Development Economics

Lecture 5:

Productivity & Technology

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1 Measuring Productivity

Reference: Chapter 7 in Weil.

Thus far in the course we have looked at how the accumulation of factors of production - physical capital, size of the workforce, human capital - affect per capita income.

At the end of the last lecture, we saw how differences in human capital explain a non-trivial share of the enormous differences in per capita income across the world - but we also saw that there remains a large unexplained 'residual' in income differences across countries not attributable to human capital. This is true for physical capital too.

We now try to understand what might account for this remaining part of income differences, which is not attributable to factors of production. Our starting point is **productivity**.

Productivity = the **effectiveness** with which factors or production are converted into output.

We have 4 main goals:

1. Understand how to measure productivity differences across countries

2. Understand how to assess the importance of productivity differences, relative to differences in factors of production, in explaining income differences

3. Understand how to measure differences in productivity growth across countries

4. Understand how to assess the importance of differences in productivity growth, relative to differences in the growth of factors of production, in explaining differences in income growth.

Our first problem is that productivity is **not measurable** in the same way as capital and years of schooling. We will now see how we can **infer** productivity from variables that **are** measurable.

1.1 Differences in the Level of Productivity Across Countries

As you know, the production function plays a very important role in the analysis of economic development. Consider the following production function for the economy:

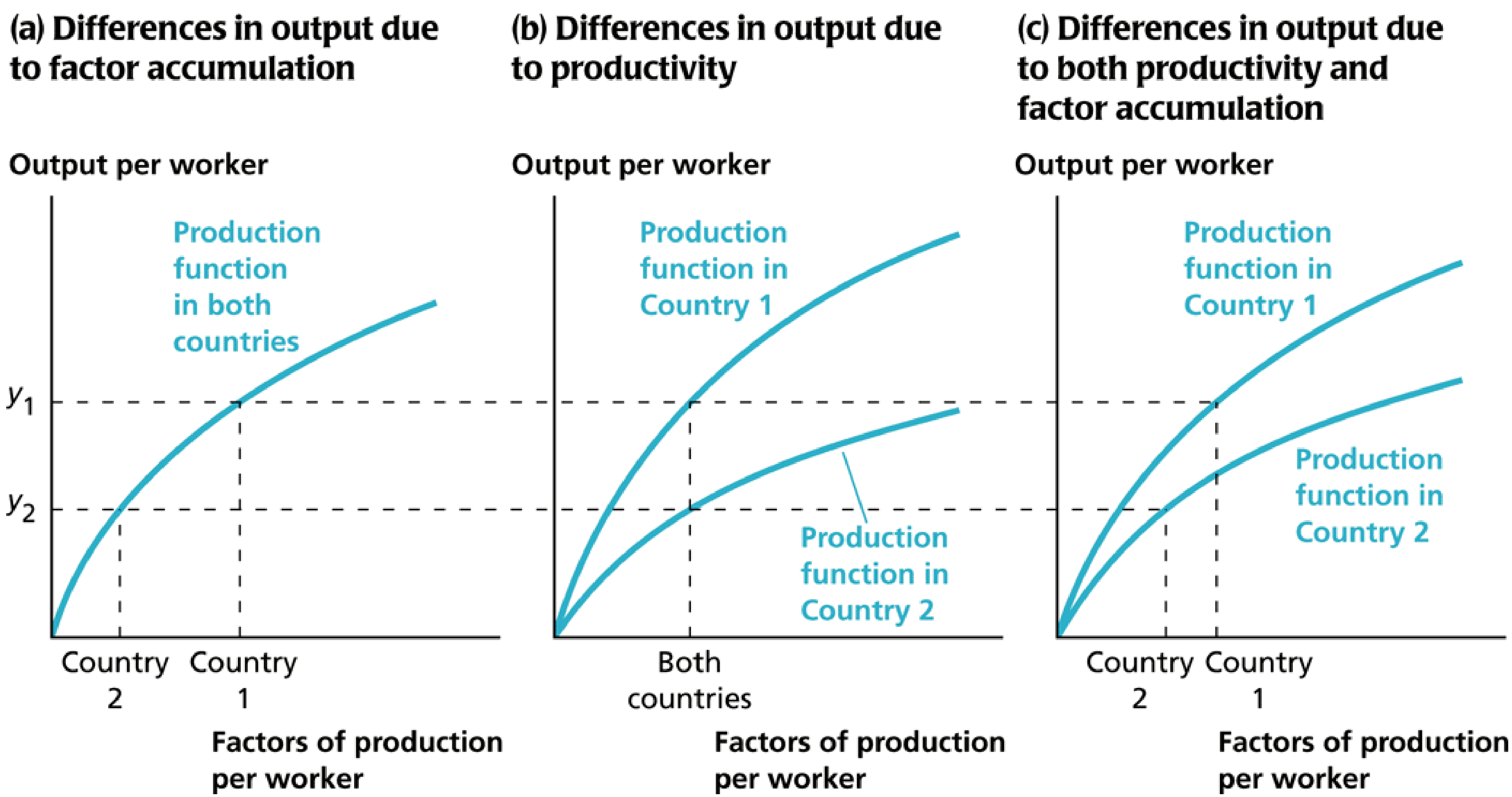
$$Y = AK^{\alpha}(hL)^{1-\alpha},$$

where Y is total output, K is the quantity of physical capital (e.g. plant & equipment), h is the quantity of human capital per worker, and L is the number of workers in the economy.

We define A as **productivity**, which can be thought of as a measure of how much output you get for your inputs.

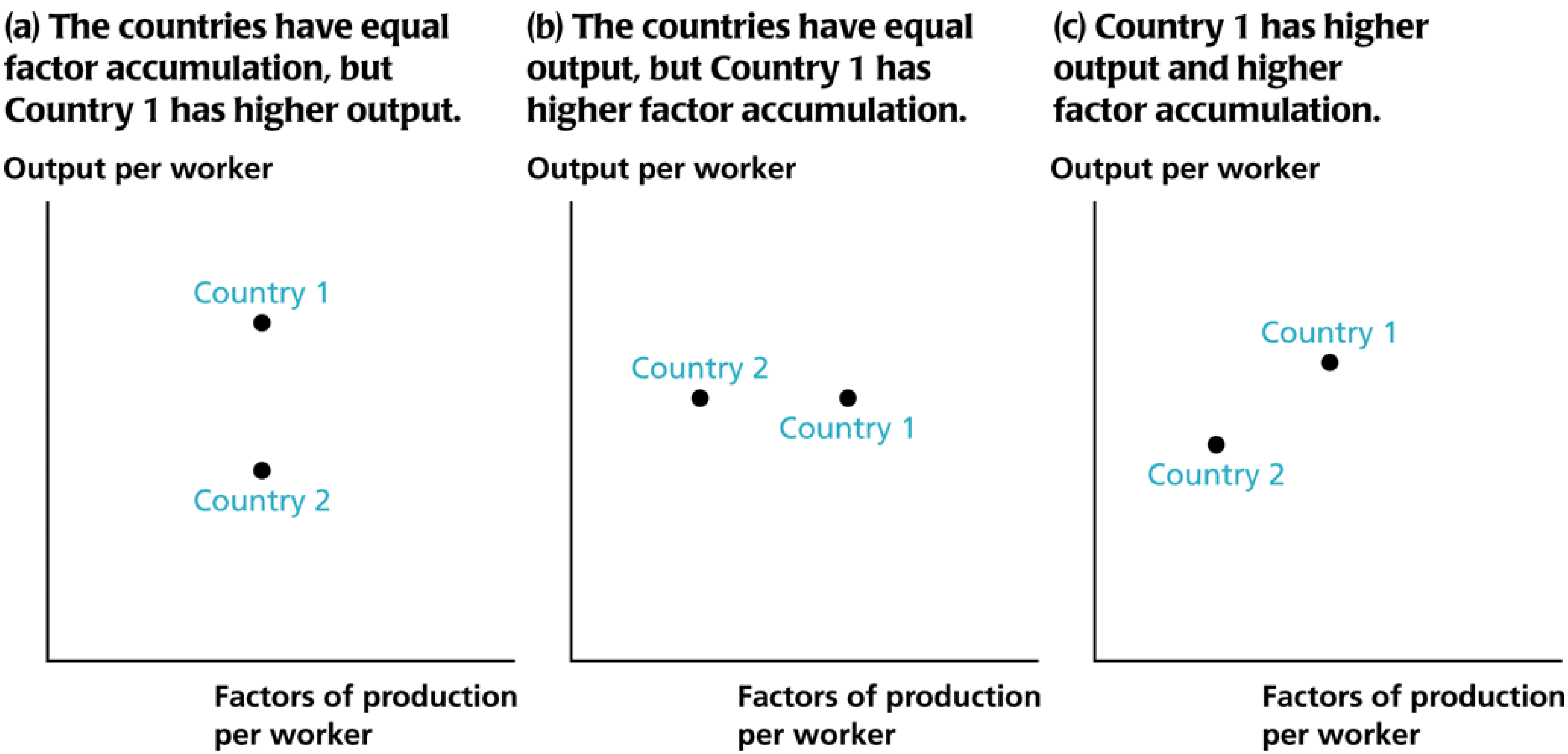
[Illustration: Figures 7.1 & 7.2 here]

