Applying the Solow Model

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Topics

We apply the Solow model to study:

1. Cross-country income differences
2. Cross-country variation in growth rates
3. Growth with non-renewable resources

Why Are Some Countries Rich and Others Poor?

What does the Solow model tells us about why some countries are much richer than others?

How important are:

- physical capital?
- human capital?
- productivity?

To analyze this: assume countries are close to steady state.

Solving for the steady state

- Recall the law of motion

$$\dot{k} = sf(k) - (n + \delta)k \tag{1}$$

  where $f(k) = A^{1-\alpha}k^{\alpha}$.
- For simplicity: we abstract from productivity growth.
- Exercise: repeat the analysis with productivity growth.

Solving for the steady state

- Impose steady state: $\dot{k} = 0$:

$$sy = (n + \delta)k \tag{2}$$

- The capital-output ratio is

$$k/y = \frac{s}{n + \delta} \tag{3}$$

- Apply production function

$$sA^{1-\alpha}k^{\alpha} = (n + \delta)\,k \tag{4}$$

- Solve for k

$$k = A\left(\frac{s}{n + \delta}\right)^{1/(1-\alpha)} \tag{5}$$

Steady state output

One approach: substitute production function into steady state k.

Easier:

$$y = (y/k) \times k \tag{6}$$
$$= \underbrace{\frac{s}{n+\delta}}_{y/k} \times \underbrace{A\left(\frac{s}{n+\delta}\right)^{1/(1-\alpha)}}_{k}$$

Collect terms:

$$y = A\left[\frac{s}{n+\delta}\right]^{\alpha/(1-\alpha)} \tag{7}$$

Reality check

A key prediction of the model: $k/y = s/(n+\delta)$.

Countries with higher saving rates have higher capital output ratios.

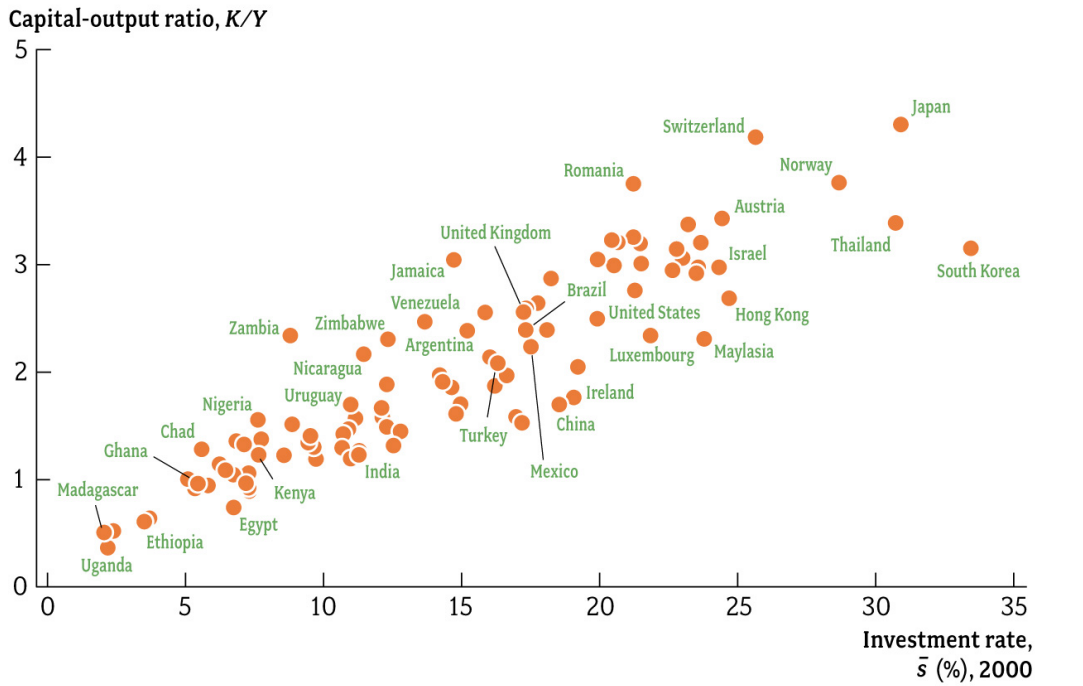


FIGURE 5.3 Explaining Capital in the Solow Model

Macroeconomics, Charles I. Jones

Why does Y/L differ across countries?

- Our static production model answered: K/L and A differ:

$$y = A^{1-\alpha} k^{\alpha} \tag{8}$$

- The Solow model gives a similar answer: s and A differ:

