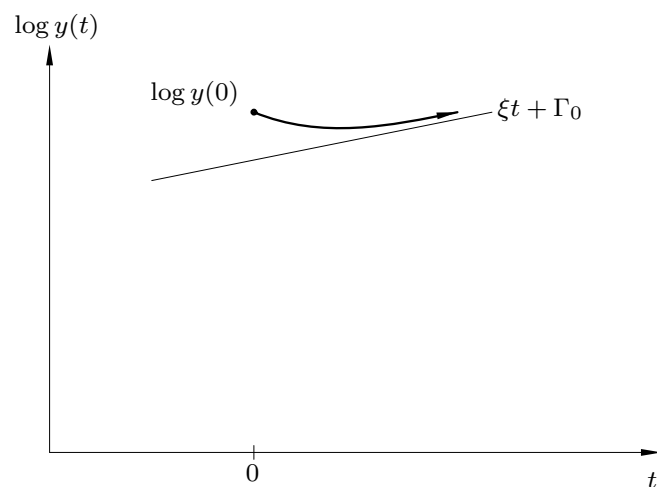
$$y = Af(k/A), \quad f' > 0, \quad f'' < 0, \quad \lim_{k \rightarrow \infty} f(k)k^{-1} = 0 \quad (2)$$

$$\dot{A}/A = \xi \geq 0, \quad A(0) > 0 \quad (3)$$

$$\dot{N}/N = \nu \geq 0, \quad N(0) > 0 \quad (4)$$

$$\dot{K} = \tau Y - \delta K, \quad \tau \text{ in } (0, 1) \text{ and } \delta > 0 \quad (5)$$

$$\implies \dot{k}/k - \dot{A}/A = \tau \frac{f(k/A)}{k/A} - (\delta + \nu + \xi) \quad (6)$$



**Fig. 4.a: Convergent time path** Convergence from initial level to steady-state path  $\xi t + \Gamma_0$ .

### Steady state

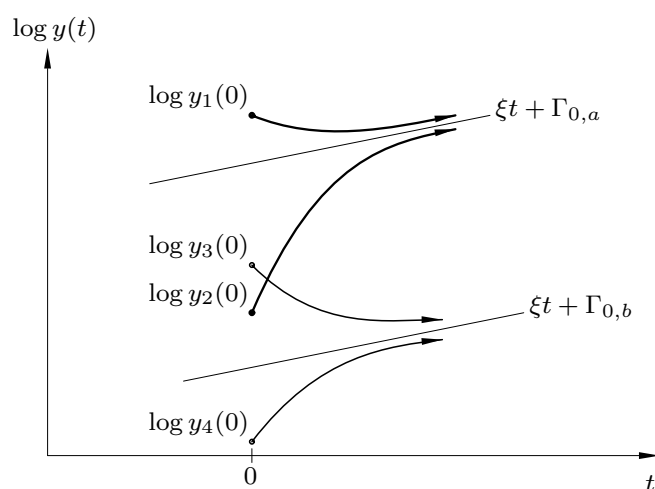
$$\begin{aligned} \log y(t) &= \log f([k/A]^*) + \log A(t) \\ &= \log f([k/A]^*) + \log A(0) + \xi \cdot t \\ &= \Gamma_0 + \xi \cdot t \end{aligned}$$

where

$$\begin{aligned} \Gamma_0 &\stackrel{\text{def}}{=} \log f([k/A]^*) + \log A(0) \\ &= g([\delta + \nu + \xi]^{-1}\tau) + \log A(0), \quad \text{with } g' > 0. \end{aligned}$$

If  $f(k/A) = (k/A)^\alpha$  with  $\alpha \in (0, 1)$ , then

$$g([\delta + \nu + \xi]^{-1}\tau) = \frac{\alpha}{1 - \alpha} \log([\delta + \nu + \xi]^{-1}\tau).$$



**Fig. 4.b: Time paths across countries** A cross section of economies, having different possible steady-state paths varying with  $\Gamma_0$ , shows a range of possible behaviors.

