ECON 164: Theory of Economic Growth

Week 4: Evaluating the Neoclassical Growth Model

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Winter 2026

Recap: The neoclassical growth model (NGM)

$$F(K_t, A_tL_t) = K_t^{\alpha}(A_tL_t)^{1-\alpha}, \qquad K_{t+1} = \boldsymbol{F(K_t, A_tL_t) - C_t} + (1-\delta)K_t$$

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. . . with **exogenous** savings (the **Solow** model)

- ad-hoc consumption rule $\longrightarrow$ savings depend on current output $\boldsymbol{y_t}$ only

. . . with **endogenous** savings (the **Ramsey-Cass-Koopmans** model)

- optimal consumption path $\longrightarrow$ savings depend on $\boldsymbol{\{w_t, r_t, \tau_t\}, \beta, k_0, \ldots}$
- can reincorporate population $(\boldsymbol{g_L})$ and productivity $(\boldsymbol{g_A})$ growth

How does the NGM answer our three organizing questions?

1. **Why are we so rich and they so poor?**

2. **What is the engine of economic growth?**

3. **How do "growth miracles" happen?**

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This week: How do these fit the data?

Development accounting (I)

Why are we so rich and they so poor?

Recall from the **Solow** model:

$$y_t^{\text{BGP}} = A_t \left(\qquad \tilde{k}^{\text{ss}} \qquad \right)^{\alpha}$$

Recall from the **Solow** model:

$$y_t^{\text{BGP}} = A_t \left(\frac{s}{\delta + g_A + g_L} \right)^{\frac{\alpha}{1-\alpha}}$$

Why are we so rich and they so poor?

Figure 3.5 GDP per Capita and the Capital Formation Rate, s_I

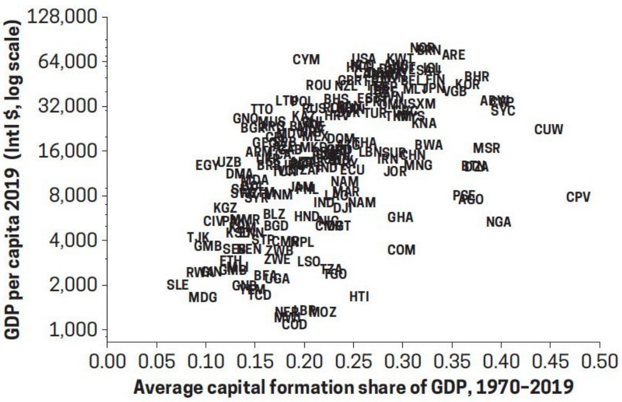

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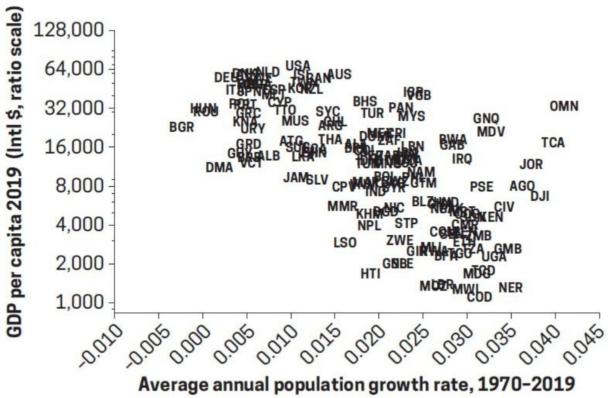
Figure 3.6 GDP per Capita and the Population Growth Rate, g_L



SOURCE: Author's calculations from Penn World Tables v10.0 (Feenstra, Inklaar, and Timmer, 2015).

NOTE: The figure plots the average growth rate of population from 1970 to 2019.

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Why are we so rich and they so poor?

Suppose countries only vary in their **savings rates** (s):

$$\frac{y_i^{\text{BGP}}}{y_j^{\text{BGP}}} = \frac{A_t \left(\frac{s_i}{\delta + g_A + g_L}\right)^{\frac{\alpha}{1-\alpha}}}{A_t \left(\frac{s_j}{\delta + g_A + g_L}\right)^{\frac{\alpha}{1-\alpha}}}$$

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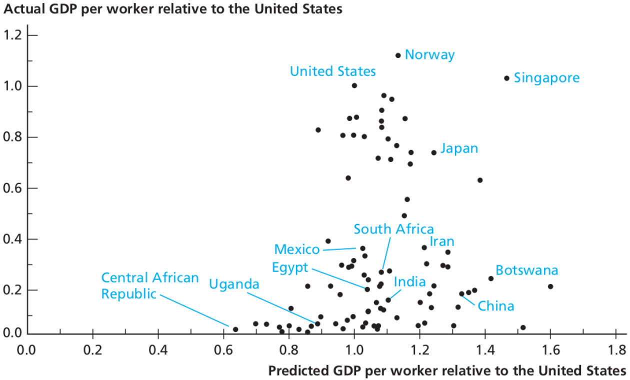
FIGURE 3.7

Predicted versus Actual GDP per Worker



Source: Author's calculations using data from Heston, Summers, and Aten (2011).

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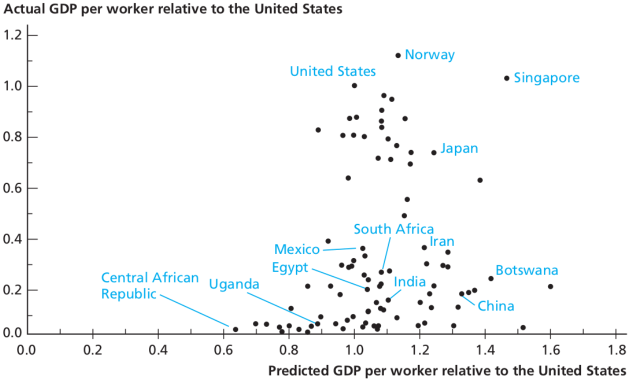

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$\leftarrow$ ***Why isn't it perfect?***

Why isn't it perfect?

1. Countries don't **only** vary in their savings rates $\rightarrow$ variation in $\tilde{\boldsymbol{k}}_{\boldsymbol{i}}^{\text{ss}}$ not enough?

A first attempt at "development accounting"

We want to **decompose** differences in $\boldsymbol{y_i}$ into $\boldsymbol{\tilde{k}_i}$ vs. $\boldsymbol{A_i}$ (i indexes countries)

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But how do we measure $\boldsymbol{A_i}$? If we have **data** re: Y_{it}, K_{it}, and L_{it}...

$$\boldsymbol{A_{it}} = \left(\frac{Y_{it}}{K_{it}^{\alpha} L_{it}^{1-\alpha}} \right)^{\frac{1}{1-\alpha}}, \qquad \boldsymbol{\tilde{k}_{it}} = \frac{K_{it}}{A_{it} L_{it}} = \frac{k_{it}}{A_{it}}$$

So $\boldsymbol{A_i}$ is a "measure of our ignorance" (Abramovitz, 1956; Solow, 1957)

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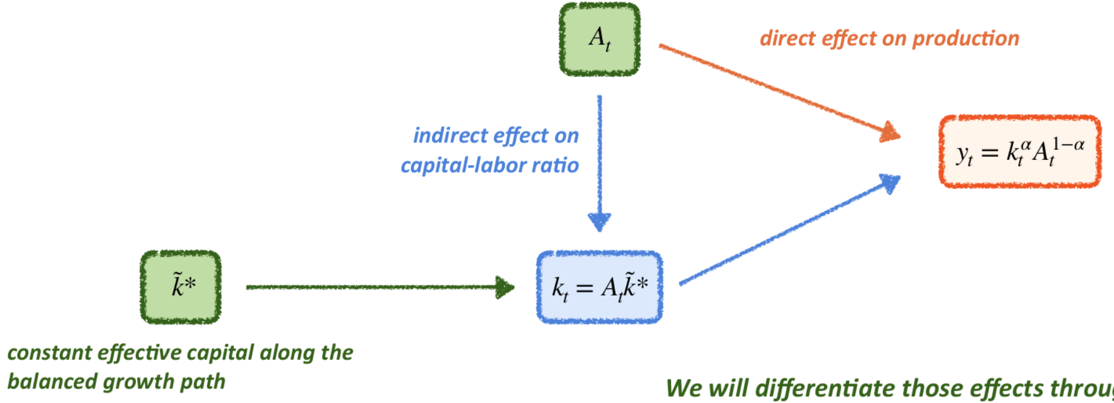
What could go wrong?

