Unit 4b

The growth theory

Prof. Stefania Rossi

DEAMS, University of Trieste

UNIVERSITÀ DEGLI STUDI DI TRIESTE

The material presented in these slides is primarily based on Mankiw's textbook: Macroeconomics, 2025 Macmillan / Worth Publishers

.

Why growth matters (2 of 2)

Anything that affects the long-run rate of economic growth—even by a tiny amount—will have huge effects on living standards in the long run.

Annual growth rate of income per capita	Increase in standard of living after 25 years	Increase in standard of living after 50 years	Increase in standard of living after 100 years
2.0%	64.0%	169.2%	624.5%
2.5%	85.4%	243.7%	1,081.4%

The lessons of growth theory

…can make a positive difference in the lives of hundreds of millions of people.

These lessons help us

- understand why poor countries are poor
- design policies that can help them grow
- learn how our own growth rate is affected by shocks and our government’s policies

The Solow model

- due to Robert Solow, won Nobel Prize for contributions to the study of economic growth
- a major paradigm:
  - widely used in policymaking
  - benchmark against which most recent growth theories are compared
- looks at the determinants of economic growth and the standard of living in the long run

How the Solow model is different from Chapter 3's model, part 1

1. ***K*** is no longer fixed: investment causes it to grow, depreciation causes it to shrink
2. ***L*** is no longer fixed: population growth causes it to grow
3. the consumption function is simpler

How the Solow model is different from Chapter 3's model, part 2

4. no ***G*** or ***T*** (only to simplify presentation; we can still do fiscal policy experiments)
5. cosmetic differences

The production function (1 of 2)

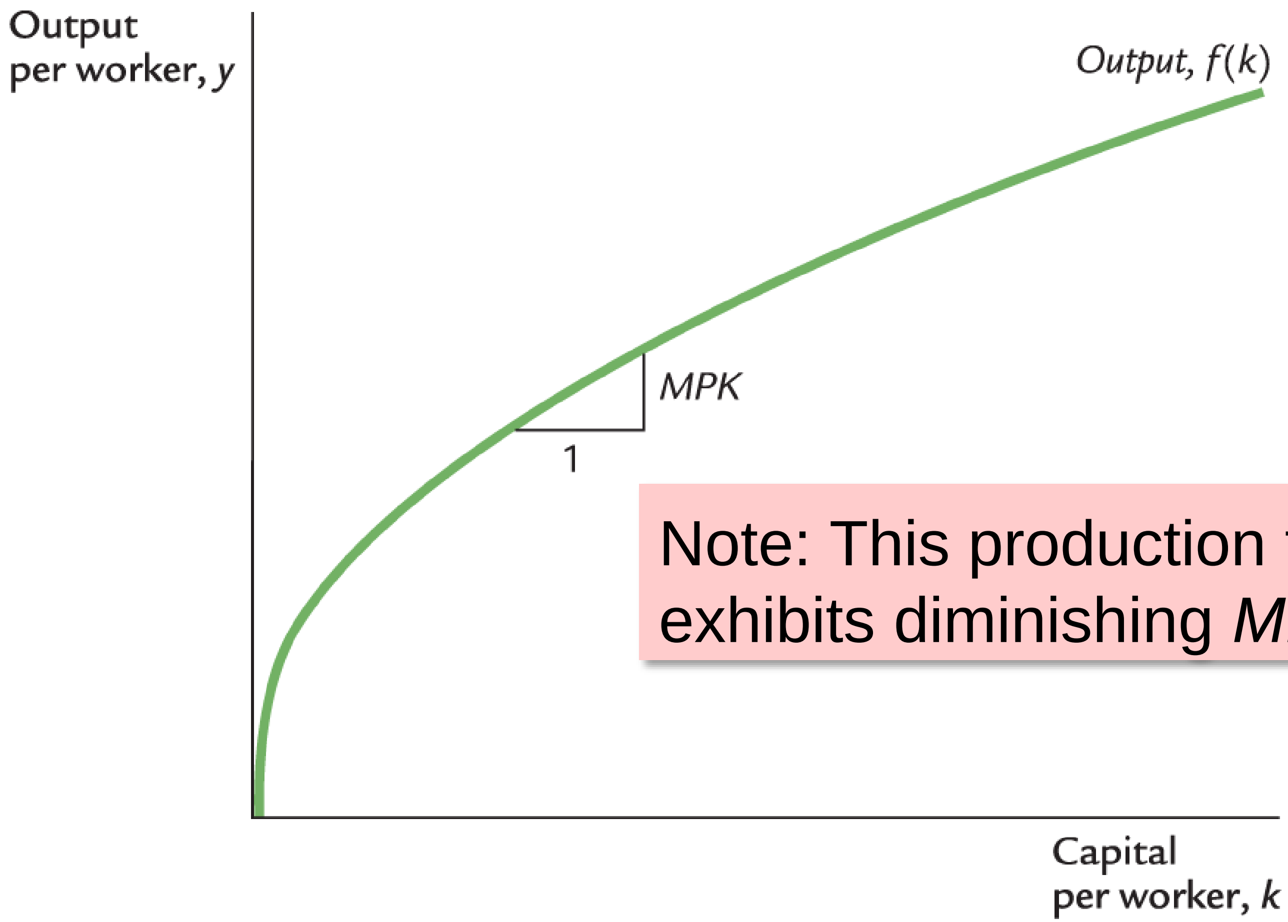
- In aggregate terms: $\boldsymbol{Y = F(K, L)}$
- Define: $\boldsymbol{y = Y/L}$ = output per worker

  $\boldsymbol{k = K/L}$ = capital per worker
- Assume constant returns to scale:

  $\boldsymbol{zY = F(zK, zL)}$ for any $\boldsymbol{z} > 0$

- Pick $\boldsymbol{z = 1/L}$. Then
  - $\boldsymbol{Y/L = F(K/L, 1)}$
  - $\boldsymbol{y = F(k, 1)}$
  - $\boldsymbol{y = f(k)}$ where $\boldsymbol{f(k) = F(k, 1)}$

The production function (2 of 2)



Note: This production function exhibits diminishing *MPK*.

The national income identity

- $\boldsymbol{Y} = \boldsymbol{C} + \boldsymbol{I}$ (remember, no $\boldsymbol{G}$)
- In "per worker" terms:

$$\boldsymbol{y} = \boldsymbol{c} + \boldsymbol{i}$$

where $\boldsymbol{c} = \boldsymbol{C}/\boldsymbol{L}$ and $\boldsymbol{i} = \boldsymbol{I}/\boldsymbol{L}$

The consumption function

- ***s*** = the saving rate, the fraction of income that is saved (***s*** is an exogenous parameter)

Note: ***s*** is the *only* lowercase variable that is *not equal to* its uppercase version divided by ***L***