Figure 7.1 Possible sources of differences in output per worker: Comparing 2 hypothetical countries



(a) Why do we conclude the level of productivity is the *same* in the 2 countries?
(b) How much more productive is country 1 compared to country 2?
(c) What's the most important source of the income difference?

Figure 7.2 Inferring productivity from Data



- In (c) which country has the highest productivity?
- Why might it be important to know the answer to this question?
- What do we need to do to find the answer?

It is straightforward to derive an expression for per capita output - just divide by L on both sides:

$$\begin{aligned}
\frac{Y}{L} &= AK^{\alpha}(hL)^{1-\alpha}L^{-1} \\
\frac{Y}{L} &= AK^{\alpha}(hL)^{1-\alpha}L^{-\alpha}L^{-(1-\alpha)} \\
\frac{Y}{L} &= A\left(\frac{K}{L}\right)^{\alpha}\left(\frac{hL}{L}\right)^{1-\alpha} \\
\frac{Y}{L} &= A\left(\frac{K}{L}\right)^{\alpha}h^{1-\alpha}.
\end{aligned}$$

We shall write this as

$$y = Ak^{\alpha}h^{1-\alpha},$$

where $y = Y/L, k = K/L$.

- Next define $k^\alpha h^{1-\alpha}$ as (per capita) **factors of production**, so that

$$\text{per capita output} = \text{productivity } \times \text{ factors of production.}$$

- Our goal is to compare productivity levels across countries. Suppose we're concerned with two countries, Country 1 and Country 2. Given the equation for per capita income just derived, it follows that the ratio of per capita income in Country 1 (C1) to that in Country 2 (C2) is given by

$$\frac{y_1}{y_2} = \frac{A_1}{A_2} \times \frac{k_1^\alpha h_1^{1-\alpha}}{k_2^\alpha h_2^{1-\alpha}},$$

  i.e. the ratio of per capita output in C1 to per capita output in C2 depends on

  - The ratio of productivity in C1 to productivity in C2

– The ratio of factors of production in C1 to productivity in C2

- If C1 is richer than C2, this could be because it is more productive, and/or it has more factors of production (per capita).

- We said earlier that productivity is not directly measurable; however per capita output and physical and human capital typically are observable (i.e. we can get data on these variables), which means we can infer productivity differences from these observable variables:

$$\frac{A_1}{A_2} = \frac{y_1/y_2}{k_1^{\alpha} h_1^{1-\alpha} / k_2^{\alpha} h_2^{1-\alpha}}$$

$$\frac{A_1}{A_2} = \frac{y_1/y_2}{(k_1/k_2)^{\alpha} \times (h_1/h_2)^{1-\alpha}}$$

That is, provided we know α (consensus is $\alpha = \mathbf{1/3}$), output per capita, physical capital per capita, and the quantity of human capital per capita, we can calculate the productivity difference using this equation.

- This technique is called **development accounting** (Weil), or **levels accounting** (Hall & Jones, 1999).

[See Table 7.2 in Weil; quiz]

Table 7.2 Development Accounting

Country	Output per Worker, *y*	Physical Capital per Worker, *k*	Human Capital per Worker, *h*	Factors of Production, $k^{1/3}h^{2/3}$	Productivity, *A*
United States	1.00	1.00	1.00	1.00	1.00
Norway	0.92	1.08	0.97	1.01	0.92
United Kingdom	0.76	0.69	0.97	0.87	0.87
Canada	0.75	0.86	1.01	0.96	0.79
Japan	0.69	1.10	0.99	1.02	0.67
South Korea	0.54	0.73	0.93	0.86	0.63
Mexico	0.29	0.27	0.79	0.56	0.52
Peru	0.14	0.12	0.82	0.44	0.32
India	0.13	0.10	0.74	0.38	0.35
Cameroon	0.10	0.036	0.58	0.23	0.44
Zambia	0.034	0.032	0.65	0.24	0.14

Sources: Output per worker: Heston, Summers, and Aten (2006); physical capital: author's calculations; human capital: Cohen and Soto (2007). The data set used here and in Section 7.3 is composed of data for 78 countries for which consistent data are available for 1970 and 2005.

- Data from 2005. United States is the baseline country, i.e. the country with which all other countries are compared (hence 1.00 everywhere for the U.S.).
- Interpretation:
  - Japan is some 31% poorer than the U.S. – is this because Japan have less factors of production or lower productivity?
  - If Cameroon could raise her productivity to the same level as the U.S., what would be the effect on the output per worker ratio (currently = 0.10)?

Table 7.2 Development Accounting

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United States	1.00	1.00	1.00	1.00		1.00	
Norway	0.92	1.08	0.97	1.01		0.92	
United Kingdom	0.76	0.69	0.97	0.87		0.87	
Canada	0.75	0.86	1.01	0.96		0.79	
Japan	0.69	1.10	0.99	1.02		0.67	
South Korea	0.54	0.73	0.93	0.86	x	0.63	= 0.54
Mexico	0.29	0.27	0.79	0.56		0.52	
Peru	0.14	0.12	0.82	0.44		0.32	
India	0.13	0.10	0.74	0.38		0.35	
Cameroon	0.10	0.036	0.58	0.23		0.44	
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Remember: Output per worker = (Factors of production) x (Productivity)

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Note: **LARGE** productivity differences across countries!

”One of the most important findings of economists studying growth” (Weil, p.194)

WHY does productivity vary so much across countries?

- How much should we trust these numbers? After all, we know that the data on output and physical and human capital are likely pretty inaccurate. This may be because these quantities are inherently difficult to measure (e.g. physical capital - we need a way of aggregating buildings, computers, cars, factory robots,.... which is not easy!) or because they are incomplete measures (e.g. measures of human capital do not take into account quality differences in schooling across countries).