### Augmented model

1. Human capital

$$y = Af(k/A, h/A), \quad h = H/N$$

$$\dot{H} = \tau_h Y - \delta_h H, \quad \tau_h, \delta_h > 0; \quad \tau + \tau_h < 1$$

2. Fig. 4 still. Only  $\Gamma_0$  and  $\lambda$  change; parameters in  $f$

3. When  $f(k/A, h/A) = (k/A)^\alpha (h/A)^{\alpha_h}$  and  $\delta_h = \delta$ , then

$$\Gamma_0 = (1 - \alpha - \alpha_h)^{-1} \left[ \alpha \log \left( \frac{\tau}{\delta + \nu + \xi} \right) + \alpha_h \log \left( \frac{\tau_h}{\delta + \nu + \xi} \right) \right] \\ + \log A(0)$$

$$\lambda = -(1 - \alpha - \alpha_h)^{-1} (\delta + \nu + \xi)$$

### Model's explanation of per capita income differences

1. Elasticity on savings, population growth rates:  $\alpha(1 - \alpha)^{-1}$

$$\alpha = \frac{1}{3} \implies \frac{1}{4}; \quad \alpha = \frac{1}{2} \implies \frac{1}{3}$$

2. Elasticity on  $A$ ? Unity
3.  $A_j = A_1$  or  $A_j$  all different?

All income levels normalized to US  $y_0$   
 (Estimates for  $A$  from Jones, 1998)

	<b>SSQ</b> or SSR	SSR Ratio (%)
$y/y_0$	<b>0.183</b>	
Residuals with just $\tau$	0.291	159.4
... adding in $\tau_h$	0.035	19.0
... further adding $A$	0.003	1.6

Table 1: Accounting for level differences

## Determinants?

- Individualistic determination of  $\tau_j, \nu_j, \tau_j^h, A_j$
- Ethno-linguistic fractionalization; democracy; inflation; openness to trade; [hay; eyeglasses; ...]
- Durlauf and Quah (1999) Table 2; many other surveys ...

**Conclusions** *Canonical growth model calibration:*

1. *Technology—or something like it in  $A$ —matters greatly. Maybe even overwhelmingly (same as in Lucas 1990, Romer 1994)*
2. *To understand rich and poor, want to understand dynamics in the cross-country distribution of  $A$*
3. *Panel data econometric techniques, condition out “nuisance” unobserved  $A$ ?*

**2.2 Models for  $A$ : Cross-country distribution dynamics**

Isolated/interacting: Analogous to static/dynamic

- $j \in J, 0 \in J, C \subseteq J$
- Scheme  $(A_*, C)$ :
- **Target**  $A_* = \begin{cases} \bar{A} & \text{average} \\ A_0 & \text{fixed-identity leader} \\ A_{\max} & \text{varying-identity leader} \end{cases}$

- **Catch-up equation**  $\xi_j, \beta_j > 0$

Continuous timepaths:

$$\dot{A}_j = \left[ A_j^{1-\beta_j} A_*^{\beta_j} \right] \xi_j \quad (\text{C1})$$

$$\dot{A}_j/A_j = \xi_j + \left( 1 - \frac{A_j}{A_*} \right) \beta_j \quad (\text{C2})$$

Discrete jump at time  $t$ :

$$A_j(t) = A_*(t) \quad [\text{to frontier}] \quad (\text{C3})$$

$$A_j(t) = (1 + \xi_j) \lim_{s \uparrow t} A_j(s) \quad (\text{C4})$$

### Alternative $(A_*, \mathcal{C})$ schemes

Define  $a_j = A_j/A_*$  (technology ratio).

$(A_*, \mathcal{C}) = (A_0, \text{C2})$

$$\dot{A}_*/A_* = \dot{A}_0/A_0 = \xi_0$$

$$\bar{a}_j = 1 + (\xi_j - \xi_0)/\beta_j^{-1}$$

$$\dot{a}_j/a_j = -(a_j - \bar{a}_j) \times \beta_j$$

- Cameron, Proudman, Redding:  $\bar{a}_j \sim 53\% - 92\%$
- Bernard-Jones, etc.
- If  $\xi_j = \xi_0$  then  $\bar{a}_j = 1$  and

$$\dot{a}_j/a_j = -(a_j - 1) \times \beta_j \implies a_j(t) \rightarrow 1$$

$$(A_*, \mathcal{C}) = (A_0, C1)$$

$$\dot{A}_*/A_* = \dot{A}_0/A_0 = \xi_0$$

$$\bar{a}_j = (\xi_j/\xi_0)^{1/\beta_j}$$

$$\dot{a}_j/a_j = \left[ (\bar{a}_j/a_j)^{\beta_j} - 1 \right] \xi_j$$

If  $\xi_j = \xi_0$  then  $\bar{a}_j = 1$  and

$$\dot{a}_j/a_j = (a_j^{-\beta_j} - 1) \times \xi_j \implies a_j(t) \rightarrow 1$$