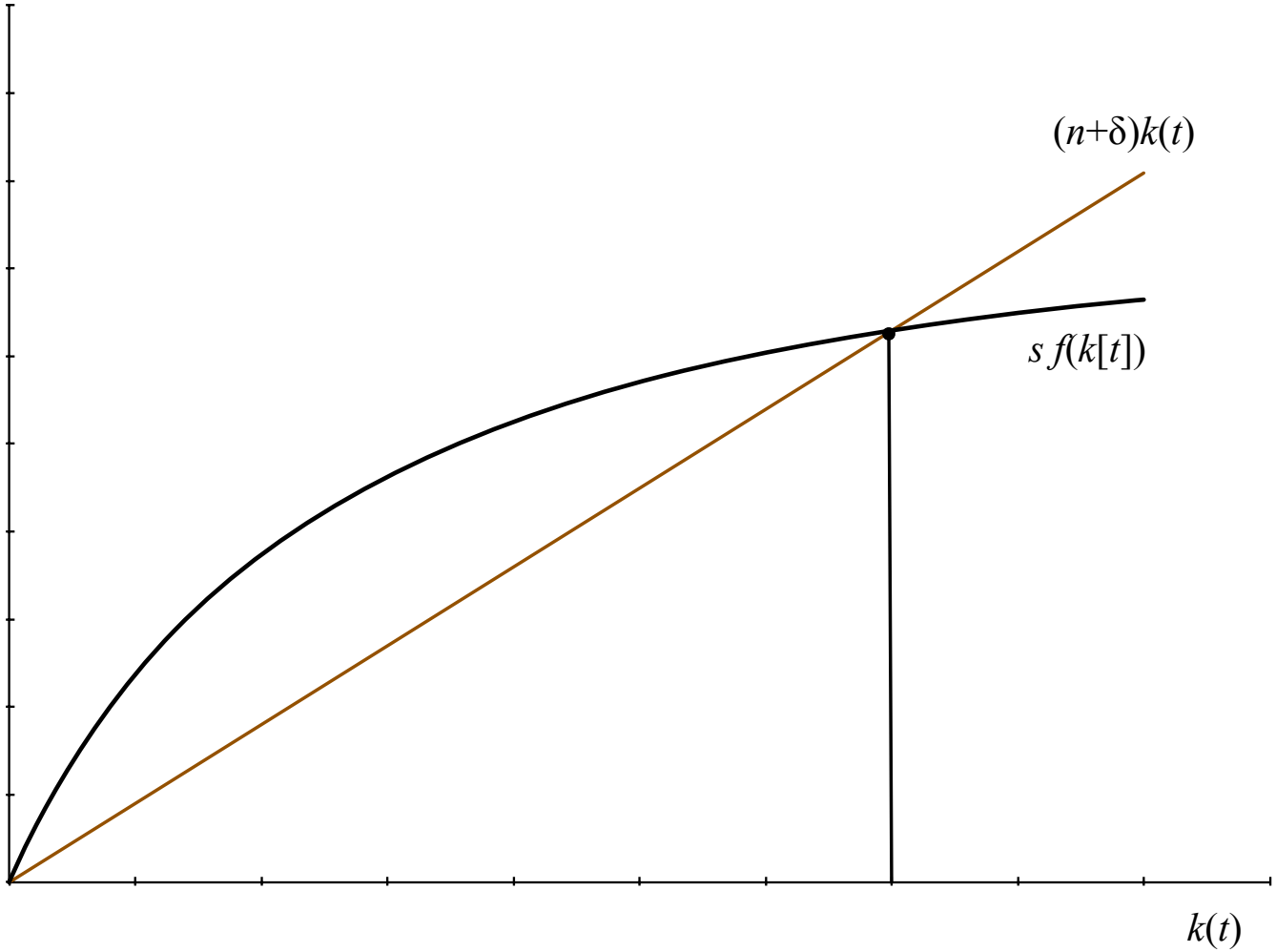
$$y^* = A \left[\frac{s}{n+\delta} \right]^{\alpha/(1-\alpha)} \tag{9}$$

- This is the same answer in disguise: higher s means higher K/L.

Why does Y/L differ across countries?

- But the answer is **quantitatively** different:
  - Production model: Double $A \rightarrow$ raise y by $2^{1-\alpha} = 2^{2/3} = 1.59$.
  - Solow model: Double $A \rightarrow$ double y^*.
- In the Solow model, the contribution of A to output gaps is larger - why?
- Draw a picture...

Saving and Output



Thought experiment: A rises.

How important is K/L for cross-country Y/L gaps?

Our previous answer was: K/L accounts for a factor near 4.

In the Solow model:

$$\frac{y^*_{US}}{y^*_{poor}} = \left(\frac{\bar{A}_{US}}{\bar{A}_{poor}}\right)\left(\frac{s_{US}}{s_{poor}}\right)^{1/2} \tag{10}$$

$$32 = 16 \times 2 \tag{11}$$

Why factor 2 for saving rates?

- Because s (or K/Y) differs by a factor near 4.
- The ratio of saving rates is taken to the power $\alpha/(1-\alpha)$

How important is K/L for cross-country Y/L gaps?

This is a central and robust result:

> ***Capital accumulation accounts for only a small fraction of cross-country income gaps.***

Exercise

How would this result change for higher values of α?

Consider a 4-fold increase in s.

Calculate the effect on y and graph it.

Long-run Growth

Long-run Growth

What does the Solow model imply for long-run growth?