Direct vs. indirect effects of productivity A_i (Klenow and Rodríguez-Clare, 1997)



We will differentiate those effects throughout.
"partial" vs "total" decomposition.

Two different decompositions

partial **decomposition**: only direct effect of productivity

$$\ln y_i = \alpha \ln k_i + (1-\alpha) \ln A_i$$

total **decomposition**: productivity gets credit for the capital accumulation it *induces*

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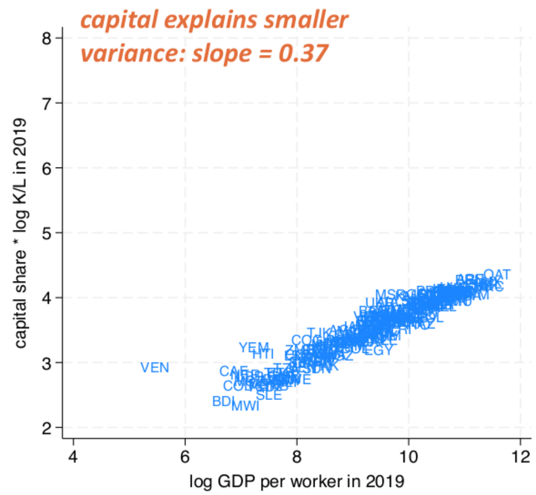
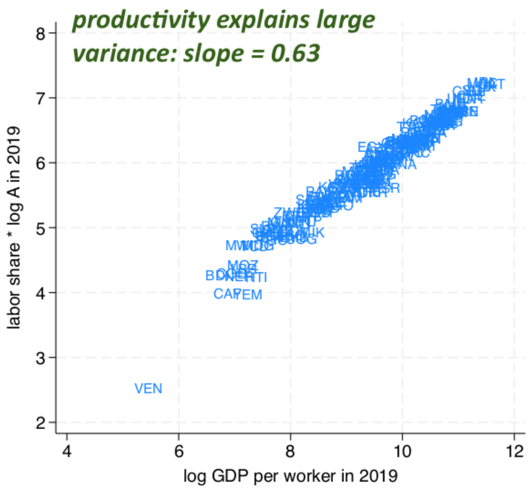
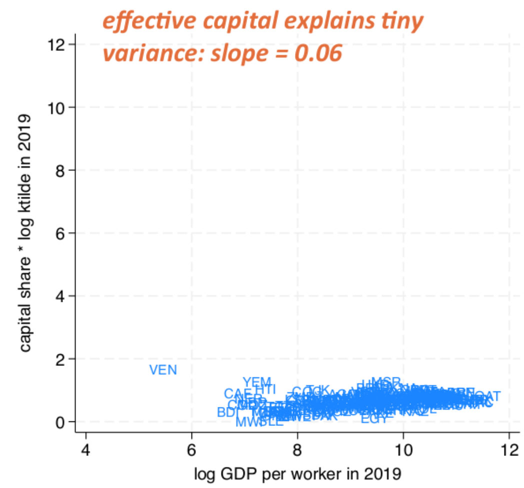
How much of the variation in y_i is due to each term?

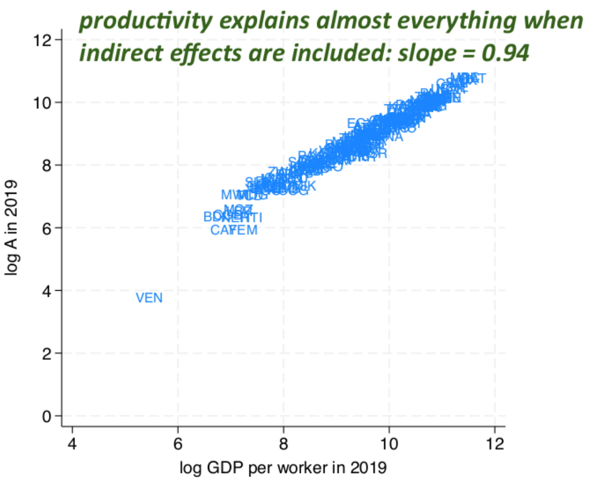
Partial decomposition: Mainly about A_i, but k_i matters





Total decomposition: *Only* about A_i, not $\tilde{k}_i$





Why isn't it perfect?

1. Countries don't **only** vary in their savings rates $\rightarrow$ variation in $\tilde{k}_i^{\text{ss}}$ not enough?
    - variation in productivity A_i matters ***a lot***
    - capital seems to only really matter insofar as it **responds** to productivity

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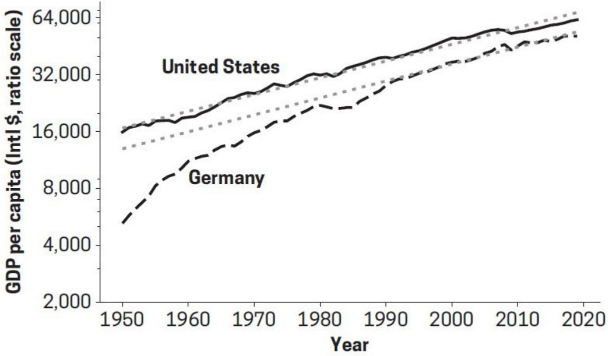
3. . . . and many more reasons → next class

Growth accounting (I)

Rapid growth is transitional growth. . .

Figure 3.1 GDP per Capita in Germany and the United States, 1950–2019



SOURCE: Author's calculations from Penn World Tables v10.0 (Feenstra, Inklaar, and Timmer, 2015).

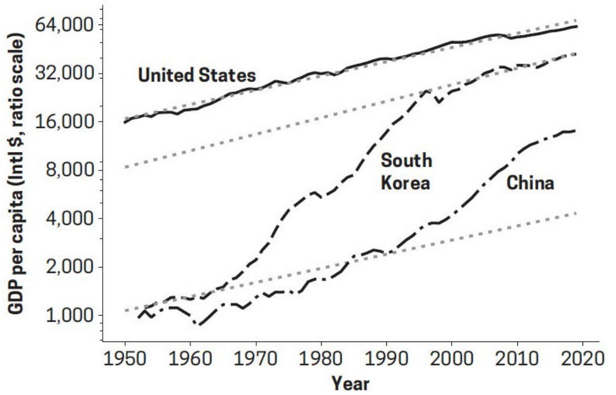
NOTE: GDP per capita is plotted on a ratio scale, so that the slopes indicate the growth rate of GDP per capita. The dotted lines represent hypothetical balanced growth paths for both the United States and Germany.

. . . back to the same BGP

post-WWII recovery from destroyed K

Rapid growth is transitional growth. . .

Figure 3.2 GDP per Capita in China, South Korea, and the United States, 1950–2019



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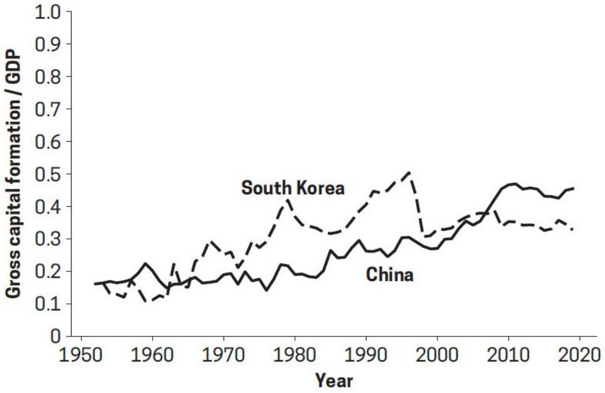
. . . up to a new, higher BGP

what's behind it?

New, higher BGP due in part to...