- What might be the consequences of such inaccuracies? Recall our basic formula for productivity differences:

$$\frac{A_1}{A_2} = \frac{y_1/y_2}{k_1^{\alpha} h_1^{1-\alpha} / k_2^{\alpha} h_2^{1-\alpha}}.$$

  You see that productivity is essentially the "unexplained" part of income - what is "left over", once we have taken into account differences in **measured** physical and human capital.

- It follows that if the data on output, physical capital, or human capital are poor quality, this will affect the productivity estimates. One common result of data problems is that productivity differences across countries are overstated. This will happen, for example if

  - There are a lot of recording errors ("noise") in the output data. Countries for which recorded output is higher than true output will look too productive, and vice versa.

  - Incomplete measure of human capital, because quality differences in schooling are ignored. As a result, differences in factor accumulation across countries would be **too small** and the implied productivity differences would be **too large**.

- How serious are these problems? Weil: Main conclusion not affected - productivity differences across countries are very large.

Light-hearted quiz: Calculate the **implied productivity** of Ghana relative to that of the US.

Use the following formula:
$$\frac{A_1}{A_2} = \frac{y_1/y_2}{k_1^{\alpha} h_1^{1-\alpha} / k_2^{\alpha} h_2^{1-\alpha}}.$$

and begin by answering the following questions:

1. What is Ghana's **per capita income** relative to that of the US?
   a) 18%
   b) 11%
   c) 4%

2. What is Ghana's **human capital** relative to that of the US?
   a) 60%
   b) 45%
   c) 10%

3. What is Ghana's **physical capital** (machinery etc.) relative to that of the US?
   a) 6%
   b) 2%
   c) 0.1%

1.2 The contribution of productivity to income differences

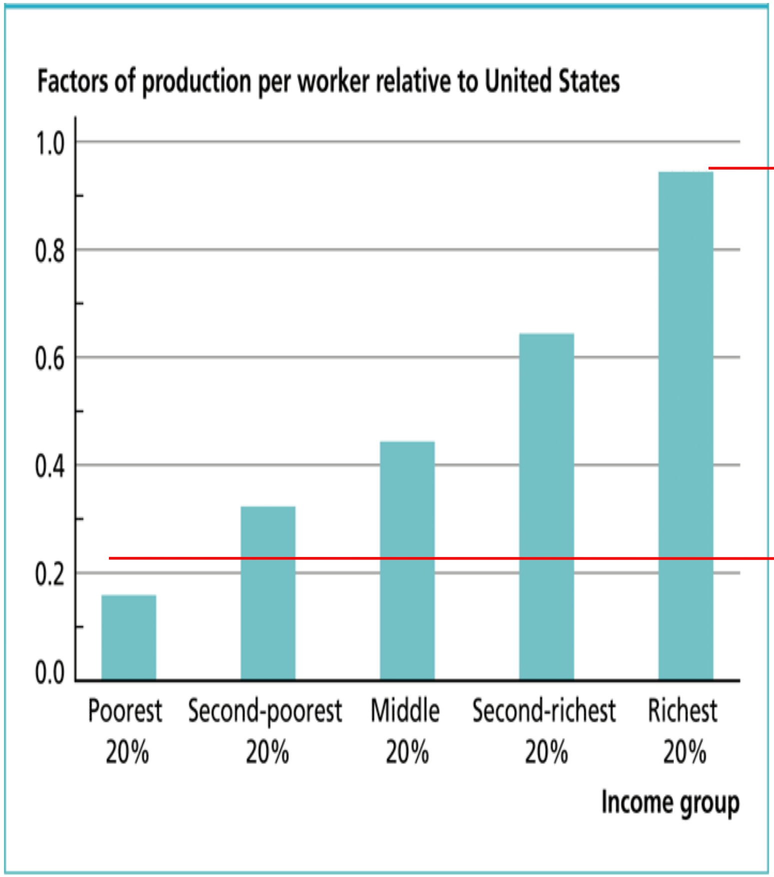
Recall that

$$\text{per capita output} = \text{productivity} \ \times \ \text{factors of production.}$$

Weil discusses the **relative** contributions of productivity and production factors to per capita output across rich and poor countries.

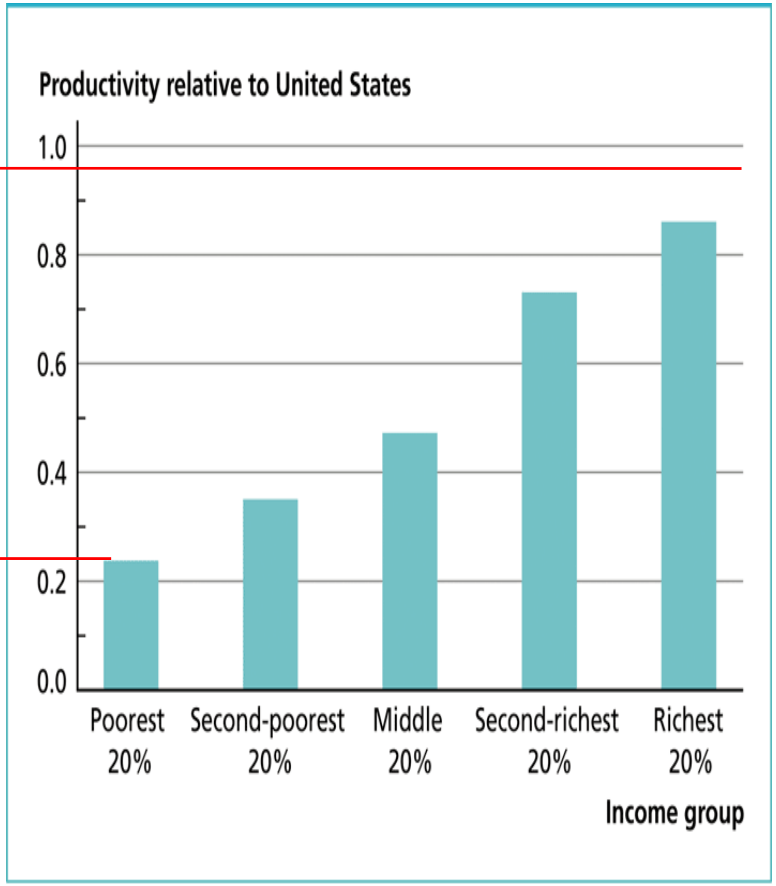
[Figures 7.3-4]

Fig 7.3: Factors of production



For sources, see Table 7.2.

Fig. 7.4: Productivity



For sources, see Table 7.2.

<u>Richest group</u>: poorer than the U.S. mainly because of **lower productivity**

<u>Poorest group</u>: poorer than the U.S. both because of lower factors of production & lower productivity – but notice the gap with respect to **production factors** is particularly big.

1.3 Differences in the Growth of Productivity Across Countries

- Using levels accounting (development accounting) we were able to assess the relative differences in the level of productivity and the level of production factors across countries in the world, and say something about the relative importance of productivity and production factors in determining the level of income at a given point in time.

- A very similar approach, known as **growth accounting**, can be used to analyze how much of a country's **growth** in income can be attributed to growth in productivity on the one hand and growth in production factors on the other.