Main result

The principle of transition dynamics

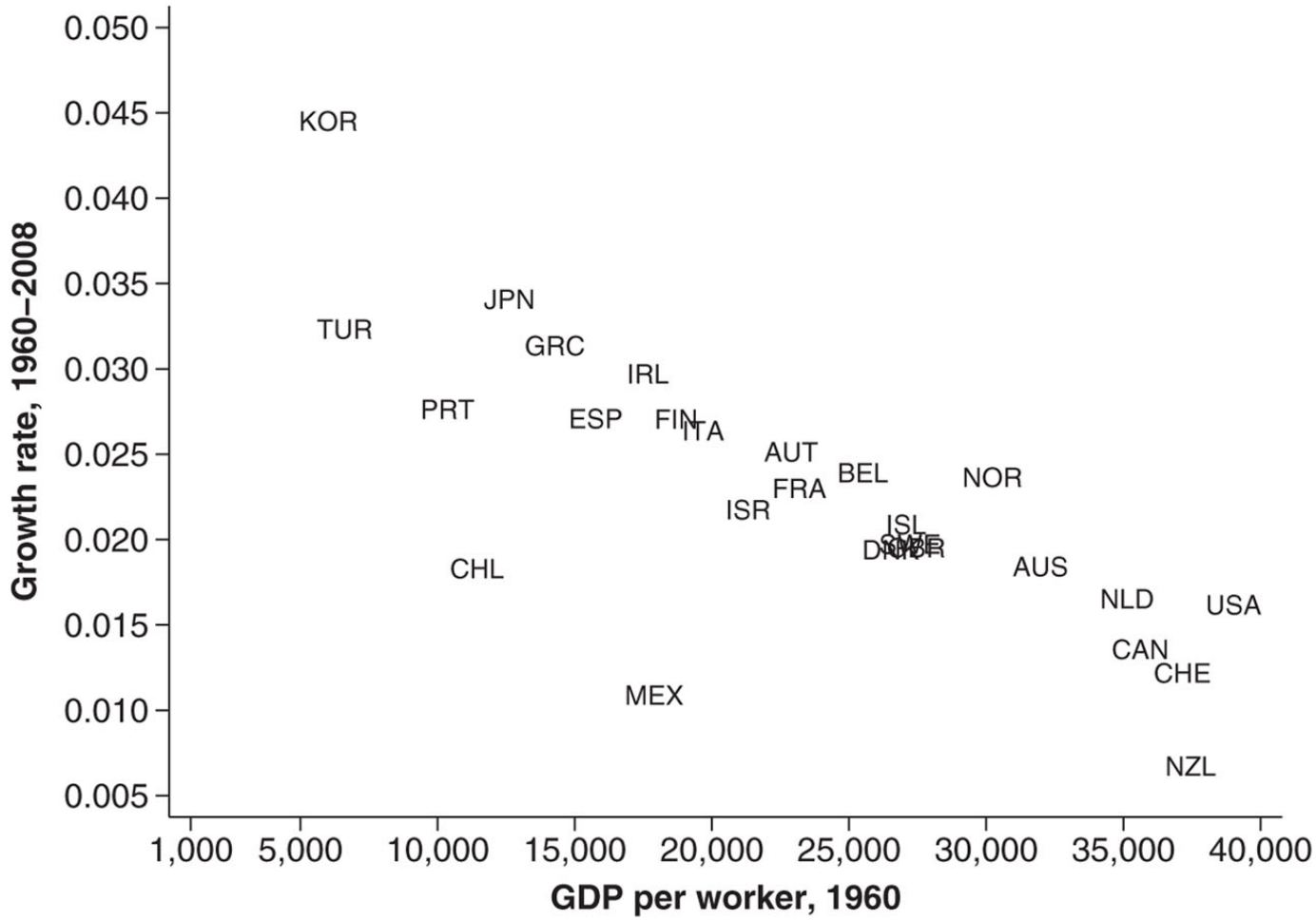
Countries grow faster when they are far below their steady state.

What is the evidence for this?

- One exercise: if countries have similar steady states, their income levels should converge over time