Figure 3.3 Gross Capital Formation Shares (s_I) in China and South Korea, 1950–2019



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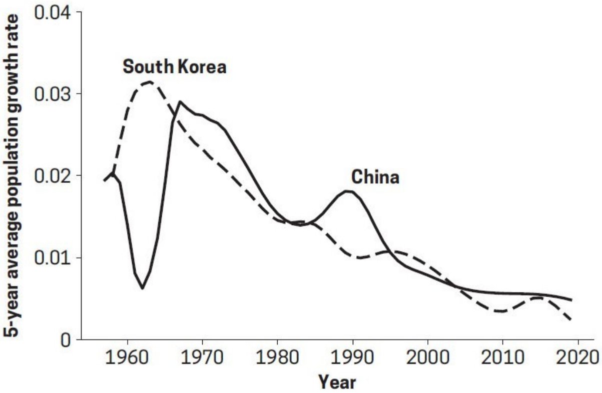
...rise in savings rates (s)

New, higher BGP due in part to. . .

Figure 3.4 Population Growth Rates (g_L) in China and South Korea, 1950–2019



SOURCE: Author's calculations from Penn World Tables v10.0 (Feenstra, Inklaar, and Timmer, 2015).

NOTE: The figure plots the average growth rate of population over a backward-looking five-year window in each year.

. . . fall in pop. growth (g_L)

Growth accounting (Solow, 1957)

From just the Cobb-Douglas production function. . .

$$y_t = A_t \tilde{k}_t^{\alpha}$$

$$= A_t^{1-\alpha} k_t^{\alpha}$$

From just the Cobb-Douglas production function...

$$y_t = A_t \tilde{k}_t^{\alpha} \quad \rightarrow \quad g_y = \alpha \underbrace{(g_K - g_A - g_L)}_{\text{transitional growth}} + \underbrace{g_A}_{\text{productivity growth}}$$

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(works for any neoclassical F)

Example: US vs. Japan

Table 3.1 Growth Accounting for Select Countries

	Growth rate (in %)					
	1955–1965	**1965–1975**	**1975–1985**	**1985–1995**	**1995–2005**	**2005–2015**
Annualized growth	(1)	(2)	(3)	(4)	(5)	(6)
United States						
GDP per capita (g_y)	2.15	2.04	2.49	1.93	2.32	0.72
Breakdown of GDP per capita growth						
Productivity (g_A)	2.25	1.90	2.73	2.10	2.59	0.75
Transitory ($\alpha(g_K - g_A - g_L)$)	−0.10	0.15	−0.24	−0.17	−0.28	−0.03
Breakdown of transitory growth						
Capital (g_K)	3.50	3.37	2.88	2.51	2.74	1.48
Productivity (g_A)	2.25	1.90	2.73	2.10	2.59	0.75
Labor (g_L)	1.58	0.99	0.93	0.98	1.07	0.84
Japan						
GDP per capita (g_y)	7.64	6.25	3.37	2.77	0.98	0.57
Breakdown of GDP per capita growth						
Productivity (g_A)	7.57	4.75	2.89	2.40	0.83	0.75
Transitory ($\alpha(g_K - g_A - g_L)$)	0.08	1.50	0.48	0.38	0.15	−0.18
Breakdown of transitory growth						
Capital (g_K)	8.79	10.99	5.31	4.02	1.48	0.12
Productivity (g_A)	7.57	4.75	2.89	2.40	0.83	0.75
Labor (g_L)	0.96	1.23	0.81	0.36	0.15	−0.03

SOURCE: Author's calculations from Penn World Tables v10.0 (Feenstra, Inklaar, and Timmer, 2015).

NOTE: Productivity growth, g_A, is determined by equation (3.1). Transitory growth is $\alpha g_{KAL} = \alpha(g_K - g_A - g_L)$.

US growth was all **productivity**...

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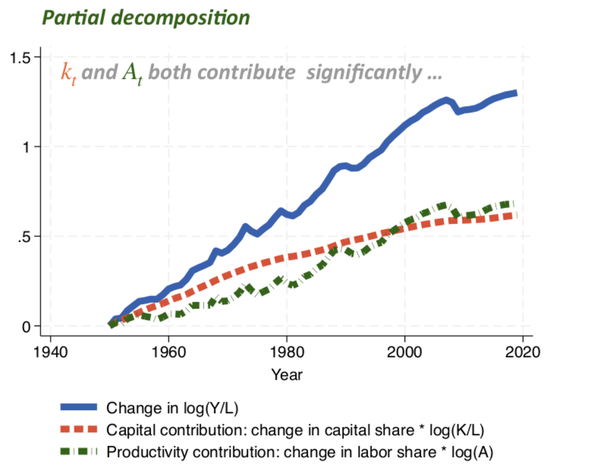
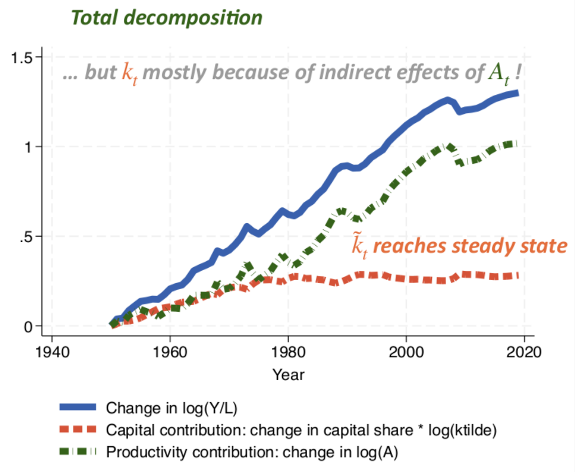
US growth was all **productivity**...