- Point of departure is the expression derived earlier for per capita output:

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

or

$$y = Ak^{\alpha}h^{1-\alpha}.$$

Now write this in natural logarithms:

$$\ln y = \ln A + \alpha \ln k + (1-\alpha)\ln h,$$

then differentiate with respect to time (t):

$$\frac{d\ln y}{dt} = \frac{d\ln A}{dt} + \frac{d}{dt}\left[\alpha \ln k + (1-\alpha)\ln h\right].$$

Recall that

$$\frac{d\ln X}{dt} = \frac{dX}{dt}\frac{1}{X} \approx \frac{X_{t+1} - X_t}{X_t},$$

in general, hence we can write growth in per capita income as

$$\frac{y_{t+1}-y_t}{y_t} = \frac{A_{t+1}-A_t}{A_t} + \left[\alpha \frac{k_{t+1}-k_t}{k_t} + (1-\alpha)\frac{h_{t+1}-h_t}{h_t}\right],$$

or

$$\widehat{y} = \widehat{A} + \left[\alpha \widehat{k} + (1-\alpha)\,\widehat{h}\right],$$

or

growth in per capita output = growth in productivity + growth in factors of production per capita.

where (following Weil) I am using a "hat" ^ to indicate percentage growth. Notice that the expression inside [.] is interpretable as the growth rate in production factors. It follows rather trivially that productivity growth can be written

$$\widehat{A} = \widehat{y} - \left[\alpha \widehat{k} + (1-\alpha)\,\widehat{h}\right].$$

Even though we don't observe productivity growth in the data, we can thus infer it from growth rates in per capita output and the two forms of capital (provided we know α, which we do).

- During 1970-2005, we have the following average annual growth rates for the U.S:

$$\begin{aligned}\widehat{y} &= 0.0157 = 1.57\% \\ \widehat{k} &= 0.0215 = 2.15\% \\ \widehat{h} &= 0.0028 = 0.28\%.\end{aligned}$$

  Using $\alpha = 1/3$, we then infer that average productivity growth in the U.S. over this period was

$$\widehat{A}_{US} = 0.0157 - \left[\frac{1}{3} \times 0.0215 + \frac{2}{3} \times 0.0028\right] = .006666,$$

  i.e. 0.67%.

- It follows that $0.0067/0.0157 = 0.42 = 42\%$ of the output growth in the U.S. can be attributed to productivity growth. The other 58% of per capita output growth is attributable to growth in physical and human capital per worker.

1.4 The contribution of productivity growth to differences in income growth

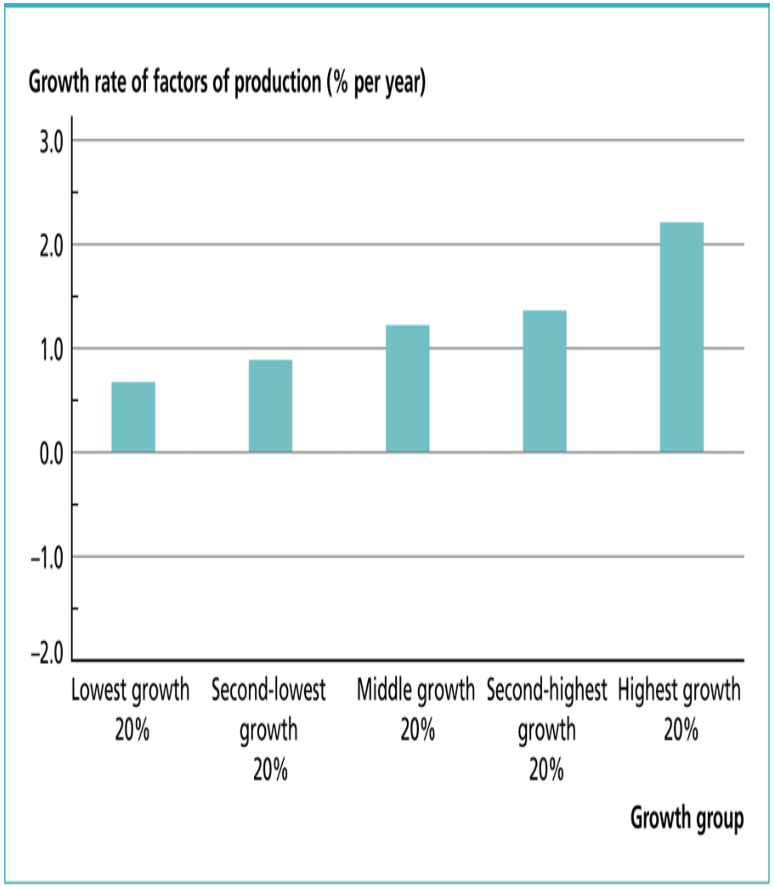
Recall that

growth in per capita output $=$ growth in productivity $+$ growth in factors of production.

We can now investigate the relative importance of productivity growth and production factor growth for per capita output growth. The approach is totally analogous to that used above focussing on levels differences.

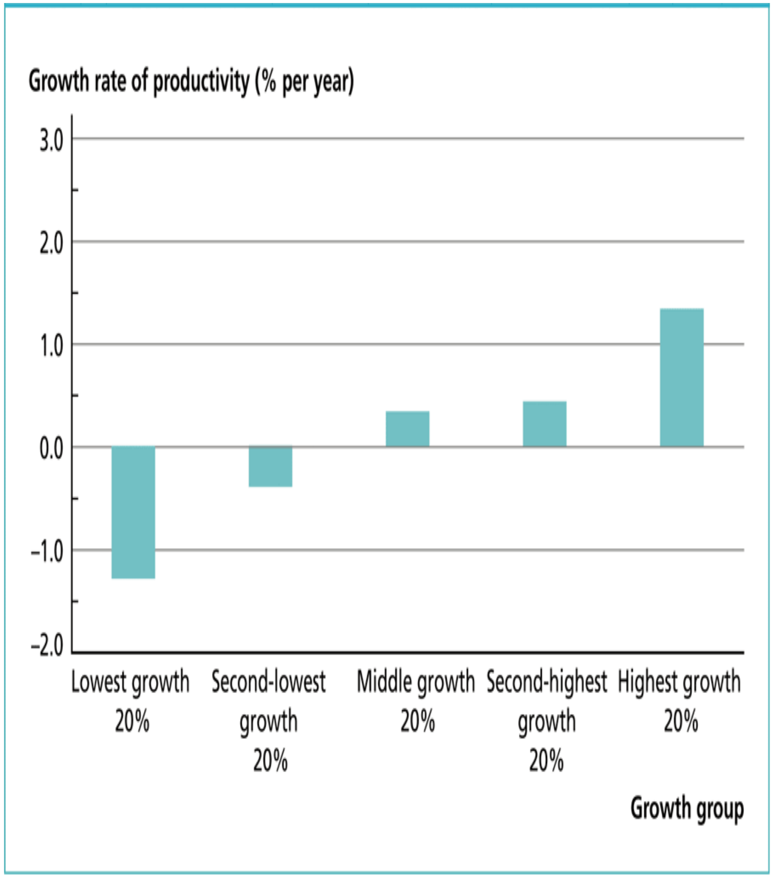
[Figures 7.5-6]

Fig 7.5: Factors of production



For sources, see Table 7.2.

Fig. 7.6: Productivity



For sources, see Table 7.2.

<u>Highest growth group</u>: high growth in both production & production factors.

<u>Lowest growth group</u>: positive growth in production factors, **negative** productivity growth.

- Thus quite a lot of variation in productivity growth rates across countries, feeding into variable growth rates in per capita income.