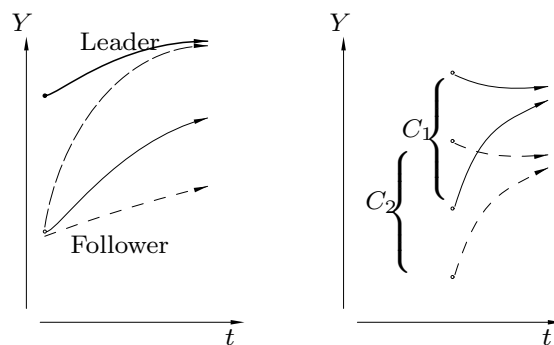
$$(A_*, \mathcal{C}) = (\bar{A}, C1) \quad (\text{Lucas 1993})$$

- If  $\xi_j = \xi_0$  then  $a_j(t) \rightarrow 1$  and in steady state  $A_j = A_0 = \bar{A}$  and  $\dot{A}_j/A_j = \xi$

1. No crossings; monotone dynamics
2. Convergence to (essentially) point mass

Targets  $A_*$  not common across  $J$ ?

1. Groupings  $C_1, C_2, \dots \subsetneq J$
2.  $A_*$  specific to  $C_k$
3. Which  $j$ 's join which  $C_k$ ?
4. Keely (1999), Quah (1999)



**Fig. 5: Duality** Modelling issue that underlies the left panel: What is the rate—fast or slow—of Follower convergence to Leader? Right panel: Which  $j$ 's join which  $C$ ? What glue?

### Random join dates

- $t \in [0, \infty)$
- $\dot{A}_j = 0$  until a *join event* occurs
- Join events: Point process, hazard rate  $h_j(t)$

$$h(t) = \frac{p(t)}{1 - P(t)} = -\frac{d}{dt} \log(1 - P(t))$$

$$P(t) = 1 - e^{-\int_0^t h(s) ds} \quad \text{and} \quad p(t) = \frac{dP}{dt}(t)$$

Join event absorbs. Scheme  $(A_*, \mathcal{C}) = (A_0, \mathcal{C}2)$

- Write  $j(s)$  to denote  $j \in J$  joining at  $s$
- Assume  $\xi_j = \xi$ ,  $\beta_j = \beta$  for all  $j \in J$ , and

$$\dot{A}_*/A_* = \xi \text{ wp 1, i.e., } j(0) = 0$$

$$\begin{cases} \dot{A}_j & = 0, \text{ or} \\ \dot{A}_j/A_j & = \xi + \left(1 - \frac{A_j}{A_*}\right) \beta \end{cases}$$

- Thus  $a_j(t) = a_j(0)e^{-\xi t}$ , while upon takeoff at  $t$ , economy  $j(t)$  enjoys a growth premium, the better, the larger is  $t$ ,

$$\dot{a}_{j(t)}(t)/a_{j(t)}(t) = -(a_{j(t)}(0)e^{-\xi t} - 1) \times \beta$$

Interactions: A model for  $h(t)$

(Lucas 2000)

$$\bar{A}(t) = E_0 A(t) = (1 - P(t)) A_0(0) + \int_0^t p(s) A_{j(s)}(t) ds$$

$W(t) = W(\bar{A}(t))$ , with  $W(0) = 0 \nearrow 1$  (world development),

$h(t) = h(W(t))$ ,  $h(0) > 0$ ,  $h$  monotone increasing

1. One cluster assumed,  $C = J$
2. Takeoffs *endogenous*
  - (a) State of world development: Initially slow, then progressively faster
  - (b) Need knowledge of entire distribution (at least up to  $\bar{A}$ )
  - (c) Growth in  $\bar{A}$  and thus  $W$  first slow, then fast, *then slow again*
  - (d) Overtaking in growth rates but not in levels
3. Spillovers critical in two senses:
  - (a) Growth premium
  - (b) Endogenous hazard rate for joins