- initially poor countries should grow faster

Convergence: Evidence

FIGURE 3.5 CONVERGENCE IN THE OECD, 1960–2008



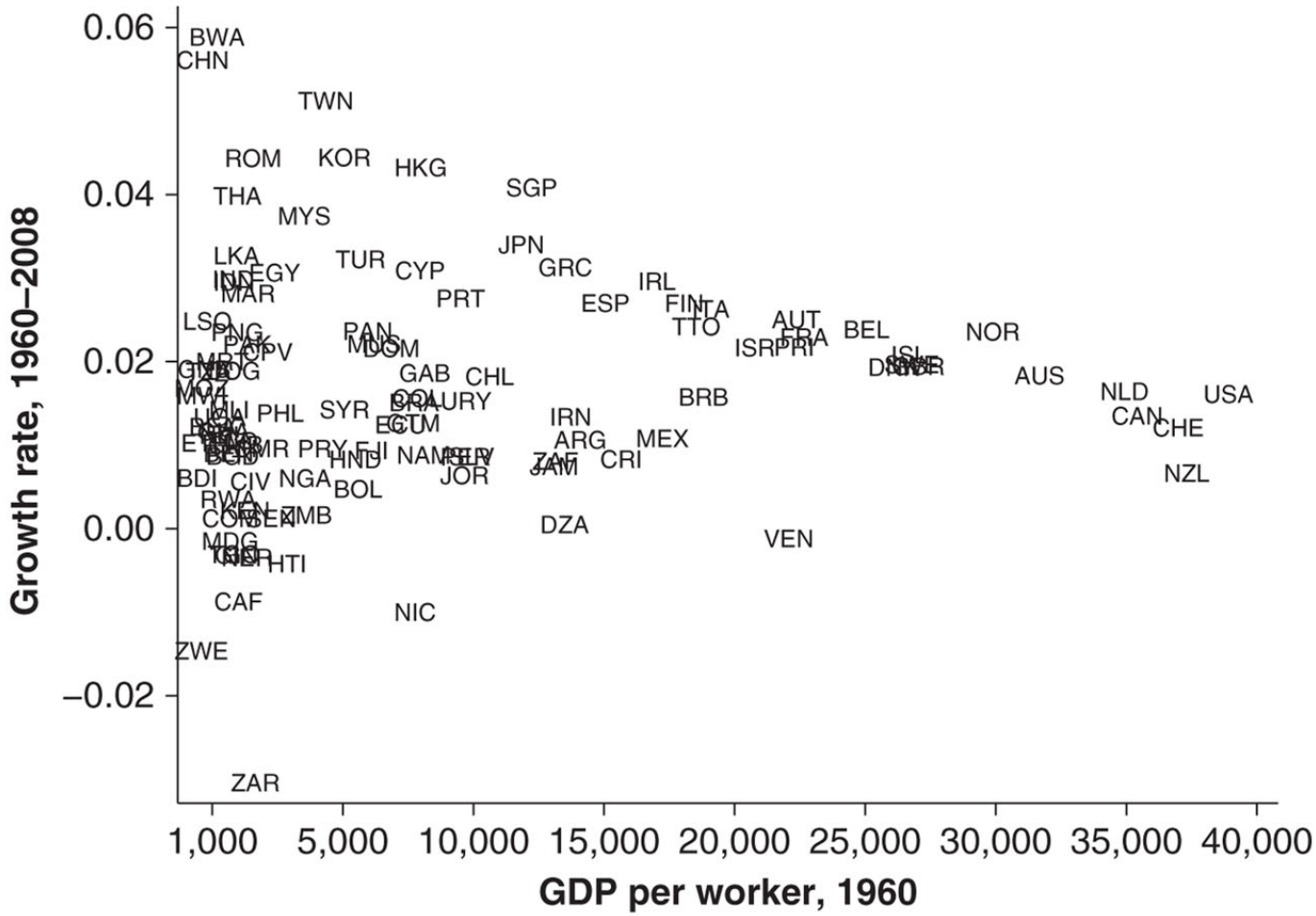
Among OECD countries: those that were initially poor grew faster.