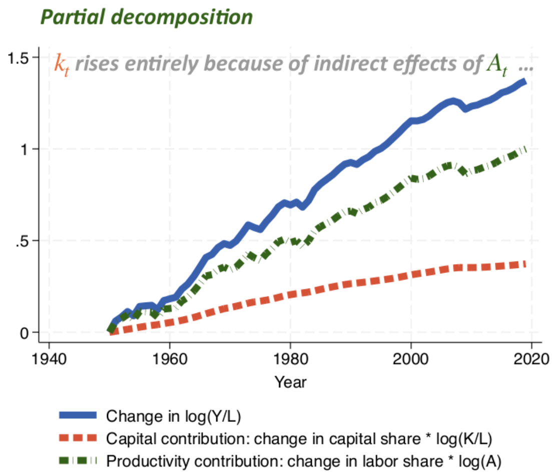
...but Japan was in **transition**

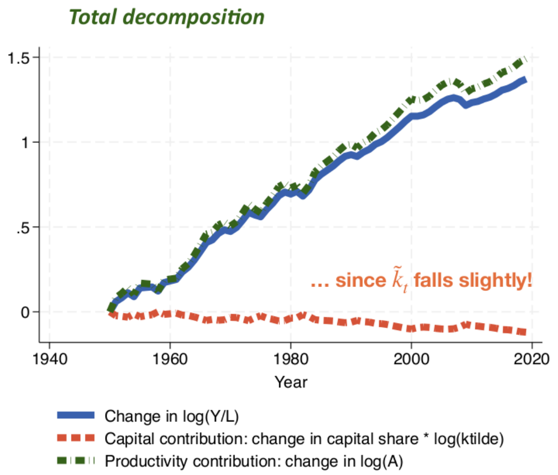
UK growth accounting



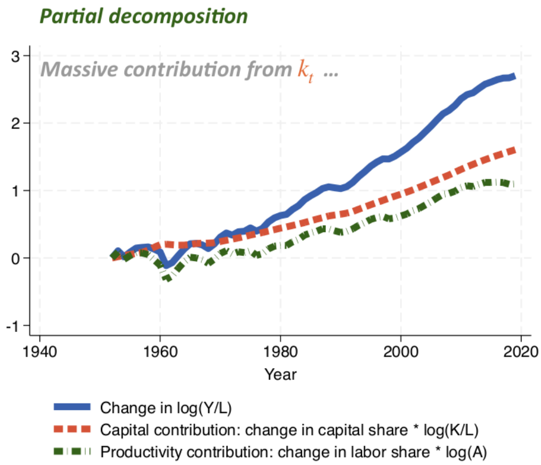


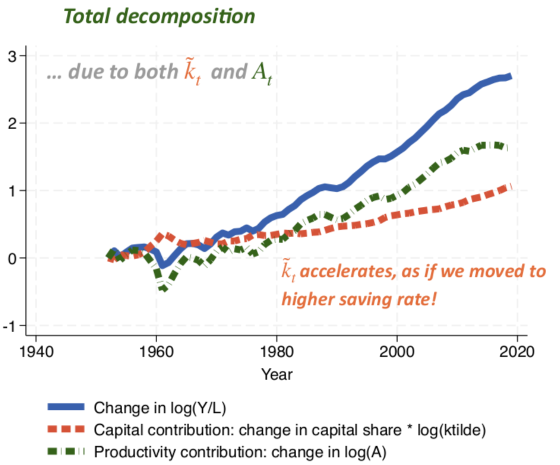
US growth accounting



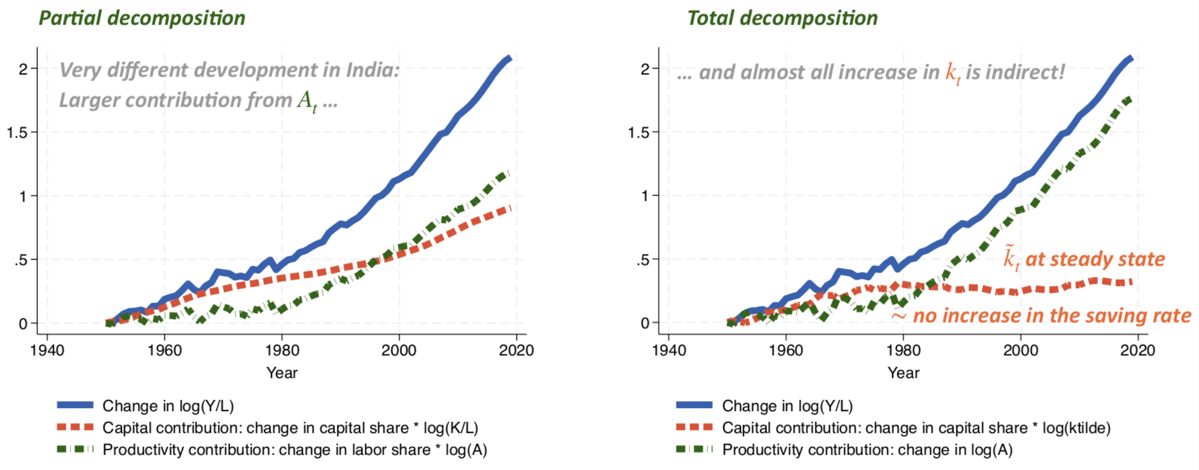


China growth accounting

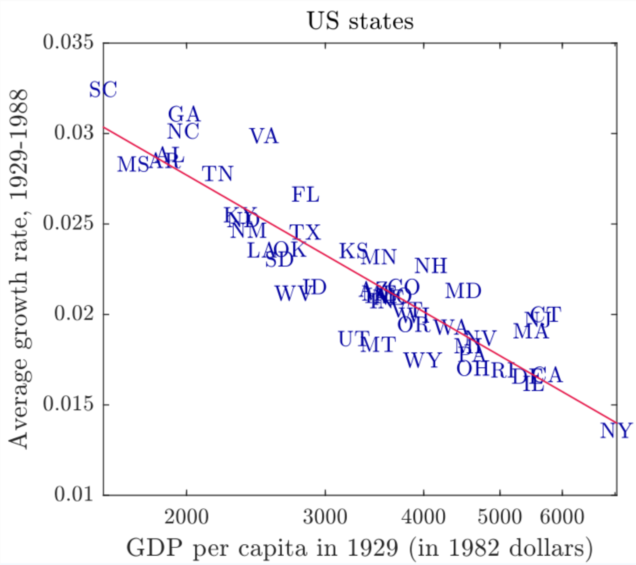




India growth accounting



Convergence

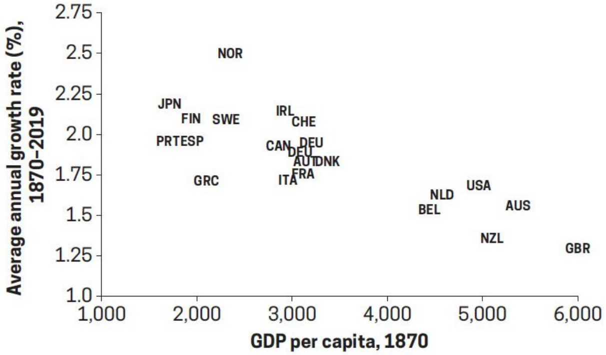


Recall from the **Solow** model:

$$g_y = \alpha\left(s\tilde{k}_t^{\alpha-1} - \delta - g_A - g_L\right) + g_A$$

$\rightarrow$ growth is faster when far from s.s.

Figure 3.7 Growth Rate versus Initial GDP per Capita, 1870–2018



SOURCE: Author's calculations from Bolt and van Zanden (2020).

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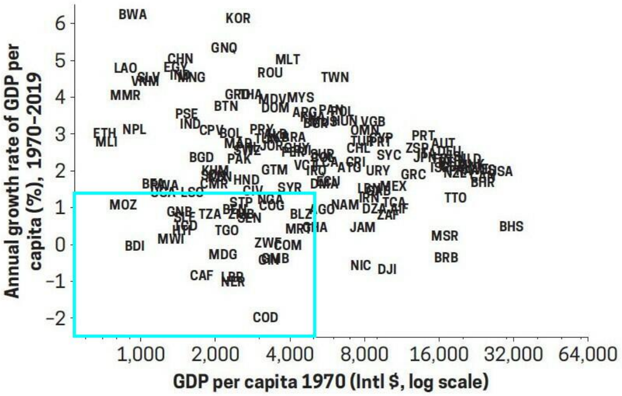
Figure 3.8 Growth Rate versus Initial GDP per Capita, 1970–2019



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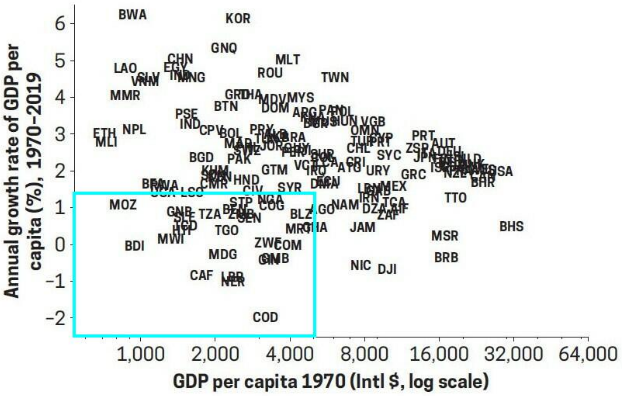
Convergence, absolutely... *not so fast* (Baumol, 1986)

Figure 3.8 Growth Rate versus Initial GDP per Capita, 1970–2019



SOURCE: Author's calculations from Penn World Tables v10.0 (Feenstra, Inklaar, and Timmer, 2015).

Recall from the **Solow** model:

$$g_y = \alpha\Big(s\tilde{k}_t^{\alpha-1} - \delta - g_A - g_L\Big) + g_A$$

$\rightarrow$ growth is faster when far from s.s.

*But why would we expect **same** s.s.?*

We wouldn't! At least not worldwide. . .

Convergence, conditionally

(Mankiw, Romer, and Weil, 1992)

We wouldn't! At least not worldwide. . .

Compare i w/ similar s_i, g_{Li} $\approx$ same s.s.