Dynamics of cross-section distribution

1. If  $A_j(0) = A_0(0)$ , then inequality across countries rises and then falls
2. (... but the same would be true if constant  $h$ )
3. Growth premium: higher inequality (typically) prior to high measured average growth—but mechanically
4. Can have positive inequality for  $t \rightarrow \infty$  if  $\mathcal{C}$  allows  $\bar{a}_j \neq 1$

Join event ergodic. Scheme  $(A_*, \mathcal{C}) = (A_{\max}, \mathcal{C}3)$

(Aghion-Howitt 1998. Stochastic leapfrogging)

Join event as (drastic) innovation event:

$$A_j(t) = A_*(t) = A_{\max}(t)$$

1. Identity of leader changes stochastically
2. Growth premium: Jump  $A_{\max}(t) - \lim_{s \uparrow t} A_j(s)$  increasing in time since last join event

**Theorem** *If proportionality between intra-distribution hazard and growth at frontier, i.e.,*

$$\forall t : h(t) = \dot{A}_*(t)/A_*(t) \times \zeta^{-1}, \quad \zeta > 0 \quad (\text{P})$$

*then the steady-state cross-country distribution  $F$  of  $a_j$  exists, is unique, and has the nondegenerate power-law form:*

$$F(a) = a^{1/\zeta} \implies f(a) = \zeta^{-1} a^{(\zeta^{-1}-1)} \quad a \in (0, 1],$$

*where the density  $f$  increases or decreases depending on  $\zeta \lessgtr 1$ .*

Dynamics of cross-section distribution

1. Convergence to steady-state  $F$  independent of initial cross-country distribution
2. Constant churning
3. Key proportionality assumption (P)
4. Again, growth premium: Higher inequality prior to high measured average growth—again, mechanically

Join event ergodic. Emerging twin peaks

(Solow 1997. “Success breeds success”)

Keep join event ergodic [possibly drastic, possibly not], but let their arrivals be path-dependent, i.e.,

1. Hazard rate  $h$  declining in time  $t - t_n$  since last join/innovation event
2.  $\implies$  emerging multi-peakedness in cross-section distribution

## SUMMARY

1. *Appropriate and inappropriate empirical methods*
2. *Importance of A's cross-section distribution dynamics for rich/poor question*
3. *Taxonomy of models for A's distribution dynamics*
4. *Inequality and growth jointly and simultaneously determined*
5. *Technology in growth—can't be savings and capital accumulation mechanism for inequality*

## 3 DISTRIBUTION DYNAMICS ACROSS THE 6 BILLION

Distribution dynamics autoregression

$$\phi_t = T^*(\phi_{t-1}, u_t) = T_{u_t}^*(\phi_{t-1}), \quad t \geq 1, \text{ given } \phi_0$$

Previously across countries; now people, seamlessly and simultaneously. Process  $\phi \implies$

- $\mathcal{E}$  – average or per capita income
- $\mathcal{I}$  – different measures of inequality
- all other statistics of the distribution

Reverse direction of reasoning

**Estimation (Analog method):** Given (hyper-)parametrized  $F_\theta$  and  $P$ , induce functionals  $\mathbf{T}_l(F_\theta, P)$ , and then match to observations:

$$\begin{aligned}\hat{\theta}_t &\stackrel{\text{def}}{=} \arg \min_{\theta \in \mathbb{R}^p} Q_{X_t}(\theta) \\ &= \arg \min_{\theta \in \mathbb{R}^p} (\mathbf{T}(F_\theta, P_t) - X_t)' \Omega (\mathbf{T}(F_\theta, P_t) - X_t), \\ &\hspace{15em} \Omega \text{ } d \times d \text{ positive definite}\end{aligned}$$

Limit distribution for inference from:

$$\hat{\theta}_t - \theta_{t,0} = - \left( \frac{d^2 Q}{d\theta d\theta'} \Big|_{\theta_{t,0}} \right)^{-1} \frac{dQ}{d\theta} \Big|_{\theta_{t,0}}$$

### Log Normal Example

$$\begin{aligned}f_{L(\theta)}(y) &= (2\pi\theta_2)^{-1/2} \cdot y^{-1} \\ &\quad \times \exp \left\{ -\frac{1}{2\theta_2} (\log y - \theta_1)^2 \right\}, \quad \theta_2 > 0, y > 0\end{aligned}$$

$$\implies \mathcal{E}(F_{L(\theta)}) = \exp \left( \theta_1 + \frac{1}{2}\theta_2 \right),$$

$$\mathcal{I}_G(F_{L(\theta)}) = 2 \times F_{N(0,1)}(\theta_2^{1/2}/\sqrt{2}) - 1$$