Empirical Evidence

- Should we conclude that transitional growth explains cross-country differences in output growth?
- No!
- Figure 5.8 only shows OECD countries - mostly rich Western European countries + North America.

Empirical Evidence

FIGURE 3.6 THE LACK OF CONVERGENCE FOR THE WORLD, 1960–2008



No luck for a broad set of countries.

Empirical Evidence

- But figure 5.9 is the wrong experiment!
- The Solow model does not say: "poor countries grow faster"
- It says: "countries that are poor **relative to their steady states** grow faster."
- That is true in the data.

Empirical Evidence

Exercise

For a set of countries gather data on s, n.

Compute steady state output: y^*

Compute output in 1960 relative to steady state: y/y^*

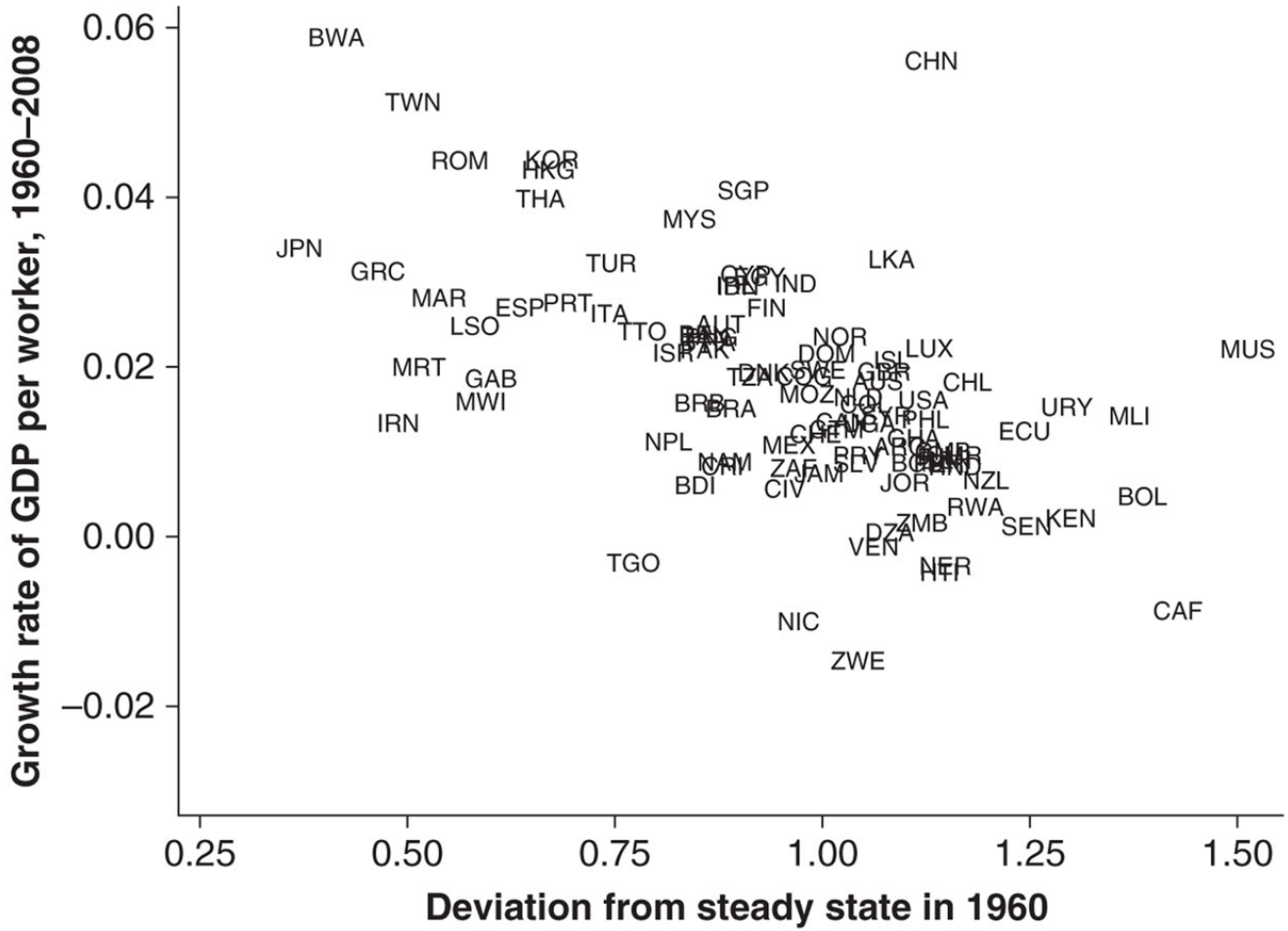
Compute average growth 1960-2000

Plot average growth against y/y^*

What do you expect to find?

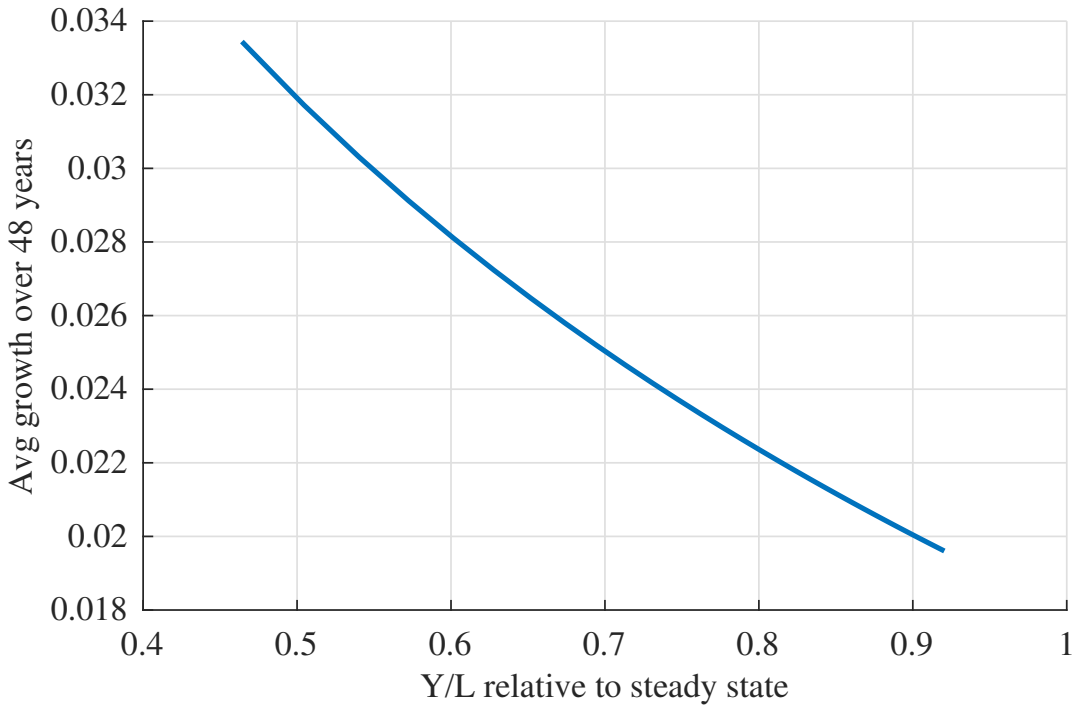
Conditional Convergence

FIGURE 3.8 "CONDITIONAL" CONVERGENCE FOR THE WORLD, 1960–2008



Source: Jones (2013)