Convergence, conditionally (Mankiw, Romer, and Weil, 1992)

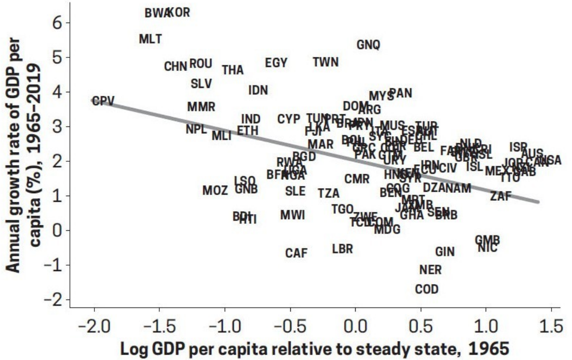
We wouldn't! At least not worldwide...

Compare i w/ similar s_i, g_{Li} $\approx$ same s.s.

Eq. for $\ln y_i^{\text{BGP}}$ suggests a **regression**:

$$\begin{aligned}\boldsymbol{\ln y_i} &= \ln\left[A_{it}\left(\frac{s_i}{\delta + g_A + g_{Li}}\right)^{\frac{\alpha}{1-\alpha}}\right] \\ &= \dots \\ &= \boldsymbol{\beta_0 + \beta_1 \ln s_i + \beta_2 \ln g_{Li} + \varepsilon_i}\end{aligned}$$

Figure 3.9 Growth Rate and Initial GDP per Capita Relative to Steady State, 1965–2019



SOURCE: Author's calculations from Penn World Tables v10.0 (Feenstra, Inklaar, and Timmer, 2015).

NOTE: Log initial GDP per capita relative to steady state is the residual from a regression of log GDP per capita in 1965 on the average capital formation rate from 1965 to 2019 and the average population growth rate from 1965 to 2019. It measures whether a country was relatively rich or poor compared to other countries with similar capital formation and population growth rates.

We wouldn't! At least not worldwide...

Compare i w/ similar s_i, g_{Li} ≈ same s.s.

Eq. for $\ln y_i^{\text{BGP}}$ suggests a **regression**:

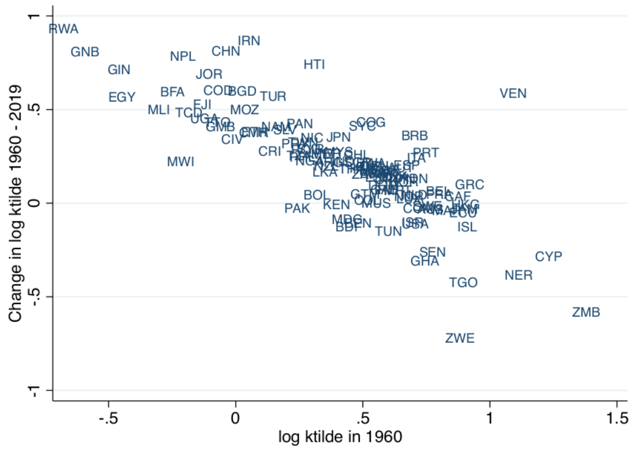
$$\ln y_i = \ln\left[A_{it}\left(\frac{s_i}{\delta + g_A + g_{Li}}\right)^{\frac{\alpha}{1-\alpha}}\right]$$

$$= \dots$$

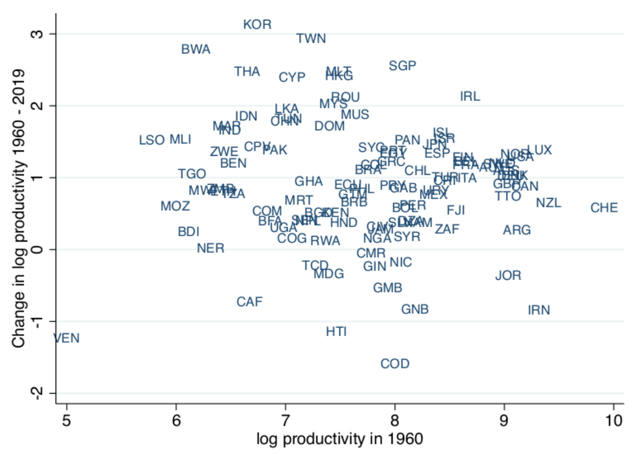
$$= \beta_0 + \beta_1 \ln s_i + \beta_2 \ln g_{Li} + \varepsilon_i$$

← plot g_y vs. ϵ_i from this regression

There is convergence of $\tilde{k}_i$...

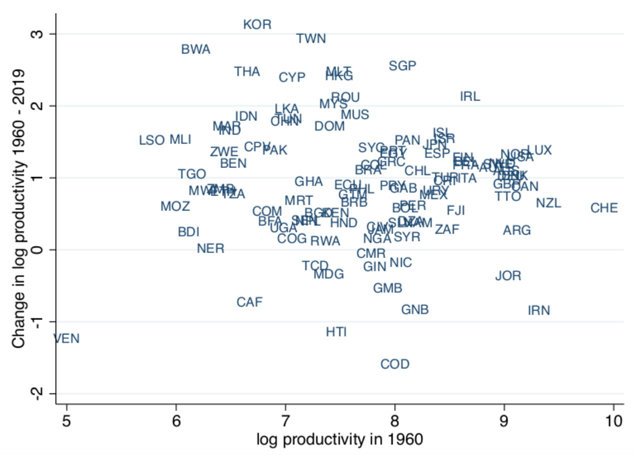


...as predicted by NGM



Not just variation in A_0 then. . .

. . . but not of A_i



Not just variation in A_0 then. . .

. . . but even in g_A

Summary so far

- **This class**, we studied empirical growth patterns through the lens of the NGM
- **For most countries**:
    - Variation in y_i determined by productivity levels A_i, directly and indirectly
    - Growth g_y determined by productivity growth g_A, directly and indirectly
    - Convergence happens for effective capital $\tilde{k}$, as in the NGM…
        - …but that is swamped by huge, persistent productivity differences
- **Not a smashing success for the neoclassical growth model**
    - Has nothing to say about determinants of A_{it}
    - Next: ***What is A_{it}? Why does it vary across countries?***

What is A?

The measure of our ignorance

NGM with Cobb-Douglas: Given **data** and an estimate of α...

$$A_{it} = \left(\frac{Y_{it}}{{K_{it}}^{\alpha} {L_{it}}^{1-\alpha}} \right)^{\frac{1}{1-\alpha}}$$ → find ***huge differences*** in A_{it}!

The measure of our ignorance

NGM with Cobb-Douglas: Given **data** and an estimate of α...

$$A_{it} = \left(\frac{Y_{it}}{{K_{it}}^{\alpha} {L_{it}}^{1-\alpha}} \right)^{\frac{1}{1-\alpha}} \rightarrow \text{find } \textit{\textbf{huge differences}} \text{ in } A_{it}!$$

What's behind this?

1. **mismeasurement**: maybe we're not measuring Y_{it}, K_{it}, L_{it} correctly
2. **misspecification**: maybe we're using the wrong $F_{it}(\cdot, \cdot)$, omitting inputs, ...
3. **true productivity differences**: maybe some i really are way more efficient!

Mismeasurement of labor L_{it}

What are we really trying to measure?

Mismeasurement of labor L_{it}

What are we really trying to measure?