- Taking stock:

  - We have studied important methods for assessing the relative contributions of productivity (growth) and production factor (growth) to income (growth).

  - While useful, these methods does not tell us **why** productivity and production factors vary across countries, or why they grow over time. The rest of the lecture will be devoted to this issue.

2 Technology

Reference: Weil, Chapter 8

- In the discussion so far, productivity is a bit of a black box - we can easily infer from the data that there are productivity differences across countries at a given point in time, and that productivity grows over time. But so far we have not said much about why this is so. In this section we look at the role of **technology** in determining productivity.

- In the context of the current discussion, the following definition of technology is useful:

- Technology $=$ how we use production factors to produce output.

- Given that per capita output is defined as

$$y = Ak^{\alpha}h^{1-\alpha},$$

  it is natural to think of technology as a determinant of productivity, A.

- Creating new technology requires investment - basically research and development (R&D). It goes without saying that most of the R&D is done by **private firms** in **developed countries**. Typically, several percent of GDP is spent on R&D research in rich countries (see Table 8.1 in Weil).

- Poor countries typically have far fewer scientists and researchers than rich countries, which puts them at a clear disadvantage when it comes to the ability of performing R&D. The good news for poor countries, however, is that technology often is **transferable** from rich to poor countries. Conventional factors of production are **objects** - machines, individuals - and so cannot be in two places at the same time. Technologies, on the other hand, are essentially **ideas** lacking physical existence, and so one person's use of technology does not prevent others from using it too.

- We say that conventional production factors are **rival** (can't be "shared"), but technology is **nonrival** (can be "shared").

- This is **good news** for poor countries, in the sense that they may be able to adopt new technologies without incurring the full cost associated with the underlying R&D.

- This is **bad news** for those that have to bear the R&D costs, because they don't get the full return on their investment. This plausibly diminishes the incentives for investing in R&D, and consequently slows technological progress. See discussion on pp. 214-216 in Weil.

2.1 The relationship between technology and growth

- What follows next is a discussion of Weil's "Two-country model" - you need to study the "one-country model too", but the good news is if you know the two-country model you know the one-country model too.

- Given that technology is nonrival, there are two ways in which a country can acquire a new technology:'

  – Innovation (inventing something new)

  – Imitation (copying from elsewhere)

- For reasons already discussed, poor countries may have to rely primarily on imitation. (We now look at some important mechanisms to do with imitation)

- Assume there are two countries, labelled 1 and 2. These countries have the same workforce size, $L_1 = L_2$, but technology is more advanced in country 1 than in country 2, $A_1 > A_2$.

- Workers are either involved in R&D, in which case they don't produce anything (their efforts lead to better technologies instead), or in direct production. Ignoring physical and human capital, we write the production function as

$$Y_j = A_j L_{Y,j},$$

where $L_{Y,j}$ denotes the number of production workers in country $j = 1, 2$.

- Denote the share of the total labour force engaged in R&D by $\gamma_{A,j}$.

- It follows that output per capita in country 1 (i.e. output divided by **all** individuals in the country) is given by

$$
\begin{aligned}
y_1 &= \frac{A_1 L_{Y,1}}{L_1} \\
y_1 &= \frac{A_1 \left(1 - \gamma_{A,1}\right) L_1}{L_1} \\
y_1 &= A_1 \left(1 - \gamma_{A,1}\right).
\end{aligned}
$$

Output per capita in country 2:

$$
y_2 = A_2 \left(1 - \gamma_{A,2}\right).
$$

- Now define country 1 as the (technology) **leader (**recall I have assumed $A_1 > A_2$). The leader will have to acquire new technologies through innovation.

- Country 2 is defined as the (technology) **follower (**since $A_2 < A_1$). The follower can acquire technologies that are new to country 2 by copying technologies already existing in country 1.

- Because the leader has to innovate whereas the follower imitates, and because innovation is costlier than imitation, it is reasonable to suppose that the leader has a higher share of the workforce in R&D:

$$\gamma_{A,1} > \gamma_{A,2}.$$

The creation of new technology

- Technological growth for **leader** is assumed to be determined as follows:

$$\widehat{A}_1 = \frac{\gamma_{A,1}}{\mu_i} L_1,$$

where μ_i measures the cost of invention (if μ_i is high, then invention is expensive, and so a given number of R&D workers will produce relatively low technological progress - and vice versa).

- Technological growth for the **follower** can be achieved by copying the leader's existing technology. Denote the cost of copying μ_c, and suppose the cost of copying is a function of the **technology gap** between the two countries:

$$\mu_c = c\left(\frac{A_1}{A_2}\right),$$

where $c(.)$ is a function decreasing in A_1/A_2; that is $c' < 0$. In other words:

  - If the leader is a **long way ahead** of the follower, then it will be **cheap** for the follower to copy

– If the leader is only slightly more advanced than the follower, then it will be **costly** for the follower to copy

- Furthermore it is assumed that

$$c\left(\frac{A_1}{A_2} = \infty\right) = 0,$$

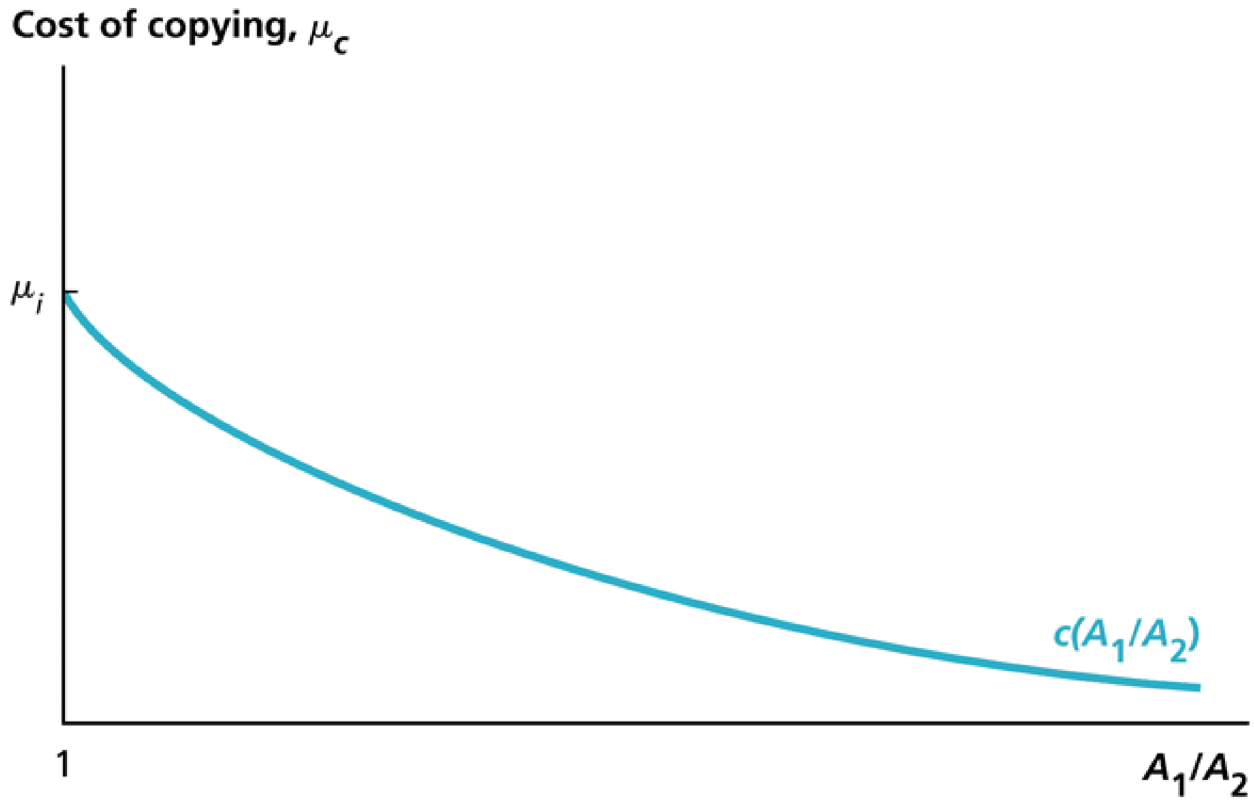
(costless to copy if the technology gap is infinite); and that

$$c\left(\frac{A_1}{A_2} = 1\right) = \mu_i$$

(if the technology gap is closed completely, so that $A_1 = A_2$, then the cost of copying will be equal to the cost of invention).