Convergence: Solow Model

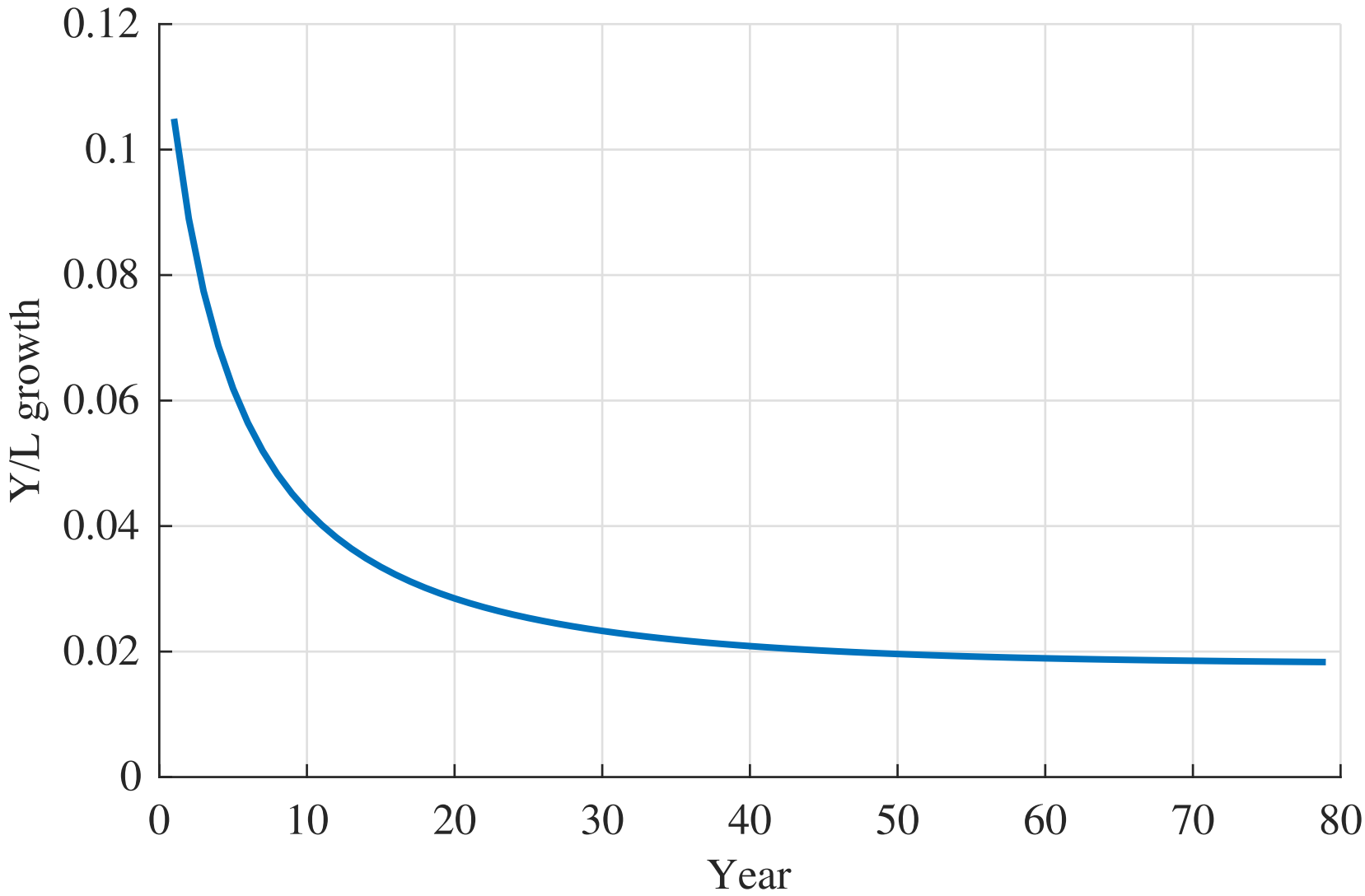


Prediction from a Solow model with capital share 1/3

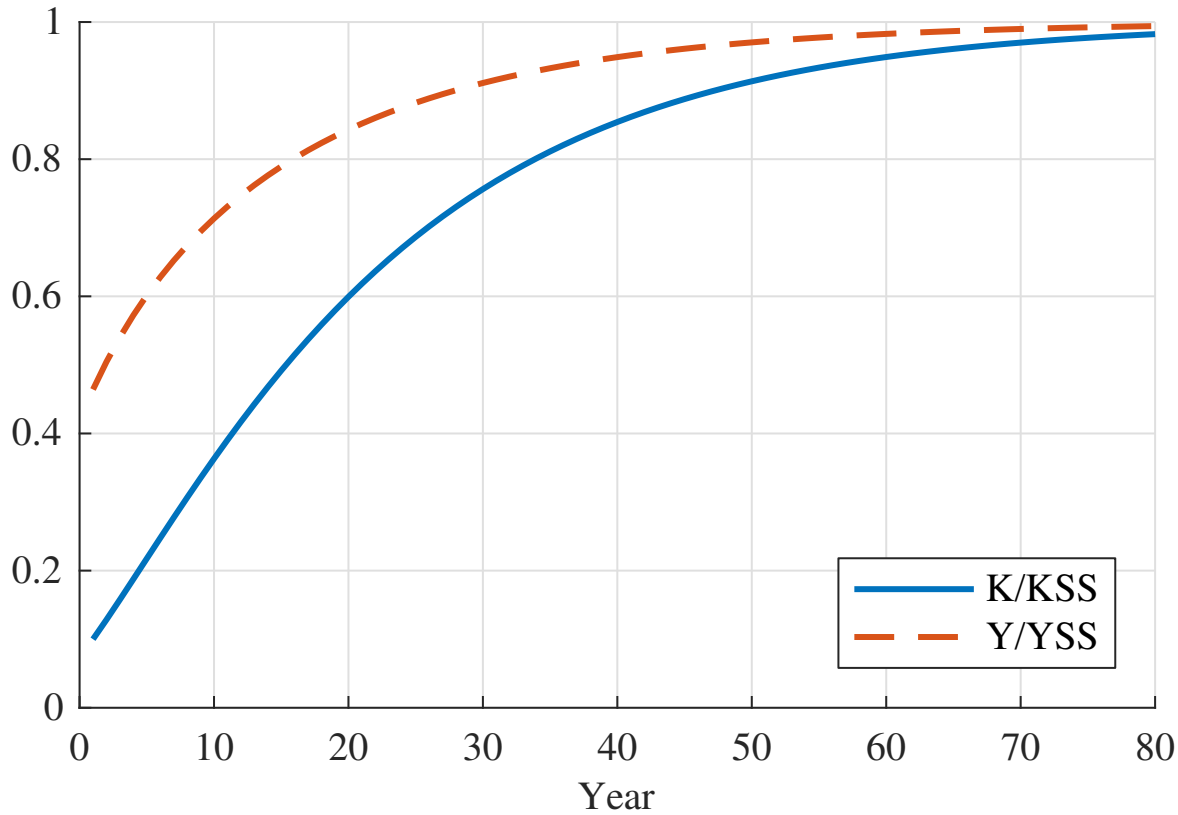
The fit is not bad, though the growth rate varies less than in the data.