- it's time to distinguish between labor $\boldsymbol{L_{it}}$ and population $\boldsymbol{N_{it}}$ again
  - recall, L_{it}/N_{it} is the labor force participation rate (Week 1)
- naive measure: $\boldsymbol{L_{it}} =$ **total hours** $= \#$ of workers $\times$ avg. hours worked
  - avg. hours worked *decrease* w/ y_{it} (Bick, Fuchs-Schündeln, and Lagakos, 2018)

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  - avg. hours worked *decrease* w/ y_{it} (Bick, Fuchs-Schündeln, and Lagakos, 2018)
- but what about **quality** of labor? one worker in Malawi ≠ one worker in Singapore
  - **human capital** = education, training, skills, health, . . . (Becker, 1964)
  - "capital" b/c it's a stock produced by investments
  - lowest-income countries avg. 4–5 years of schooling, highest-income avg. 12–13

Adding human capital to the NGM

Suppose now that the production function includes **human capital**:

$$Y_{it} = K_{it}^{\alpha}(A_{it}\boldsymbol{h_{it}}L_{it})^{1-\alpha}$$

Adding human capital to the NGM

Suppose now that the production function includes **human capital**:

$$Y_{it} = K_{it}^{\alpha}(A_{it}\boldsymbol{h_{it}}L_{it})^{1-\alpha} = \left(\frac{K_{it}}{A_{it}h_{it}L_{it}}\right)^{\alpha} A_{it}h_{it}L_{it}$$

Adding human capital to the NGM

Suppose now that the production function includes **human capital**:

$$
\begin{aligned}
Y_{it} = K_{it}^{\alpha}(A_{it}\boldsymbol{h_{it}}L_{it})^{1-\alpha} &= \left(\frac{K_{it}}{A_{it}h_{it}L_{it}}\right)^{\alpha} A_{it}h_{it}L_{it} \\
&= \left(\frac{K_{it}^{1-\alpha}}{(A_{it}h_{it}L_{it})^{1-\alpha}}\right)^{\frac{\alpha}{1-\alpha}} A_{it}h_{it}L_{it}
\end{aligned}
$$

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&= \left(\frac{K_{it}}{Y_{it}}\right)^{\frac{\alpha}{1-\alpha}} A_{it}h_{it}L_{it}
\end{aligned}
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&= \left(\frac{K_{it}}{K_{it}^{\alpha}(A_{it}h_{it}L_{it})^{1-\alpha}}\right)^{\frac{\alpha}{1-\alpha}} A_{it}h_{it}L_{it} \\
&= \left(\frac{K_{it}}{Y_{it}}\right)^{\frac{\alpha}{1-\alpha}} A_{it}h_{it}L_{it} \\
\boldsymbol{y_{it} \equiv \frac{Y_{it}}{N_{it}}} &= \boldsymbol{\left(\frac{K_{it}}{Y_{it}}\right)^{\frac{\alpha}{1-\alpha}} A_{it}h_{it}\frac{L_{it}}{N_{it}}}
\end{aligned}
$$

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&= \left(\frac{K_{it}}{Y_{it}}\right)^{\frac{\alpha}{1-\alpha}} A_{it}h_{it}L_{it}
\end{aligned}
$$

$$
\boldsymbol{y_{it} \equiv \frac{Y_{it}}{N_{it}} = \left(\frac{K_{it}}{Y_{it}}\right)^{\frac{\alpha}{1-\alpha}} A_{it}h_{it}\frac{L_{it}}{N_{it}} = \left(\tilde{k}^{ss}\right)^{\alpha} \underbrace{A_{it}h_{it}\frac{L_{it}}{N_{it}}}_{\text{before, just } A_{it}!}}
$$

Mankiw, Romer, and Weil (1992): Just add human capital!

A CONTRIBUTION TO THE EMPIRICS OF ECONOMIC GROWTH*

N. GREGORY MANKIW
DAVID ROMER
DAVID N. WEIL

This paper examines whether the Solow growth model is consistent with the international variation in the standard of living. It shows that an augmented Solow model that includes accumulation of human as well as physical capital provides an excellent description of the cross-country data. The paper also examines the implications of the Solow model for convergence in standards of living, that is, for whether poor countries tend to grow faster than rich countries. The evidence indicates that, holding population growth and capital accumulation constant, countries converge at about the rate the augmented Solow model predicts.

Young (1995): Now the East Asian growth miracle is not so “miraculous”

THE TYRANNY OF NUMBERS: CONFRONTING THE STATISTICAL REALITIES OF THE EAST ASIAN GROWTH EXPERIENCE*

ALWYN YOUNG

This paper documents the fundamental role played by factor accumulation in explaining the extraordinary postwar growth of Hong Kong, Singapore, South Korea, and Taiwan. Participation rates, educational levels, and (excepting Hong Kong) investment rates have risen rapidly in all four economies. In addition, in most cases there has been a large intersectoral transfer of labor into manufacturing, which has helped fuel growth in that sector. Once one accounts for the dramatic rise in factor inputs, one arrives at estimated total factor productivity growth rates that are closely approximated by the historical performance of many of the OECD and Latin American economies. While the growth of output and manufacturing exports in the newly industrializing countries of East Asia is virtually unprecedented, the growth of total factor productivity in these economies is not.

Young (1995): Now the East Asian growth miracle is not so "miraculous"

TABLE V
TOTAL FACTOR PRODUCTIVITY GROWTH: HONG KONG

growth in Y around 6-8%! | Annual growth of: | growth in A around 2-3%

Time period	Output	Raw capital	Weighted capital	Raw labor	Weighted labor	TFP	Labor share
61–66	0.109	0.169	0.162	0.032	0.025	0.035	0.643
66–71	0.065	0.075	0.078	0.025	0.024	0.023	0.660
71–76	0.081	0.075	0.080	0.033	0.024	0.039	0.662
76–81	0.099	0.093	0.098	0.051	0.064	0.022	0.617
81–86	0.058	0.078	0.079	0.019	0.027	0.009	0.593
86–91	0.063	0.062	0.066	0.005	0.022	0.024	0.609
66–91	**0.073**	**0.077**	**0.080**	**0.026**	**0.032**	**0.023**	**0.628**

Raw inputs are the arithmetic sum of subcomponents, with no adjustment for hours of work. Weighted inputs are translog indices of factor input growth, with labor services measured by hours of work.

How do we measure human capital?

- MRW (1992): $h = \sqrt{\text{share of working-age pop. enrolled in H.S.}}$
  - *why*: available for many countries, seemed to fit the data...
  - ...but **lots** of later work pointed out issues (only counts H.S., no quality, ...)

How do we measure human capital?

- MRW (1992): $\boldsymbol{h} = \sqrt{\text{share of working-age pop. enrolled in H.S.}}$
  - *why*: available for many countries, seemed to fit the data...
  - ...but **lots** of later work pointed out issues (only counts H.S., no quality, ...)
- **main problem**: implausibly big vs. micro evidence on returns to schooling
  - instead, set $\ln \boldsymbol{h_{it}} = \boldsymbol{\mu E_i}$ where E_i is avg. years of schooling
  - *why*: can show

    $$\ln \boldsymbol{w_{it}} = \Lambda_{it} + \ln h_{it} = \boldsymbol{\Lambda_{it}} + \boldsymbol{\mu E_i}$$

    so μ is the **% increase** in the **wage** for an **extra year** of schooling
  - lots of estimates of μ ("Mincer returns") $\rightarrow$ $\mu \approx \mathbf{0.10}$ **worldwide**
  - so just need data on E_i (Barro and Lee, 2013)

Development accounting, revisited (Hall and Jones, 1999)

Same idea as before: **solve for A_{it} as a residual in terms of data**

$$y_{it} = \left(\frac{K_{it}}{Y_{it}}\right)^{\frac{\alpha}{1-\alpha}} A_{it} h_{it} \frac{L_{it}}{N_{it}} \quad \rightarrow \quad A_{it} = \frac{y_{it}}{\left(\frac{K_{it}}{Y_{it}}\right)^{\frac{\alpha}{1-\alpha}} e^{\mu E_{it}} \frac{L_{it}}{N_{it}}}$$

We'll focus on comparing to the US in 2019:

$$\frac{y_i}{y_{\text{US}}} = \left[\frac{(K/Y)_i}{(K/Y)_{\text{US}}}\right]^{\frac{\alpha}{1-\alpha}} \times \frac{A_i}{A_{\text{US}}} \times \frac{h_i}{h_{\text{US}}} \times \frac{(L/N)_i}{(L/N)_{\text{US}}}$$

Development accounting, revisited

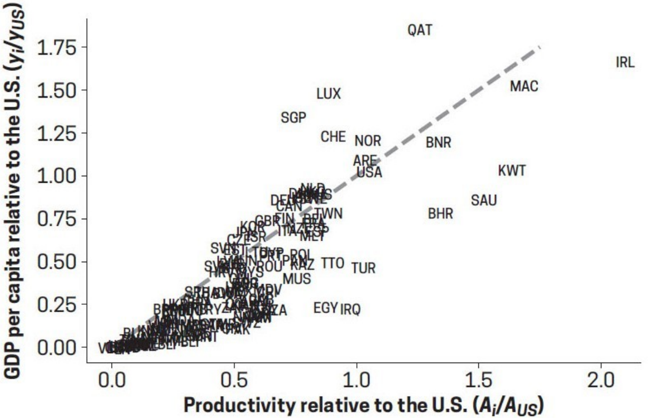
Table 7.1 Development Accounting across Countries, 2019