- Consumption function: ***c*** = (**1**–***s***)***y*** *(per worker)*

Saving and investment

- Saving (per worker) = $\boldsymbol{y} - \boldsymbol{c}$

  $= \boldsymbol{y} - (\mathbf{1} - \boldsymbol{s})\boldsymbol{y}$

  $= \boldsymbol{sy}$

- National income identity is $\boldsymbol{y} = \boldsymbol{c} + \boldsymbol{i}$

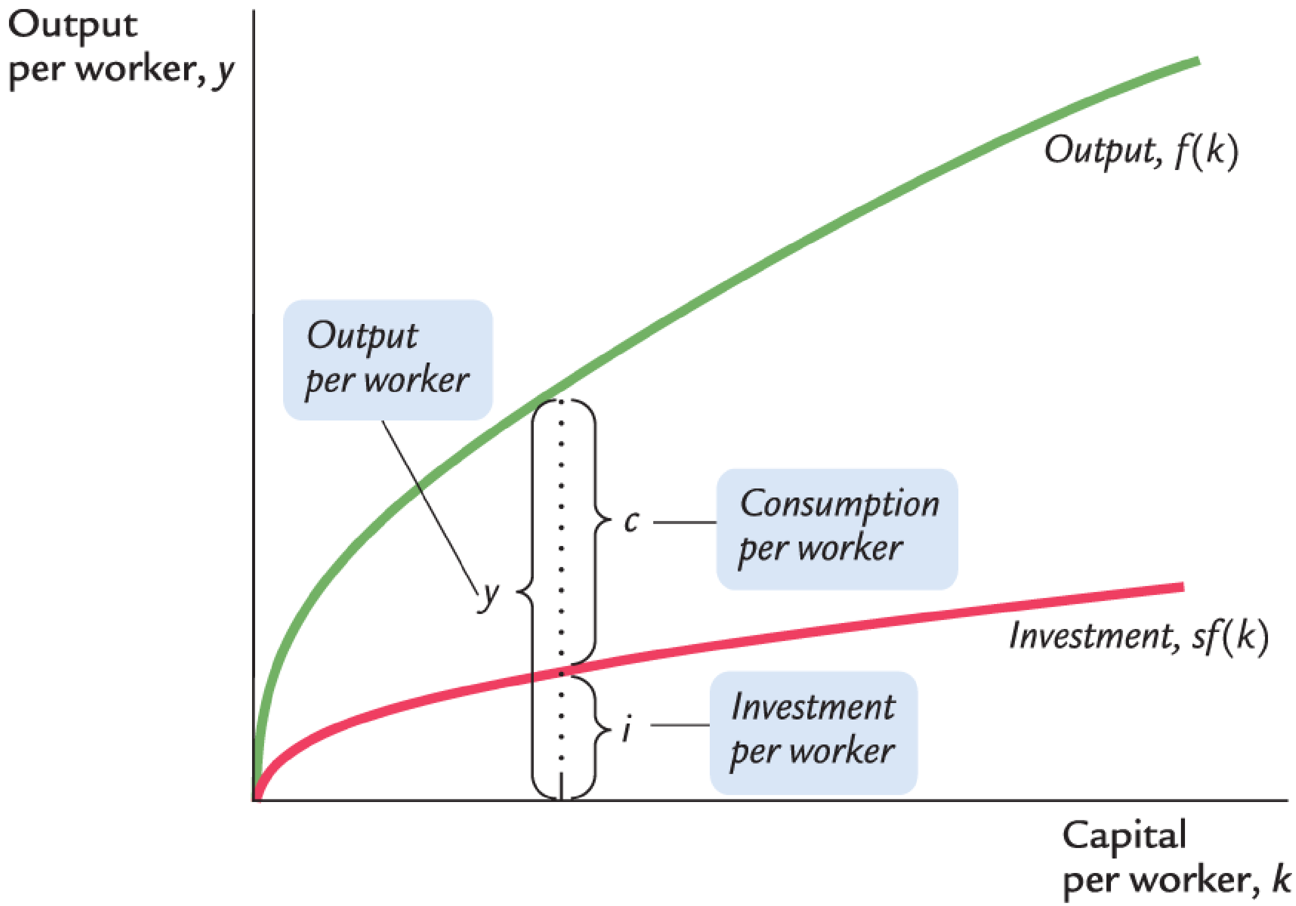
  Rearrange to get $\boldsymbol{i} = \boldsymbol{y} - \boldsymbol{c} = \boldsymbol{sy}$

  (investment = saving, as in Chapter 3!)

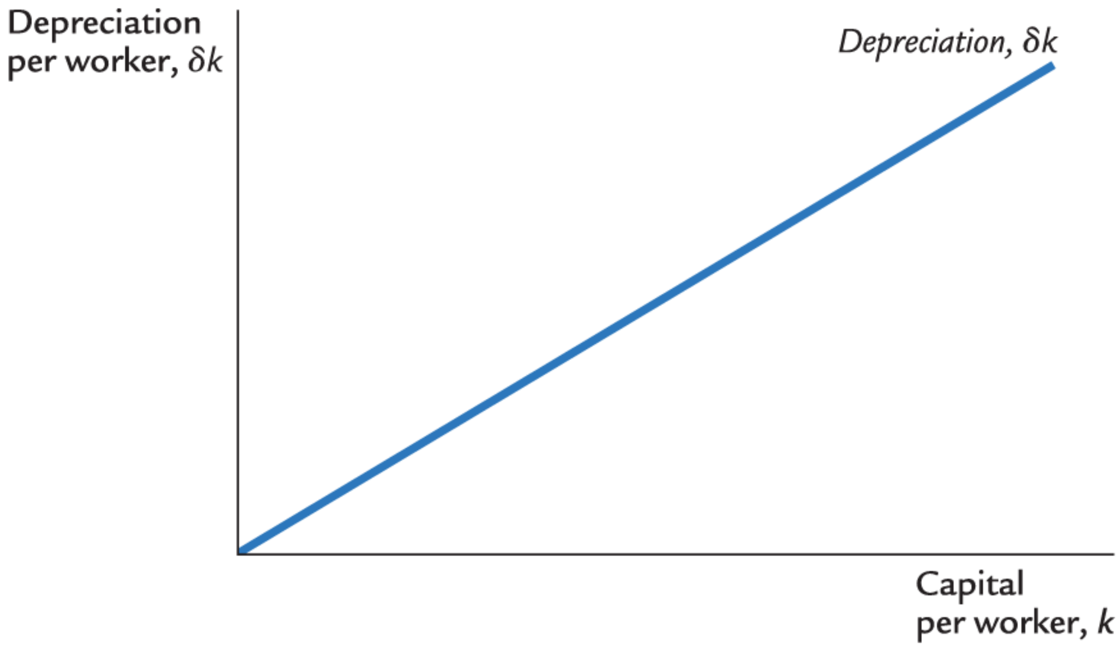
- Using the results above,

$$\boldsymbol{i} = \boldsymbol{sy} = \boldsymbol{sf(k)}$$

Output, consumption, and investment



Depreciation



Mankiw, *Macroeconomics*, 10e, © 2019 Worth Publishers

δ = the rate of depreciation

= the fraction of the capital stock that wears out each period

Capital accumulation

The basic idea: Investment increases the capital stock; depreciation reduces it.