[Illustration of the function $c(.)$ in Figure 8.2]

Fig 8.2: The cost of copying as a function of the technology gap



- Now consider the rate of technological growth for the follower - this is assumed to be:

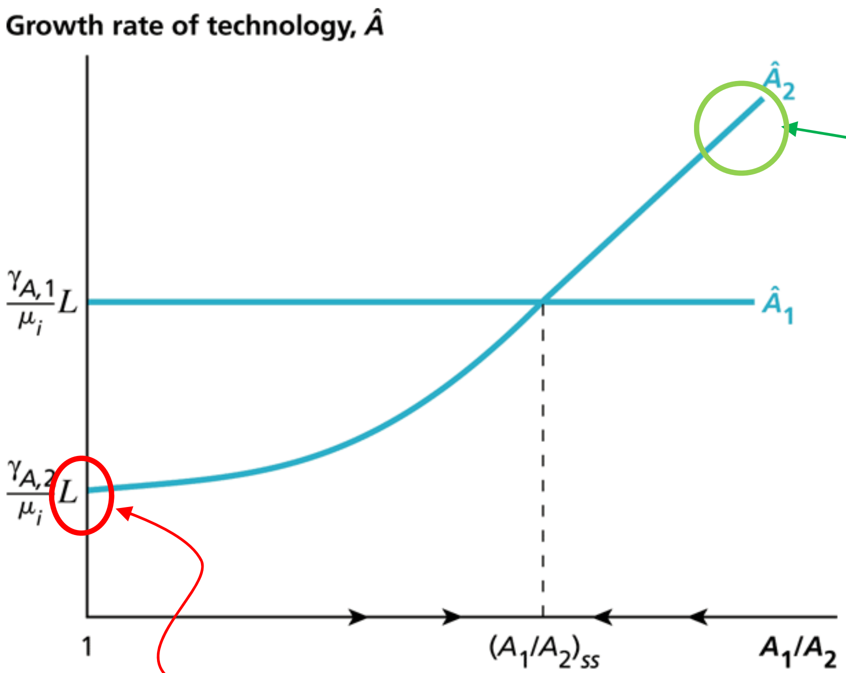
$$
\begin{aligned}
\widehat{A}_2 &= \frac{\gamma_{A,2}}{\mu_c} L_2, \\
\widehat{A}_2 &= \frac{\gamma_{A,2}}{c\left(A_1/A_2\right)} L_2.
\end{aligned}
$$

- Now here is a **remarkable result**: In the steady state (think: long run), the leader and the follower will grow at the same rate

- Note: the follower will always be less technologically advanced than the leader - we will come back to this shortly. The point is that growth rates will be the same, in the steady state.

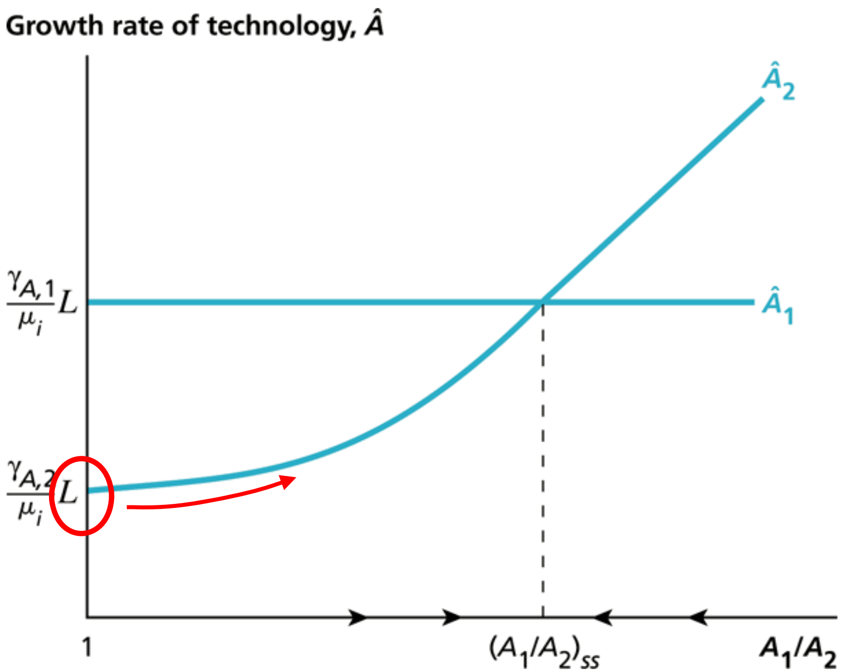
[Figure 8.3]

Fig 8.3: The steady state



- Remember $\gamma_{A,2} < \gamma_{A,1}$ - i.e. fewer people in R&D for "follower"
- If there is NO technology gap, the cost of copying = cost of innovating: $c(A_1/A_2 = 1) = \mu_i$.
  - In this case, the technological growth rate MUST be lower for follower
- If there is a LARGE technology gap, the cost of copying is very low.
  - Result: Rapid technological progress

Fig 8.3: The steady state

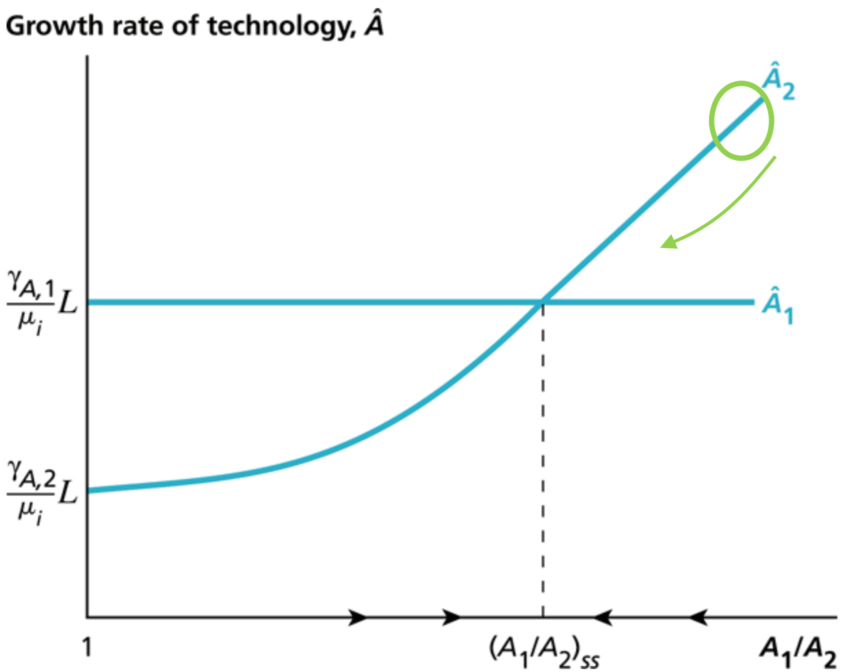


• If the initial technological growth rate is **low** for the follower (red circle), then the technology gap A1/A2 will **increase**. We move to the right in the graph.