Country	GDP per capita $\frac{y_t}{y_{US}}$	Components of GDP per capita: Capital / output $\left[\frac{(K/Y)_t}{(K/Y)_{US}}\right]^{\frac{\alpha}{1-\alpha}}$	Human capital $\frac{h_t}{h_{US}}$	Labor force participation $\frac{(L_t/N_t)}{(L_{US}/N_{US})}$	Productivity $\frac{A_t}{A_{US}}$
Selected countries:					
United States	1.000	1.000	1.000	1.000	1.000
Germany	0.818	1.175	0.971	1.115	0.643
Canada	0.797	1.153	0.989	1.072	0.652
United Kingdom	0.707	1.197	1.010	1.015	0.576
South Korea	0.675	1.204	1.006	1.087	0.512
Japan	0.634	1.205	0.940	1.147	0.489
Turkey	0.431	1.140	0.560	0.700	0.963
Mexico	0.299	1.141	0.643	0.896	0.455
Brazil	0.233	1.127	0.753	0.925	0.297
China	0.226	1.084	0.617	1.158	0.291
South Africa	0.200	1.071	0.688	0.662	0.411
Egypt	0.193	0.709	0.609	0.555	0.804
Indonesia	0.185	1.266	0.511	1.008	0.284
Vietnam	0.120	0.922	0.675	1.086	0.177
India	0.107	1.062	0.485	0.757	0.275
Nigeria	0.080	0.982	0.441	0.755	0.243
Kenya	0.068	0.869	0.523	0.991	0.150
Summary statistics over all countries:					
Mean	0.352	1.110	0.654	0.891	0.463
Std. Dev.	0.346	0.241	0.207	0.205	0.345
Coef. of Var.	0.983	0.217	0.316	0.229	0.746

- very little variation in $\tilde{k}^{ss}$ rel. to US
- more variation in human capital h_{it}
- still huge variation needed in A_{it}
- overall, **literature typically finds**:
  - contribution of $\tilde{k}_{it} \approx 5\%$
  - contribution of $h_{it} \approx 30\%$
  - contribution of $A_{it} \approx 65\%$

Punchline: A_i/A_{US} is *still* the best predictor of y_i/y_{US}

Figure 7.1 Productivity and GDP per Capita



SOURCE: Authors' calculations from Penn World Tables v10.0 (Feenstra, Inklaar, and Timmer, 2015).

NOTE: Productivity is calculated according to equation (7.6) and the assumptions outlined in the notes of Table 7.1.

Growth accounting, revisited

(Jones, 2016)

Table 3 Growth accounting for the United States

Period	Output per hour	Contributions from		
		K/Y	Labor composition	Labor-Aug. TFP
1948–2013	**2.5**	**0.1**	**0.3**	**2.0**
1948–1973	3.3	−0.2	0.3	3.2
1973–1990	1.6	0.5	0.3	0.8
1990–1995	1.6	0.2	0.7	0.7
1995–2000	3.0	0.3	0.3	2.3
2000–2007	2.7	0.2	0.3	2.2
2007–2013	1.7	0.1	0.5	1.1

Note: Average annual growth rates (in percent) for output per hour and its components for the private business sector, following Eq. (3).
Source: Authors calculations using Bureau of Labor Statistics, *Multifactor Productivity Trends*, August 21, 2014.

Still an active area of research

How much of the variation in $\boldsymbol{y_i}$ is accounted for by $\boldsymbol{h_i}$?

- **Jones (2014)**: include imperfect substitutability $\rightarrow$ **all the rest** of it
- **Caselli and Ciccone (2019)**: change Jones (2014) assumptions $\rightarrow$ **none** of it
- **Hendricks and Schoellman (2018)**: check Δw_i for migrants $\rightarrow$ $\approx$ **60%** of it
- **Angrist et al. (2021)**: build a harmonized measure of learning-adjusted years of schooling around the world (but not accounting for Jones (2014)) $\rightarrow$ $\approx$ **25%** of it

Mismeasurement of capital K_{it}

What are we really trying to measure?

Mismeasurement of capital K_{it}

What are we really trying to measure?

- capital **stock** K_{it} measured from **expenditure** I_{it} w/ perpetual inventory method
    - add up across different types of capital w/ price or user cost weights

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- **main problem**: conflates **price** and **quantity** of investment
  - relative price of K has long been *falling* (Greenwood, Hercowitz, and Krusell, 1997)
  - relative price of K is *higher* in poor countries (Hsieh and Klenow, 2007)

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- capital share α depends on how we treat self-employment (Gollin, 2002)

Mismeasurement, generally

Should we even trust the data?

- Jerven (2013) *Poor Numbers* (h/t Oliver Kim)
  - late 1980s, Tanzanian y_{it} dropped by 33%, but it probably **didn't happen**
  - how many people live in Nigeria? failed censuses + fast pop. growth = **no clue!**
  - World Bank Statistical Capacity Indicator avg. score in Africa was **61.4/100**

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- Angrist, Goldberg, and Jolliffe (2021): hard to measure in LMIC because...
  - limited statistical capacity
  - use of outdated data and methods
  - large share of the agricultural sector
  - informal economy
  - limited price data

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    - limited statistical capacity
    - use of outdated data and methods
    - large share of the agricultural sector
    - informal economy
    - limited price data
- still debate even for the US: Feldstein (2017) vs. Syverson (2017)

Misspecification: Increasing returns to scale

- How could our production function be **misspecified**?
- Imagine all countries produced with the same production technology ($A = 1$):

$$Y = F(K, L) = \left[K^{\alpha} L^{1-\alpha}\right]^{\gamma}$$

  where $\gamma > 1$ indicates **increasing returns to scale**: $F(\lambda K, \lambda L) = \lambda^{\gamma} F(K, L)$

- As observers, we don't know this and apply our formula from before:

$$A = \left(\frac{Y}{K^{\alpha} L^{1-\alpha}}\right)^{\frac{1}{1-\alpha}} = Y^{\frac{\gamma-1}{\gamma(1-\alpha)}}$$

- Although all countries have the same technology, we pick up differences in $\boldsymbol{A}$!

Misspecification: Imperfect substitutes (Caselli and Coleman, 2006)

Our setup has assumed workers of different skills are **perfect substitutes**...

$$y_{it} = k_{it}^{\alpha}(A_{it}\boldsymbol{h_{it}})^{1-\alpha} = k_{it}^{\alpha}\Big(A_{it}\underbrace{\Big(\sum\nolimits_j h_{jit}\Big)}_{\text{worker types}}\Big)^{1-\alpha}$$

...but the micro evidence suggests they're **quite imperfect**:

$$y_{it} = k_{it}^{\alpha}\left[(A_{it}^{u}h_{it}^{u})^{\sigma} + (A_{it}^{s}h_{it}^{s})^{\sigma}\right]^{\frac{1-\alpha}{\sigma}}$$

for skilled $\boldsymbol{s}$ and unskilled $\boldsymbol{u}$ labor

Misspecification: Imperfect substitutes (Caselli and Coleman, 2006)

The World Technology Frontier

By Francesco Caselli and Wilbur John Coleman II*

We study cross-country differences in the aggregate production function when skilled and unskilled labor are imperfect substitutes. We find that there is a skill bias in cross-country technology differences. Higher-income countries use skilled labor more efficiently than lower-income countries, while they use unskilled labor relatively and, possibly, absolutely less efficiently. We also propose a simple explanation for our findings: rich countries, which are skilled-labor abundant, choose technologies that are best suited to skilled workers; poor countries, which are unskilled-labor abundant, choose technologies more appropriate to unskilled workers. We discuss alternative explanations, such as capital-skill complementarity and differences in schooling quality. (*JEL* E13, E23, J31, O14)