change in capital stock = investment – depreciation

$$\Delta \boldsymbol{k} = \boldsymbol{i} - \delta \boldsymbol{k}$$

Since $\boldsymbol{i} = \boldsymbol{sf(k)}$, this becomes:

$$\Delta \boldsymbol{k} = \boldsymbol{s f(k)} - \delta \boldsymbol{k}$$

The equation of motion for k

$$\Delta k = s f(k) - \delta k$$

- The Solow model's central equation
- Determines behavior of capital over time . . .
- . . . which, in turn, determines behavior of all the other endogenous variables because they all depend on ***k***.
- Example:

income per person: $y = f(k)$

consumption per person: $c = (1 - s)\, f(k)$

The steady state, part 1

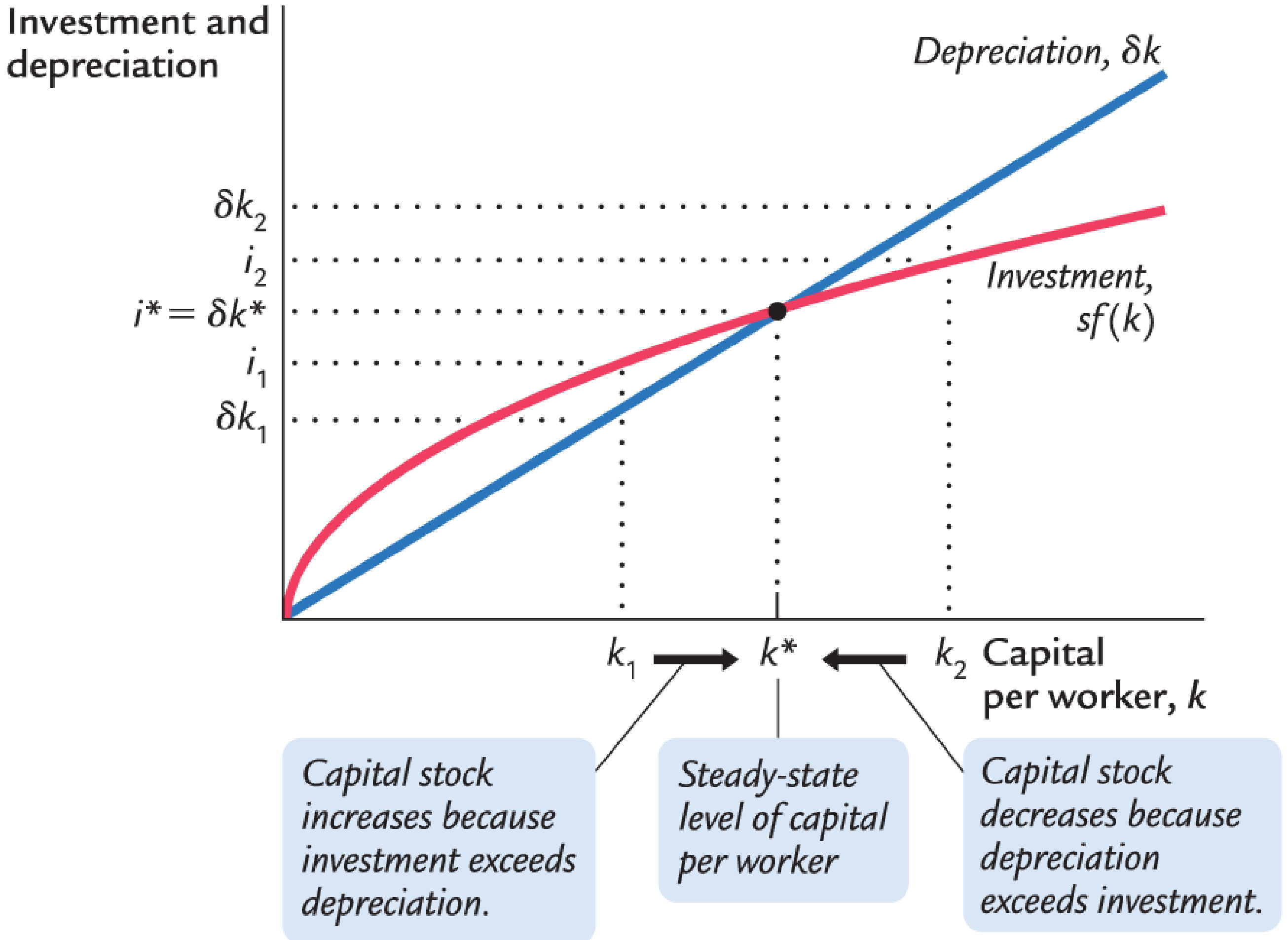
$$\Delta k = s f(k) - \delta k$$

If investment is just enough to cover depreciation
[$sf(k) = \delta k$],
then capital per worker will remain constant:

$$\Delta k = 0.$$

This occurs at one value of k, denoted k^*, called the ***steady-state capital stock***.