• That, in turn, **reduces the cost of copying** in the next period – this **speeds up** technological progress for the follower. We move upwards in the graph.

• Combined effect: red arrow.

Fig 8.3: The steady state

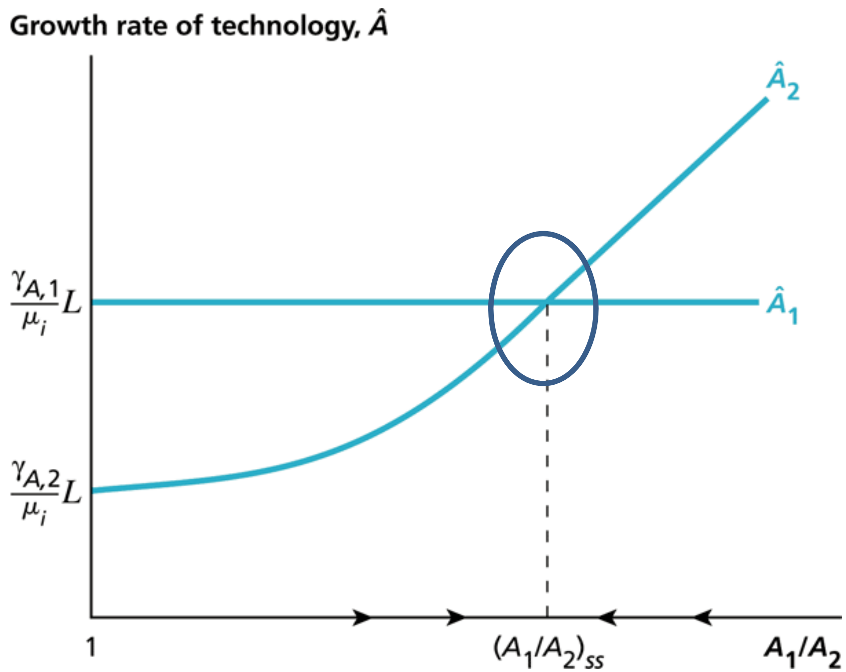


• If the initial technological growth rate is **high** for the follower (green circle), then the technology gap A1/A2 will **shrink**. We move to the left in the graph.

• That, in turn, **increases the cost of copying** in the next period – this **slows down** technological progress for the follower. We move downwards in the graph.

• Combined effect: green arrow.

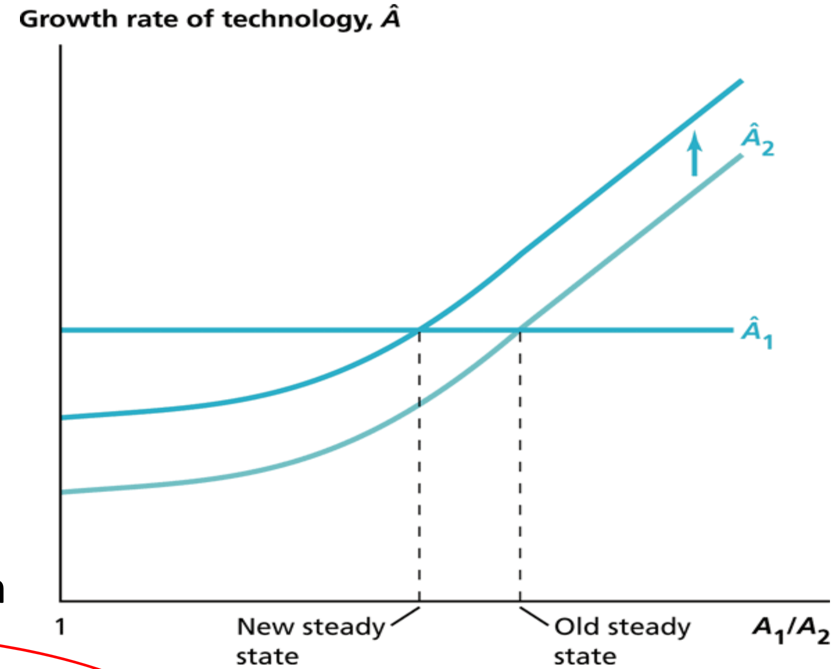
Fig 8.3: The steady state



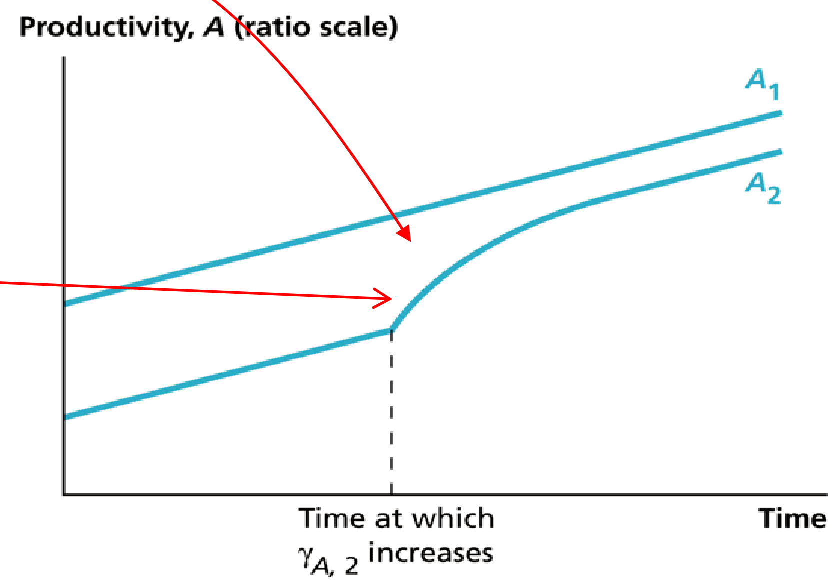
- In equilibrium, technological growth rate is **the same** for the follower as for the leader (blue circle).
- Same growth rates imply the technology gap A1/A2 will not change. This means the cost of copying will not change.
- Nothing now changes any more – this is the **steady state**.
- But notice that A1/A2>1, in other words there is a permanent difference in the **level** of technology across the two countries, in the steady state equilibrium.

Now consider a "policy change" for the **follower** – more people devoted to R&D:

- Follower will now be more similar to leader (increase in $\gamma_{A,2}$ but still $\gamma_{A,2} < \gamma_{A,1}$). Hence lower technology gap in steady state.
- In moving from old to new steady state, the follower will have **higher** growth than the leader.
- But eventually - in the steady state - the growth rates in the 2 countries will be the same – just like before.
- Hence, the increase in R&D for the follower leads to a **temporary** increase in technological growth.



(a) Path of Productivity



- Important contrast: consider a "policy change" for the **leader** – more people devoted to R&D. Recall that the formula for technological growth for the leader is

$$\widehat{A}_1 = \frac{\gamma_{A,1}}{\mu_i} L_1,$$

  and so a (permanent) increase in $\gamma_{A,1}$ simply increases the growth rate permanently - for the leader **and** for the follower. Make sure you understand why.