Misspecification: Sectoral heterogeneity (Caselli, 2005)

. . . large differences in TFP could also be the result of ***variation in the weights in GDP*** *of sectors with different sectorial-level productivity—even when these sectorial productivities are* ***identical*** *across countries*

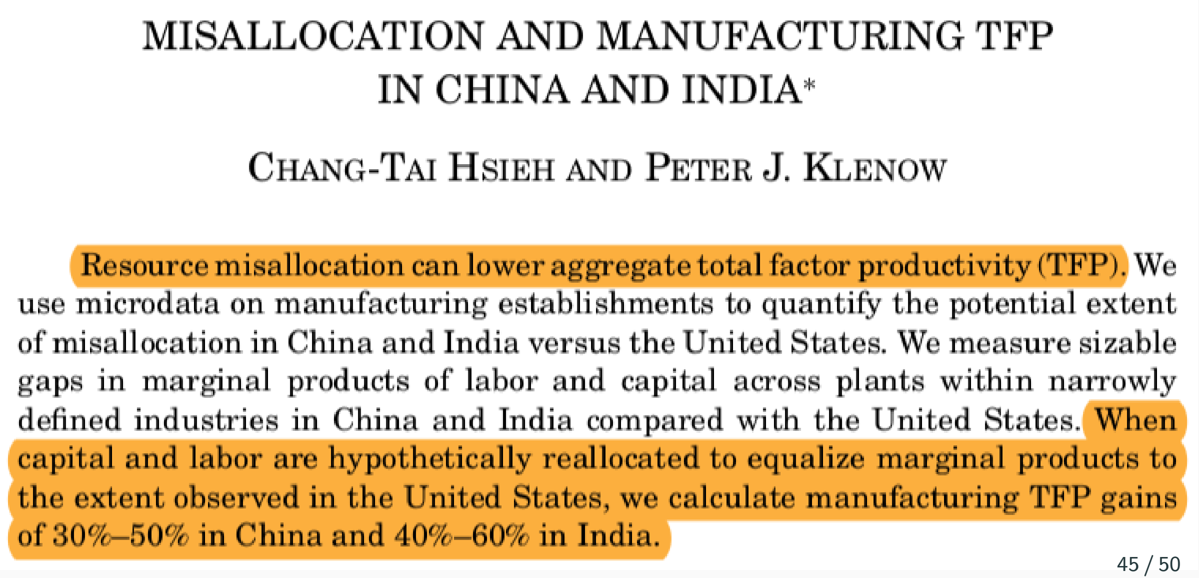
- poorest countries have the **highest** agricultural employment shares. . .
- . . . but the **lowest** relative productivity of agriculture!

Misspecification: Misallocation (Hsieh and Klenow, 2009)

- what if many, heterogeneous firms with productivity A_j? (j indexes firms)
- **can show**: measured economy-wide A is **highest** when…

$$\text{MPK}_j = \text{MPK}_{j'} \quad \forall j, j'$$
$$\text{MPL}_j = \text{MPL}_{j'} \quad \forall j, j'$$

…which happens in equilibrium if **no distortions** (taxes, market power, …)


MISALLOCATION AND MANUFACTURING TFP IN CHINA AND INDIA*

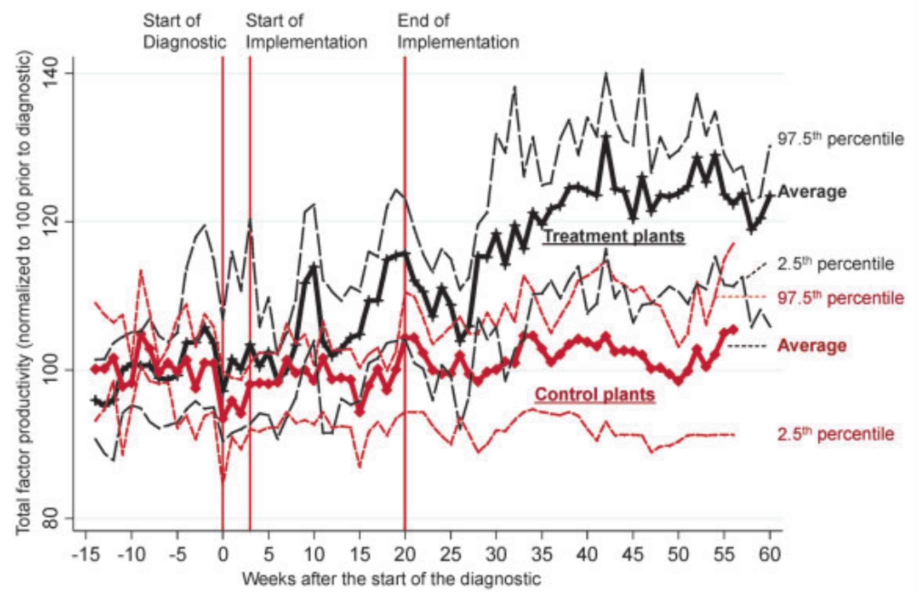
CHANG-TAI HSIEH AND PETER J. KLENOW

Resource misallocation can lower aggregate total factor productivity (TFP). We use microdata on manufacturing establishments to quantify the potential extent of misallocation in China and India versus the United States. We measure sizable gaps in marginal products of labor and capital across plants within narrowly defined industries in China and India compared with the United States. When capital and labor are hypothetically reallocated to equalize marginal products to the extent observed in the United States, we calculate manufacturing TFP gains of 30%–50% in China and 40%–60% in India.

True technology differences: Management

- What if the variation in A_i across countries partly captures **true productivity differences**?
- **Bloom et al. (2013)**: Randomly provide management consultants to Indian manufacturing plants to help with things like:
  - Inventory management
  - Preventative maintenance, measurement of defects
  - Daily meetings, standard operating procedures
  - ...
- Hugely successful: **In one year, productivity rises 17% at treated plants**, increasing profitability by $300,000!
- Why was this not implemented before? Mostly **lack of knowledge**!

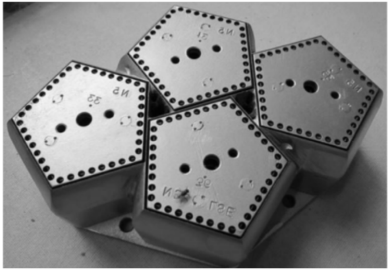
True technology differences: Management

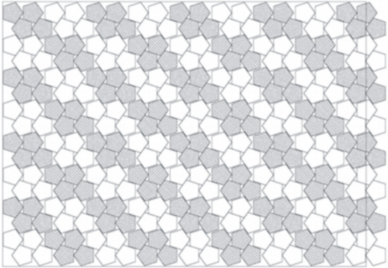


True technology differences: Soccer balls

Typical stamp and waste

Soccer ball =
pentagons and hexagons





New stamp and waste for pentagons

True technology differences: Soccer balls

- Is the more efficient stamp adopted? **Not that much!** Why?
  - Cutters and printers are paid per panel cut $\rightarrow$ no incentive to waste less
  - Learning the new technique slows them down initially, costs wage
- **Organizational design** and **misaligned incentives** can inhibit tech. advance!
- **Atkin et al. (2017)**: Randomly pay cutters and printers to learn new technology and show to owner
- This created **widespread adoption**

What's behind huge variation in the "measure of our ignorance"?

1. **mismeasurement**: maybe we're not measuring $\boldsymbol{Y_{it}}$, $\boldsymbol{K_{it}}$, $\boldsymbol{L_{it}}$ correctly

2. **misspecification**: maybe we're using the wrong $\boldsymbol{F}_{it}(\cdot, \cdot)$, omitting inputs, ...

3. **true productivity differences**: maybe some i really are way more efficient!

Summary

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2. **misspecification**: maybe we're using the wrong $\boldsymbol{F}_{it}(\cdot, \cdot)$, omitting inputs, ...

3. **true productivity differences**: maybe some i really are way more efficient!

next: Models that endogenize $\boldsymbol{A_{it}}$

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