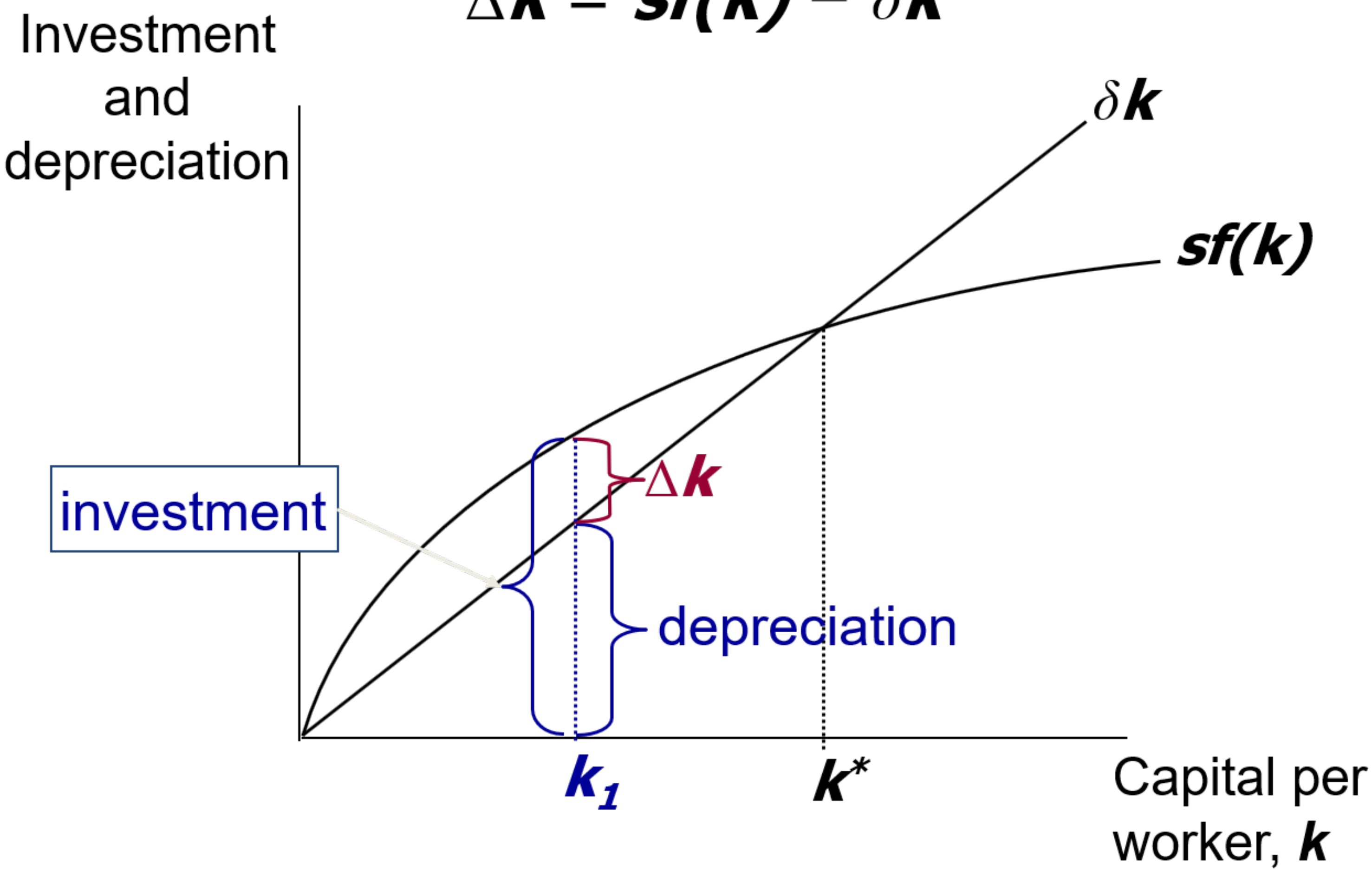
The steady state, part 2



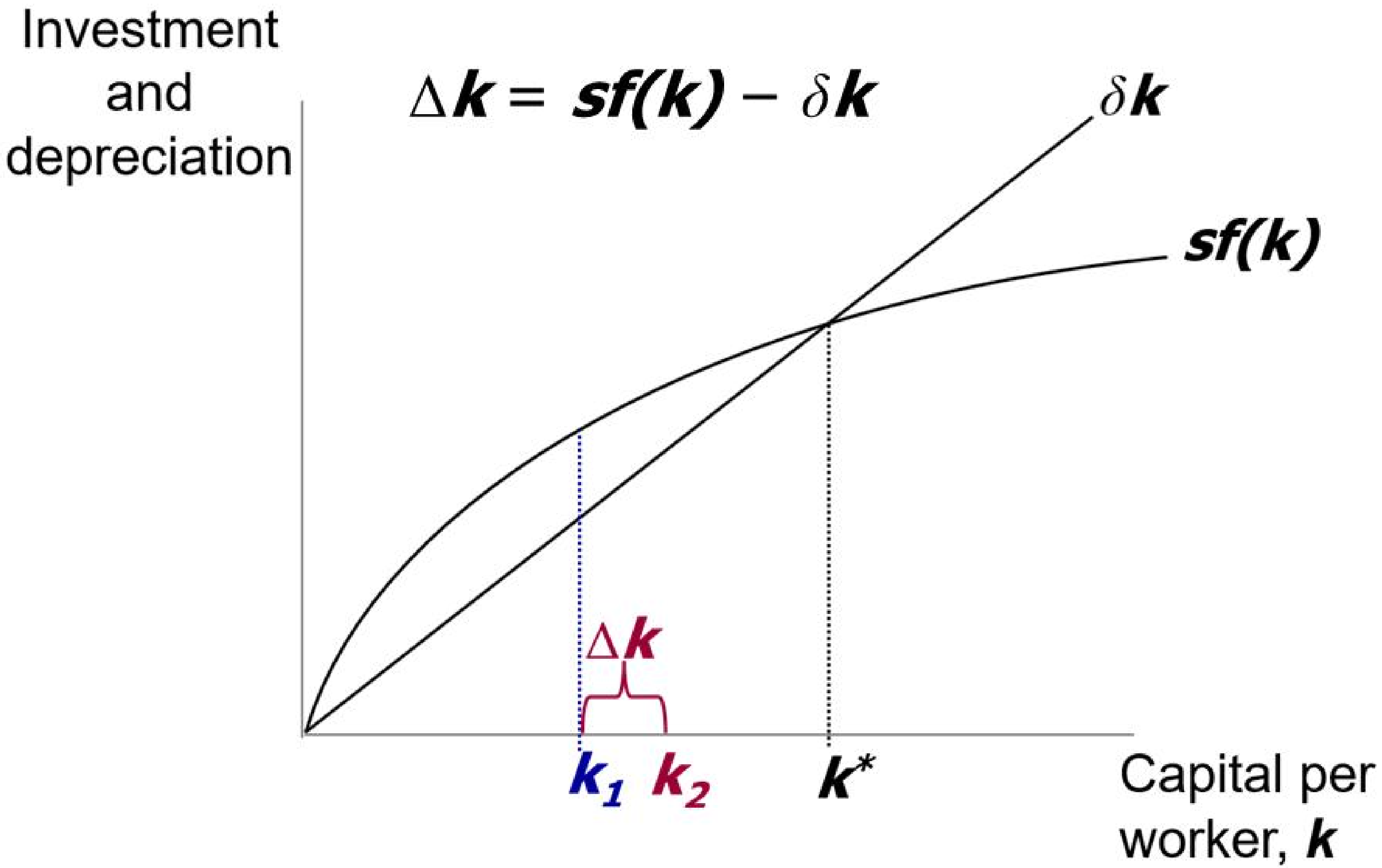
Mankiw, *Macroeconomics*, 10e, © 2019 Worth Publishers