- General lesson of model:

  – To the extent that a given country is primarily a "follower", increased R&D spending within that country will bring a period of transitory increase in the growth rate

– To the extent that a given country is primarily a "leader", increased R&D spending within that country will bring permanent higher growth rates - for the leader and its followers.

– In the real world, it is not so clear-cut which country is the leader. Different countries lead with respect to different technologies. The above model is useful for shaping our thoughts on technology transfer but should not be taken as a literal description of how the world works. See Weil for further discussion.

2.2 Barriers to International Technology Transfer

Given the model above, things look quite hopeful for the ability of poor countries to take advantage of technological advances in the rich world. In practice, however, technology may not flow so freely across borders. Two "barriers" to international technology transfers are discussed by Weil - I will just summarize the discussion here:

- **Appropriate technology**: It may be that the technologies developed in rich countries are simply not appropriate or relevant in less developed countries. For example, technologies developed in rich countries may be specific to the mix of factors there (e.g. technological progress in agriculture - different climate zones).

Figure 8.6 Neutral Technological Change

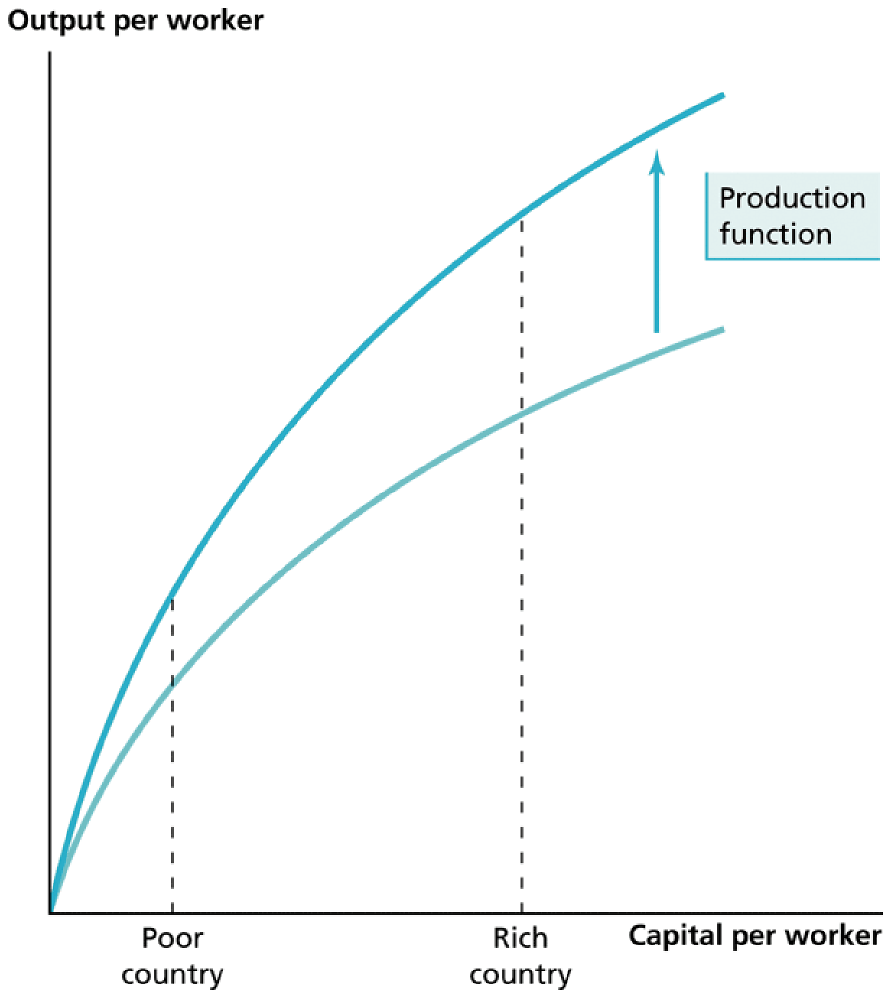
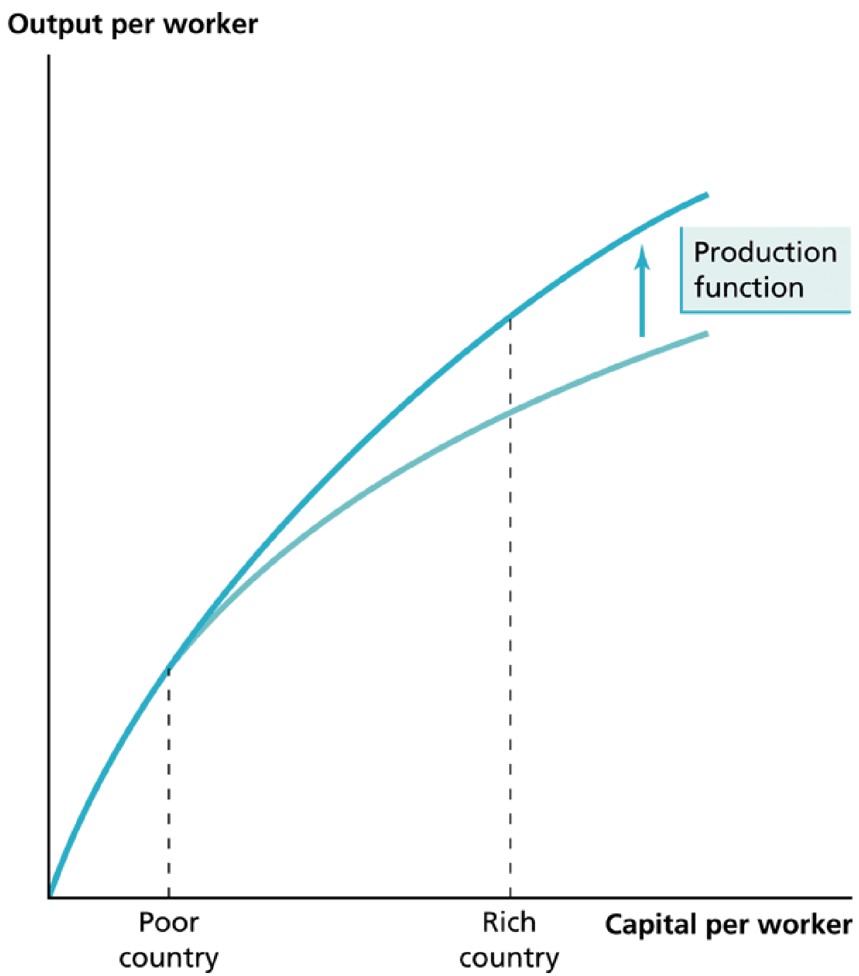


Figure 8.7 Capital-Biased Technological Change



[Illustration of neutral & capital-biased technological change; Fig. 8.6-7]

- **Tacit knowledge**: knowledge is acquired through direct investigation. Difficult to write down in a manual. The skill of riding a bike is a common example of tacit knowledge - there is no manual of how to cycle, so you have to be taught by someone who already can. The same principle may apply for new technology.

- That is, **using** the new technology may require skills not present in poor countries. Using technologically advanced robots in a factory, for example, probably requires the **physical presence** of engineers with a lot of practical experience in robots, for example. Sometimes tacit knowledge is referred to as absorptive capacity.

- Clearly such barriers imply that less developed countries may not benefit from technological progress in rich countries as much as the model in the previous section might suggest.