Simulating the Solow Model

High growth rates do not last as long as in the data.



Simulating the Solow Model



Convergence is too fast.

In the data, the "**half-life**" is about 30 years – 10 years in the model.

Convergence is even faster when the saving rate is endogenous.

Convergence implications

The Solow model makes a quantitative prediction about growth rates.

Countries **converge fairly quickly** to their steady states (perhaps within 20 years).

Then they all should grow at almost the same rates.

Fact

The Solow model cannot explain why countries grow at different rates for long periods of time.

"Growth accounting" shows that much of variation in long-run growth is due to A, not k.

Did we just invalidate the Principle of Transition Dynamics?

- No, we did not.
- Countries grows faster when their capital stocks are low.
- But this does not account for the observed differences in long-run (40 year) growth rates across countries.
- It does account for growth rates at business cycle frequencies.

The Tigers

There are a few countries that sustained growth by capital accumulation for a long period of time.

How?

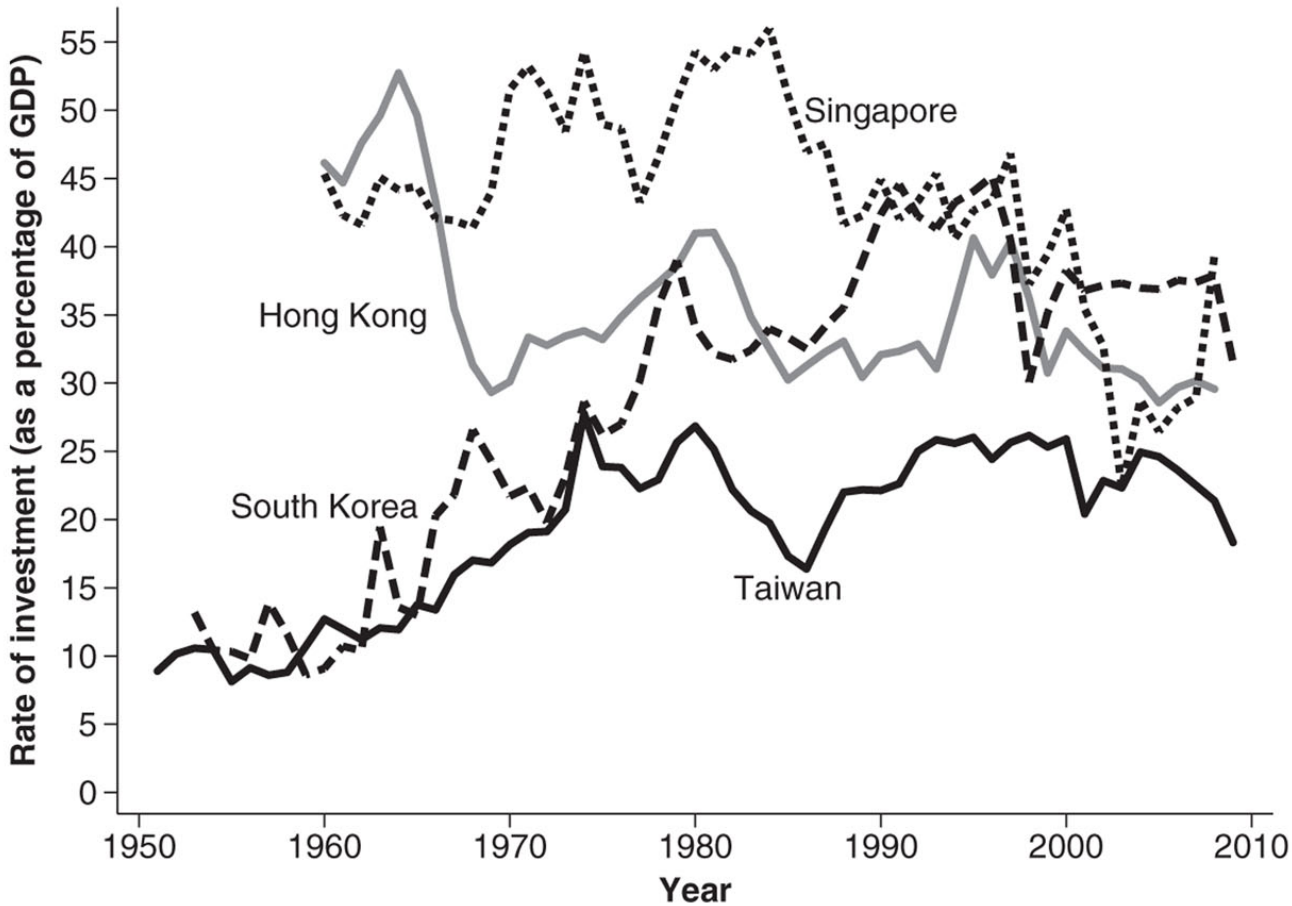
It cannot work with a constant saving rate s - the Solow model shows this.

Such countries must have saving rates that **rise over time**.

Examples are: South Korea, Singapore, Hong-Kong.