Moving toward the steady state, part 1

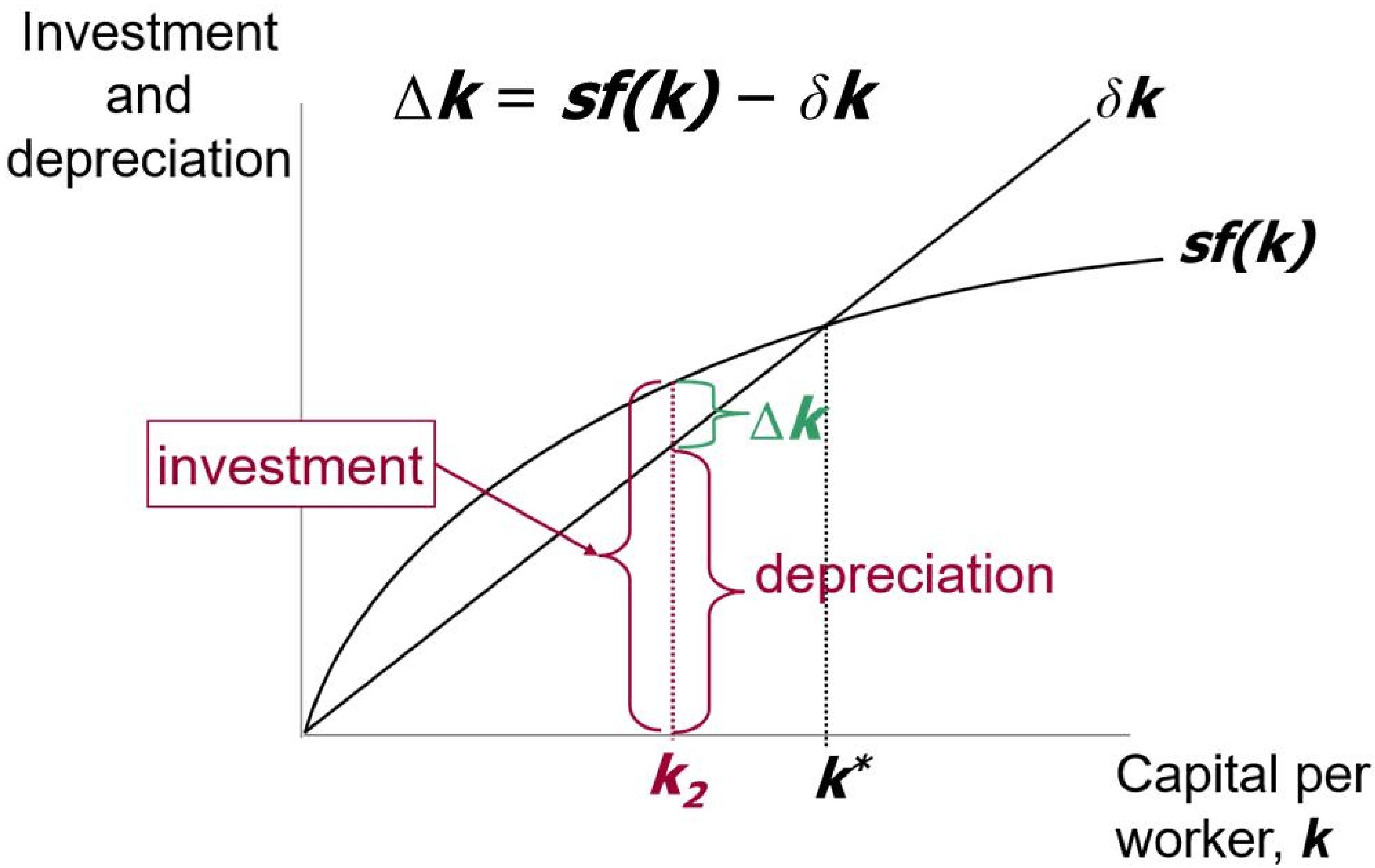
$$\Delta k = sf(k) - \delta k$$



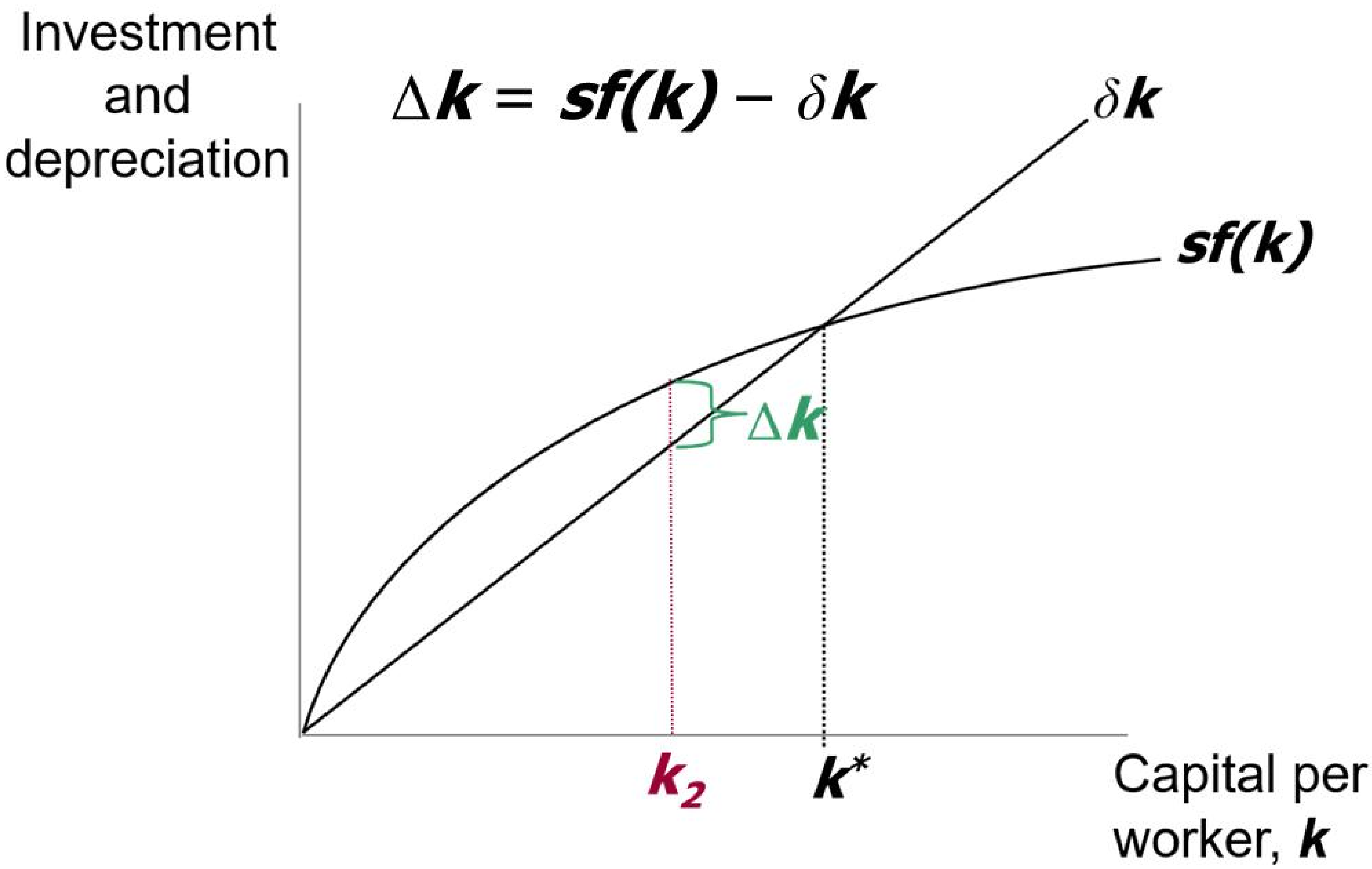
Moving toward the steady state, part 2



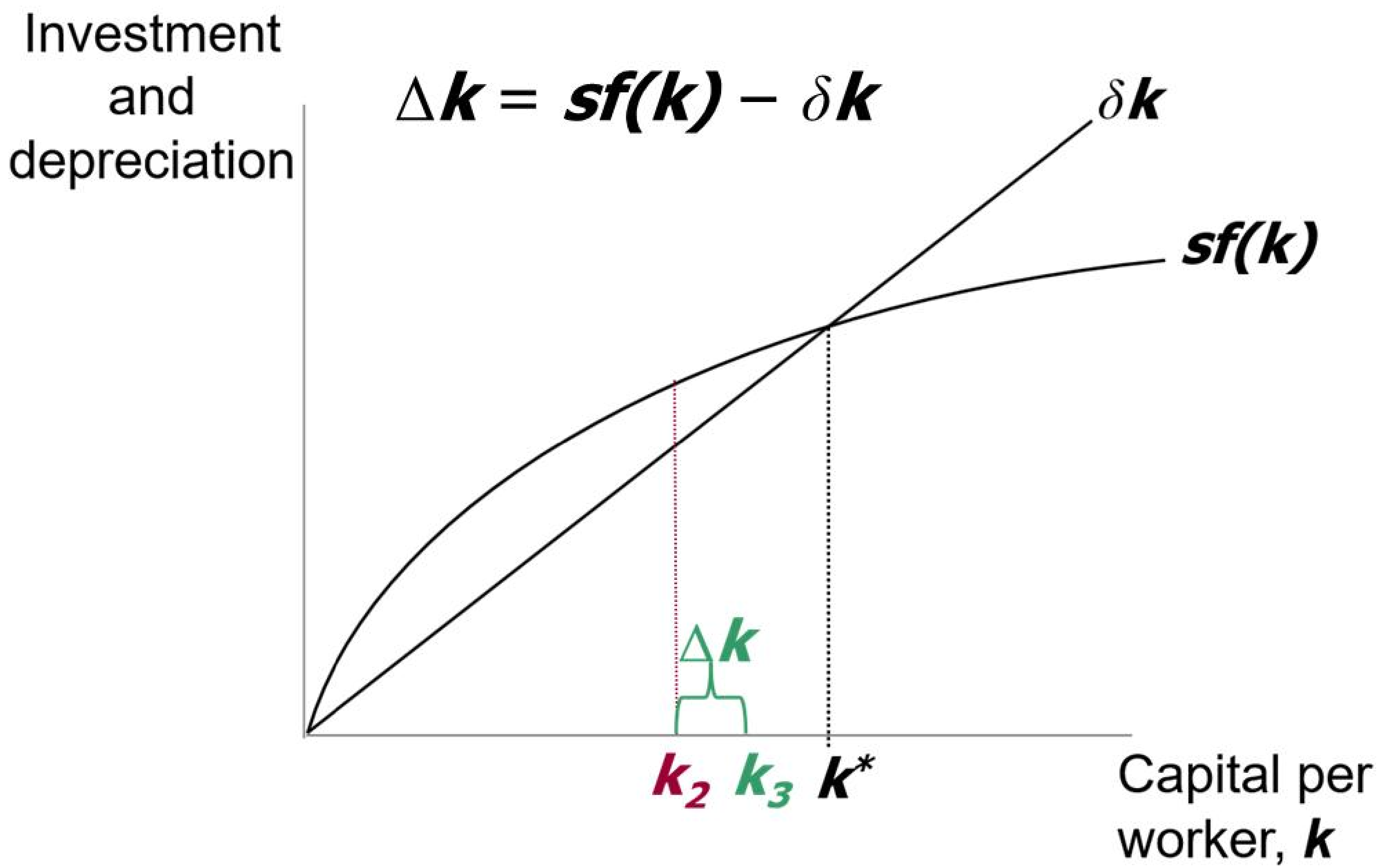
Moving toward the steady state, part 3



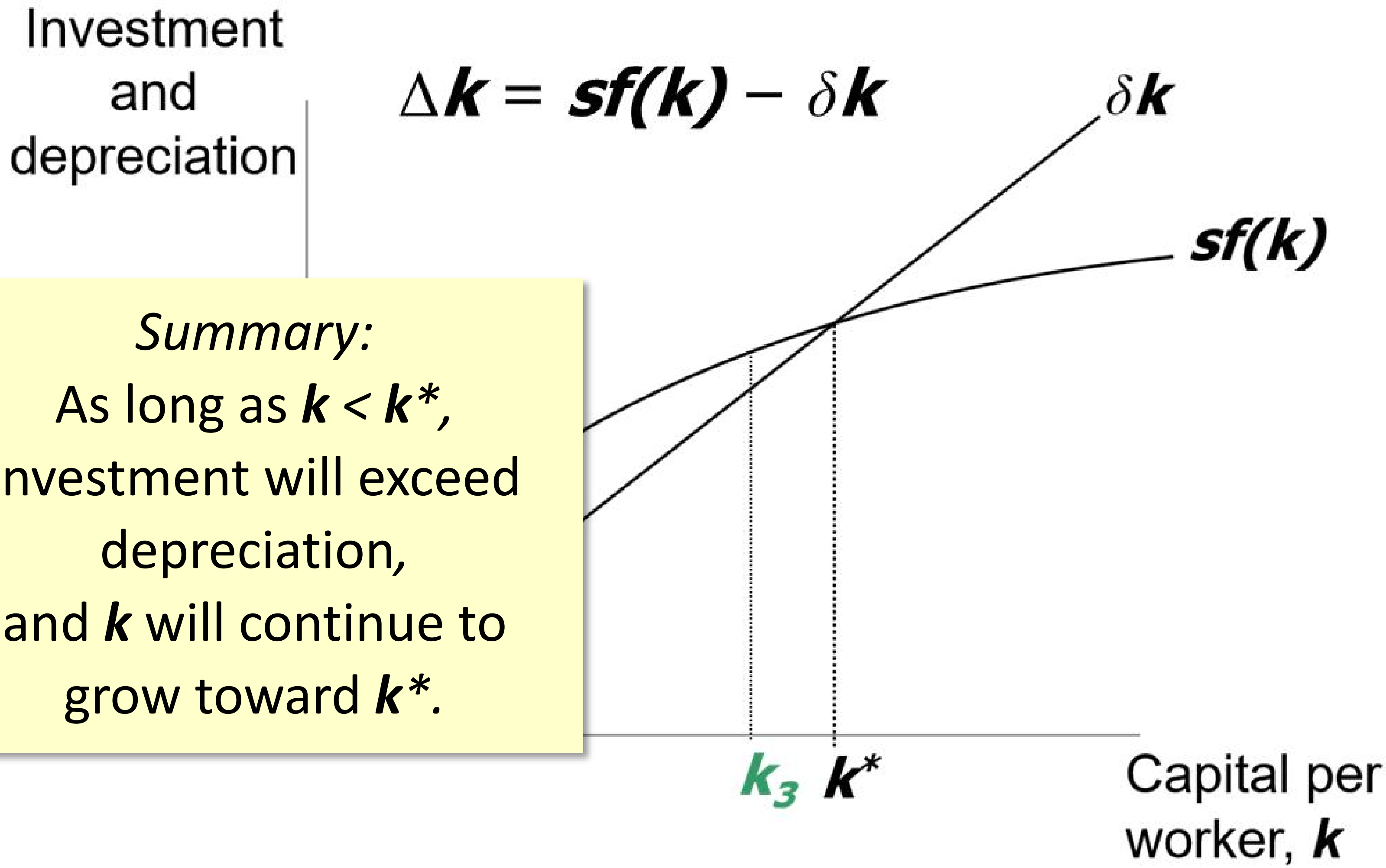
Moving toward the steady state, part 4



Moving toward the steady state, part 5



Moving toward the steady state, part 6



Summary:
As long as $k < k^*$,
investment will exceed depreciation,
and k will continue to grow toward k^*.

NOW YOU TRY
Approaching k^* from above

Draw the Solow model diagram, labeling the steady state $\boldsymbol{k^*}$.

On the horizontal axis, pick a value greater than $\boldsymbol{k^*}$ for the economy's initial capital stock. Label it $\boldsymbol{k_1}$.

Show what happens to ***k*** over time.
Does ***k*** move toward the steady state or away from it?

A numerical example, part 1

Production function (aggregate):

$$Y = F(K, L) = \sqrt{K \times L} = K^{1/2} L^{1/2}$$

To derive the per-worker production function, divide through by ***L***:

$$\frac{Y}{L} = \frac{K^{1/2} L^{1/2}}{L} = \left(\frac{K}{L}\right)^{1/2}$$

Then substitute ***y*** = ***Y/L*** and ***k*** = ***K/L*** to get

$$y = f(k) = k^{1/2}$$

A numerical example, part 2

Assume:

- s = 0.3
- δ = 0.1
- initial value of k = 4.0

Approaching the steady state: A numerical example

$$\text{Assumptions}: y = \sqrt{k}; s = 0.3; \delta = 0.1; \text{initial } k = 4.0$$

Year	*k*	*y*	*c*	*i*	δ*k*	Δ*k*
1	4.000	2.000	1.400	0.600	0.400	0.200
2	4.200	2.049	1.435	0.615	0.420	0.195
3	4.395	2.096	1.467	0.629	0.440	0.189
4	4.584	2.141	1.499	0.642	0.458	0.184
5	4.768	2.184	1.529	0.655	0.477	0.178
10	5.602	2.367	1.657	0.710	0.560	0.150
25	7.321	2.706	1.894	0.812	0.732	0.080
100	8.962	2.994	2.096	0.898	0.896	0.002
∞	9.000	3.000	2.100	0.900	0.900	0.000

NOW YOU TRY
Solve for the steady state

Continue to assume

$\boldsymbol{s} = 0.3$, $\delta = 0.1$, and $\boldsymbol{y} = \boldsymbol{k}^{1/2}$

Use the equation of motion

$$\Delta \boldsymbol{k} = \boldsymbol{s}\,\boldsymbol{f(k)} - \delta \boldsymbol{k}$$

to solve for the steady-state values of ***k***, ***y***, and ***c***.