If only these, then:

$$\hat{\theta}_2 = \left[ F_{N(0,1)}^{-1}((\mathcal{I}_G + 1)/2) \right]^2 \times 2,$$

$$\hat{\theta}_1 = \log \mathcal{E} - \hat{\theta}_2/2$$

Induce

$$\dot{\mathcal{E}}/\mathcal{E} = \dot{\theta}_1 + \frac{1}{2}\dot{\theta}_2,$$

$$\dot{\mathcal{I}}_G/\mathcal{I}_G = \frac{f_{\mathbf{N}(0,1)}([\theta_2/2]^{1/2})}{2F_{\mathbf{N}(0,1)}([\theta_2/2]^{1/2}) - 1} \cdot (\theta_2/2)^{1/2} \times \dot{\theta}_2/\theta_2,$$

and

$$-\frac{d}{dt}F_{\mathbf{L}(\theta)}(\underline{Y}) = \int_0^{\underline{Y}} -\frac{d}{dt}f_{\mathbf{L}(\theta)} dy$$

### Pareto (Type 1) Example

$$f_{\mathbf{P}(\theta)}(y) = \begin{cases} 0 & \text{if } y \leq 0, \\ \theta_2(\theta_1 y^{-1})^{\theta_2} y^{-1} & \text{otherwise.} \end{cases}$$

$$\implies \mathcal{E}(F_{\mathbf{P}(\theta)}) = (\theta_2 - 1)^{-1} \theta_2 \theta_1,$$

$$\mathcal{I}_G(F_{\mathbf{P}(\theta)}) = (2\theta_2 - 1)^{-1}$$

If only these, then:

$$\hat{\theta}_2 = (1 + \mathcal{I}_G^{-1})/2,$$

$$\hat{\theta}_1 = (1 - \hat{\theta}_2^{-1})\mathcal{E}$$

Induce

$$\begin{aligned}\dot{\mathcal{E}}/\mathcal{E} &= \frac{\dot{\theta}_1}{\theta_1} - (\theta_2 - 1)^{-1} \frac{\dot{\theta}_2}{\theta_2}, \\ \dot{\mathcal{I}}_G/\mathcal{I}_G &= \left( \frac{-2\theta_2}{2\theta_2 - 1} \right) \frac{\dot{\theta}_2}{\theta_2} \\ -\frac{d}{dt} \mathbb{F}_{\mathbb{P}(\theta)}(\underline{Y}) &= (1 - \mathbb{F}_{\mathbb{P}(\theta)}(\underline{Y})) \theta_2 \times \left[ \frac{\dot{\theta}_1}{\theta_1} + \log \left( \frac{\theta_1}{\underline{Y}} \right) \frac{\dot{\theta}_2}{\theta_2} \right]\end{aligned}$$

### 3.1 Alternative functionals $\mathbf{T}_l$

$$\begin{aligned}\mathcal{E}(\mathbb{F}, P) &\stackrel{\text{def}}{=} \int_{-\infty}^{\infty} y d\mathbb{F}(y) \\ \mathcal{I}_G(\mathbb{F}, P) &\stackrel{\text{def}}{=} [2^{-1} \mathcal{E}(\mathbb{F})]^{-1} \int_{-\infty}^{\infty} \left( \mathbb{F}(y) - \frac{1}{2} \right) y d\mathbb{F}(y)\end{aligned}$$

$$\begin{aligned}Y_{0.2i}(\mathbb{F}, P) &\stackrel{\text{def}}{=} \sup_{y \in \mathbb{R}} \{y \mid \mathbb{F}(y) \leq 0.2i\} \\ S_{0.2i}(\mathbb{F}) &\stackrel{\text{def}}{=} \left( \int_{-\infty}^{Y_{0.2i}(\mathbb{F}, P)} y d\mathbb{F}(y) \right) \times \mathcal{E}(\mathbb{F}, P)^{-1}\end{aligned}$$