The Tigers

FIGURE 2.14 INVESTMENT RATES IN SOME NEWLY INDUSTRIALIZING ECONOMIES



Source: Jones (2013)

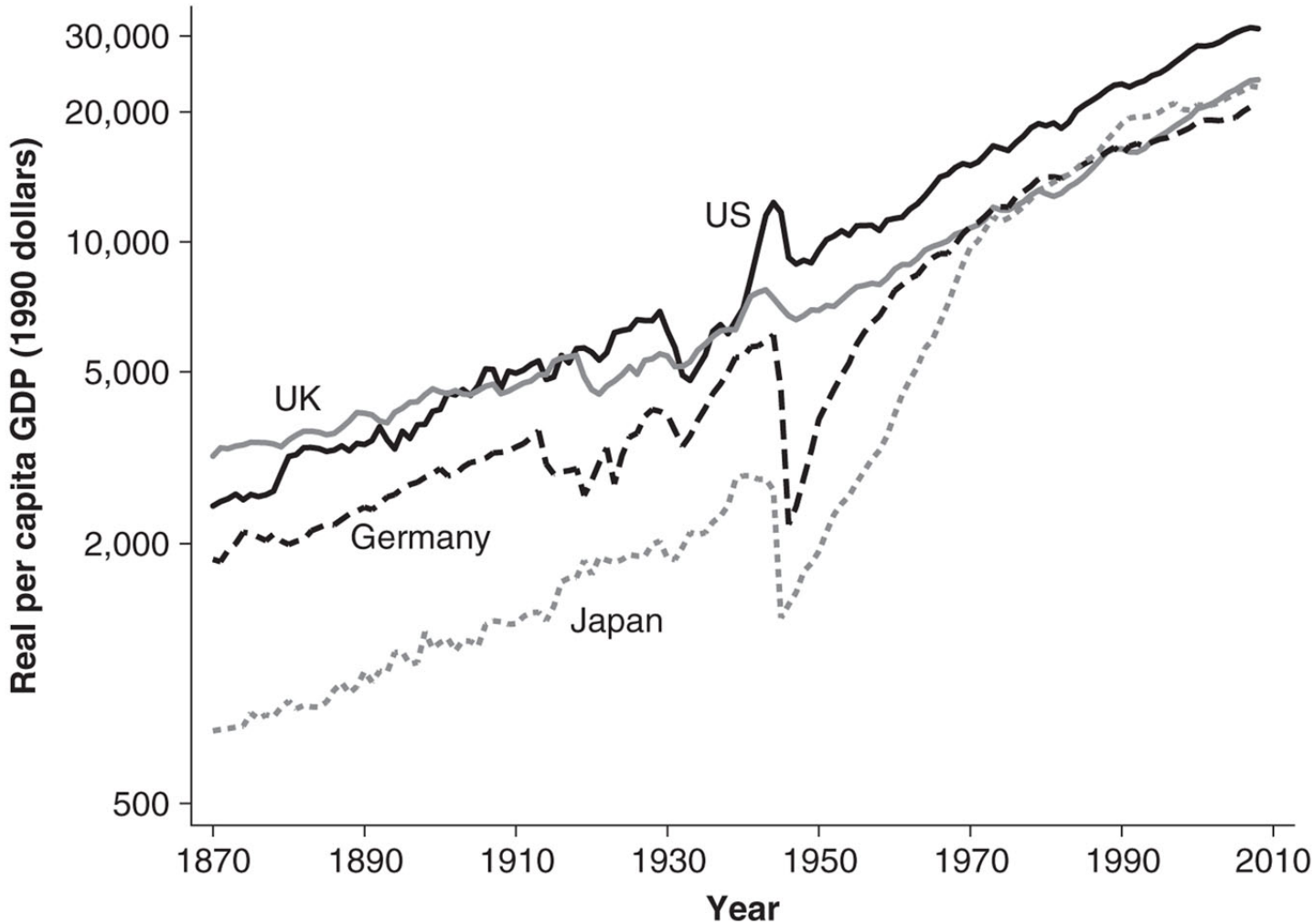
Exercise: Rising saving rate

- Simulate the Solow model with a saving rate that rises from 10% to 40% (Singapore).
- Start the model in steady state: $K_0 = K^*$.
- Show that the growth rate of y stays positive for a long time.
- You could now compare that growth path with data for Singapore and convince yourself that a large share of Singapore's spectacular growth since 1960 is indeed due to capital accumulation (as shown by Alwyn Young).

Convergence and Post-war Growth

One episode where convergence was very fast: growth after WW2

FIGURE 3.3 **PER CAPITA GDP, 1870–2008**



Convergence and Post-war Growth

Convergence to pre-war trends was very fast after WW2

Many countries were back on their trend paths after 5-7 years

Much of the convergence after the initial years was growth in TFP, not capital accumulation.

Exercise

- Take a spreadsheet.
- Fix parameters at plausible empirical values: $\alpha = 1/3$, $d = 0.08$, $s = 0.2$.
- Compute the steady state.
- Fix K_0 at some multiple of K^*.
- Compute the transition path for K_t by iterating over $K_{t+1} = sY_t + (1-d)K_t$.
- Plot the growth rate of Y_t against time.
  - You should see that growth is very high initially, if K_0 is small. But growth slows dramatically very quickly.
- Now plot the growth rate of Y_t against over 40 years against initial Y_t - this is the model analogue of figure 5.8.
  - You should see that the model relationship is much flatter than the data relationship.
  - The model fails to explain large variation in 40 year average growth rates.

Reading

- Jones (2013), ch. 2, 3

Advanced Reading:

- Hall and Jones (1999)

References I

Hall, R. E. and C. I. Jones (1999): "Why do some countries produce so much more output per worker than others?" *Quarterly Journal of Economics*, 114, 83–116.

Jones, Charles; Vollrath, D. (2013): *Introduction To Economic Growth*, W W Norton, 3rd ed.