NOW YOU TRY
Solve for the steady state, answers

$\Delta \boldsymbol{k} = 0$ definition of steady state

$\boldsymbol{s}\,\boldsymbol{f}(\boldsymbol{k}^*) = \delta \boldsymbol{k}^*$ eq'n of motion with $\Delta \boldsymbol{k} = 0$

$0.3\sqrt{\boldsymbol{k}^*} = 0.1\boldsymbol{k}^*$ using assumed values

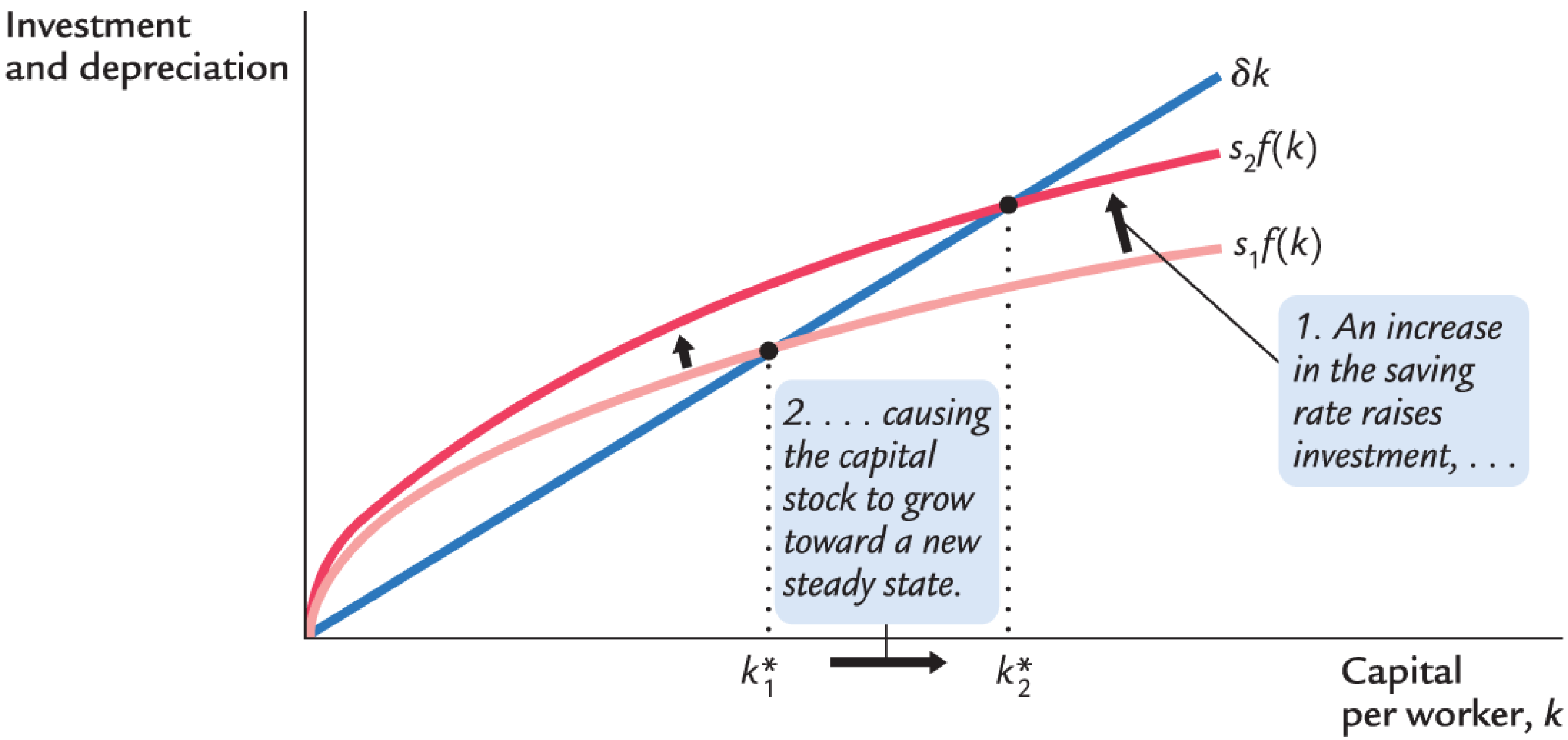
$$3 = \frac{\boldsymbol{k}^*}{\sqrt{\boldsymbol{k}^*}} = \sqrt{\boldsymbol{k}^*}$$

Solve to get: $\boldsymbol{k}^* = 9$ and $\boldsymbol{y}^* = \sqrt{\boldsymbol{k}^*} = 3$

Finally, $\boldsymbol{c}^* = (1 - \boldsymbol{s})\boldsymbol{y}^* = 0.7 \times 3 = 2.1$

An increase in the saving rate

An increase in the saving rate raises investment…
…causing ***k*** to grow toward a new steady state:



Mankiw, *Macroeconomics*, 10e, © 2019 Worth Publishers

Prediction: Countries with higher rates of saving and investment

- The Solow model predicts that countries with higher rates of saving and investment will have higher levels of capital and income per worker in the long run.
- Are the data consistent with this prediction?

The Golden Rule: Introduction

- Different values of ***s*** lead to different steady states. How do we know which is the "best" steady state?
- The "best" steady state has the highest possible consumption per person: $c^* = (1-s)\, f(k^*)$.
- An increase in ***s***
  - leads to higher ***k**** and ***y****, which raises ***c****
  - reduces consumption's share of income (1–***s***), which lowers ***c*.***
- So, how do we find the ***s*** and ***k**** that maximize ***c****?