### 3.2 (More) Alternative functionals $\mathbf{T}_l$

$$HC_{\underline{Y}}(\mathbf{F}, P) \stackrel{\text{def}}{=} \mathbf{F}(\underline{Y}) = \int_{-\infty}^{\underline{Y}} d\mathbf{F}(y)$$

$$P_{\underline{Y}}(\mathbf{F}, P) \stackrel{\text{def}}{=} P \times \mathbf{F}(\underline{Y})$$

$$PGI_{\underline{Y}}(\mathbf{F}, P) \stackrel{\text{def}}{=} \frac{\int_{-\infty}^{\underline{Y}} y d\mathbf{F}(y)}{\underline{Y}}$$

$$Y_{0.1i}(\mathbf{F}, P) \stackrel{\text{def}}{=} \sup_{y \in \mathbb{R}} \{y \mid \mathbf{F}(y) \leq 0.1i\}, \quad i = 0, 1, \dots, 9$$

$$\mathcal{E}_{0.1i}(\mathbf{F}, P) \stackrel{\text{def}}{=} \int_{Y_{0.1 \times (i-1)}}^{Y_{0.1i}} y d\mathbf{F}(y), \quad i = 1, \dots, 9$$

$$\mathcal{E}_1(\mathbf{F}, P) \stackrel{\text{def}}{=} \int_{Y_{0.9}}^{\infty} y d\mathbf{F}(y)$$

$$Y_{0.5}(\mathbf{F}, P) \stackrel{\text{def}}{=} \sup_{y \in \mathbb{R}} \left\{ y \mid \mathbf{F}(y) \leq \frac{1}{2} \right\}$$

$$Pz(\mathbf{F}, P) \stackrel{\text{def}}{=} \left[ (1 - \mathcal{I}_G) \mathcal{E} - \frac{\int_{-\infty}^{Y_{0.5}} y d\mathbf{F}(y)}{\int_{-\infty}^{Y_{0.5}} d\mathbf{F}(y)} \right] \times \frac{2}{Y_{0.5}}$$

$$\begin{aligned} Fl_{\underline{Y}}(\mathbf{F}_{\theta_t}, P_t) &\stackrel{\text{def}}{=} -\frac{d}{dt} (\mathbf{F}_{\theta_t}(\underline{Y}) \cdot P_t) \\ &= - \left[ P_t \frac{d}{dt} \mathbf{F}_{\theta_t}(\underline{Y}) + \mathbf{F}_{\theta_t}(\underline{Y}) \frac{dP_t}{dt} \right] \end{aligned}$$

	Variance decomposition (%)	
	Across countries	Over time
(575) Gini coeff. $\mathcal{I}_G$	91.2	8.8
(1750) Per capita $\mathcal{E}$	72.8	27.2
(1732) Growth $\dot{\mathcal{E}}/\mathcal{E}$	8.6	91.4
(1702) Smoothed [5 yr.] $\dot{\mathcal{E}}/\mathcal{E}$	22.1	77.9
(1750) Population $P$	95.2	4.8

Table 2: Inequality variation

### 3.3 A WORKED EXAMPLE: China, India, the US

	Gini coefficient $\mathcal{I}_G$		
	1980	1992	Min. (year)
China	0.32	0.38	0.26 (1984)
India	0.32	0.32	0.29 (1973)
US	0.35	0.38	0.34 (1968)

	Per capita incomes (US\$)			Population ( $\times 10^6$ )	
	1980	1992	$\dot{\mathcal{E}}/\mathcal{E}$	1980	1992
China	972	1493	3.58%	981	1162
India	882	1282	3.12%	687	884
US	15295	17945	1.33%	228	255

**Consequences:**

	$\underline{Y} = 2; HC_{\underline{Y}} (P_{\underline{Y}}, 10^6)$	
	1980	1992
China	0.37–0.54 (360–530)	0.14–0.17 (158–192)
India	0.48–0.62 (326–426)	0.12–0.19 (110–166)

From 1980 perspective:

	$\mathcal{I}_G, P$ constant: $-\dot{P}_{\underline{Y}}$	$HC_{\underline{Y}}$ constant: $\dot{\mathcal{I}}_G/\mathcal{I}_G$
China	33m/year	8.3%/year
India	17m/year	8.8%/year

## 4 CONCLUSIONS

1. Economic growth: The rich and the poor. Growth and distribution seamlessly conceptually indistinguishable
2. Technology, for most of cross-section distribution dynamics
3. Models for cross-section distribution dynamics: Theoretical and empirical. Simple taxonomy
4. One integrated view of growth and inequality. Relative importance of aggregate growth for shifting the distribution