The Golden Rule capital stock, part 1

k^*_{gold} = the **Golden Rule level of capital**, the steady-state value of k that maximizes consumption

To find it, first express c^* in terms of k^*:

$$c^* = y^* - i^*$$

$$= f(k^*) - i^*$$

$$= f(k^*) - \delta k^*$$

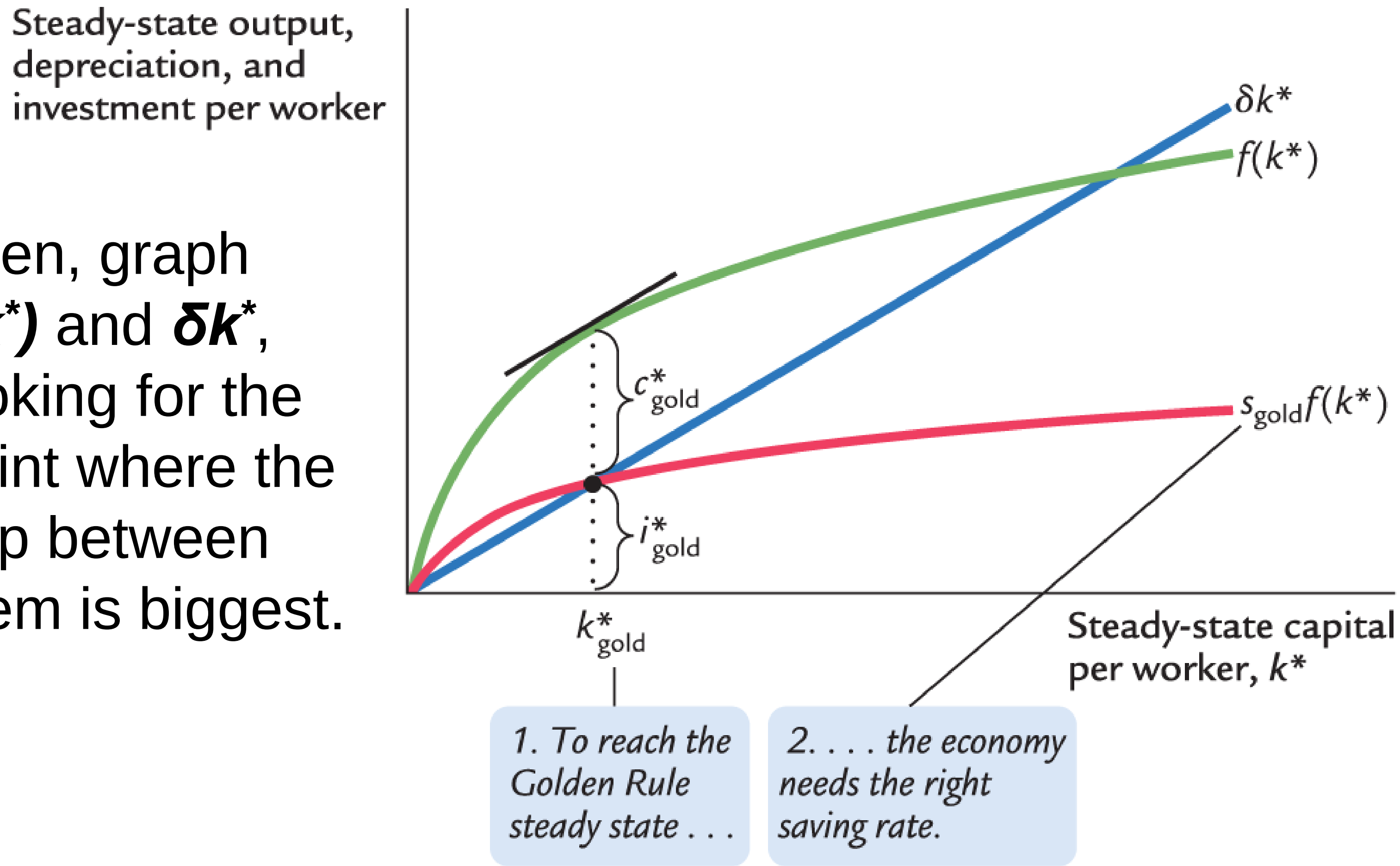
In the steady state:

$$i^* = \delta k^*$$

because $\Delta k = 0$.

The Golden Rule capital stock, part 2

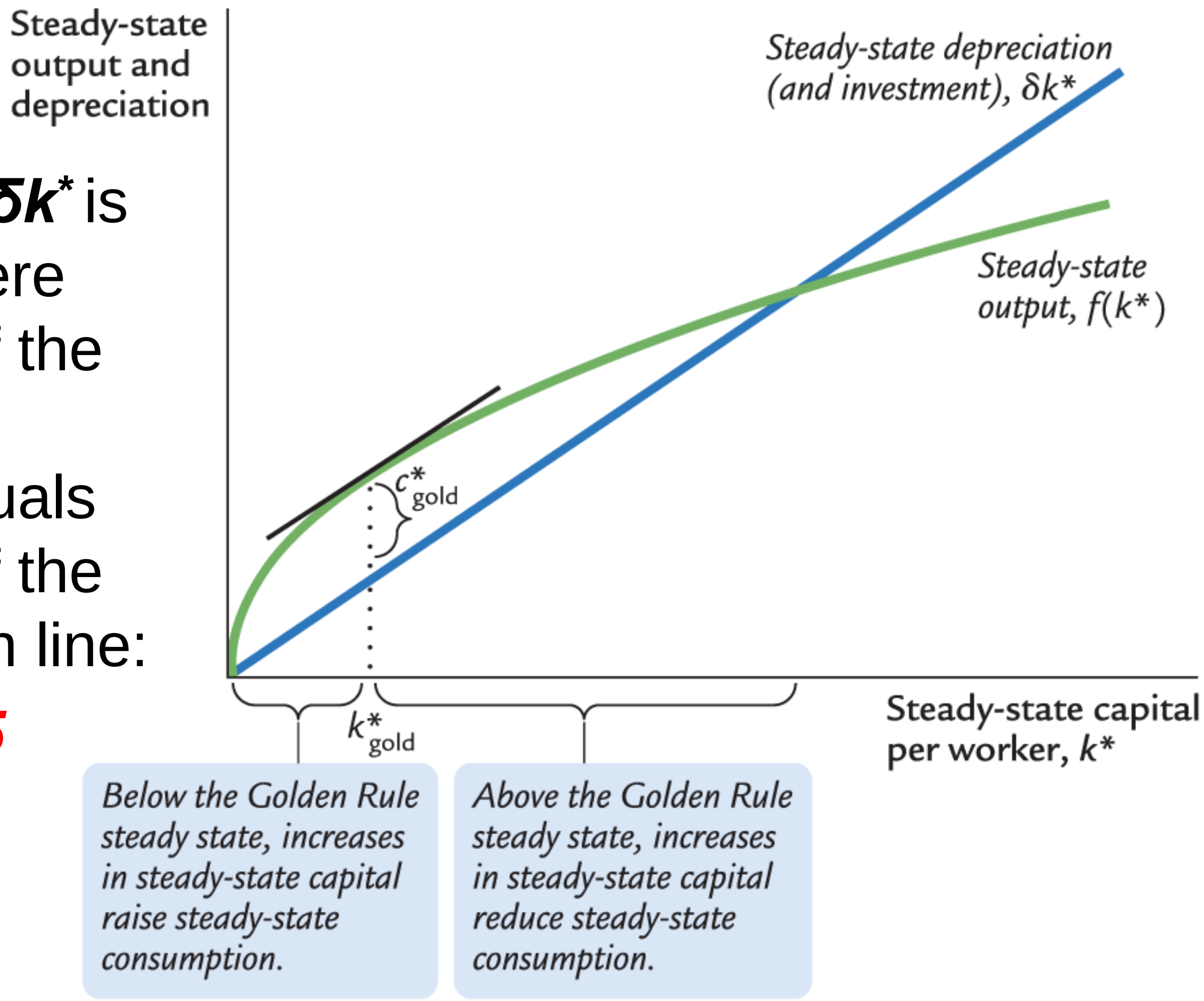
Then, graph ***f*(*k**)** and ***δk****, looking for the point where the gap between them is biggest.



The Golden Rule capital stock, part 3

$c^* = f(k^*) - \delta k^*$ is biggest where the slope of the production function equals the slope of the depreciation line:

$MPK = \delta$



The transition to the Golden Rule steady state

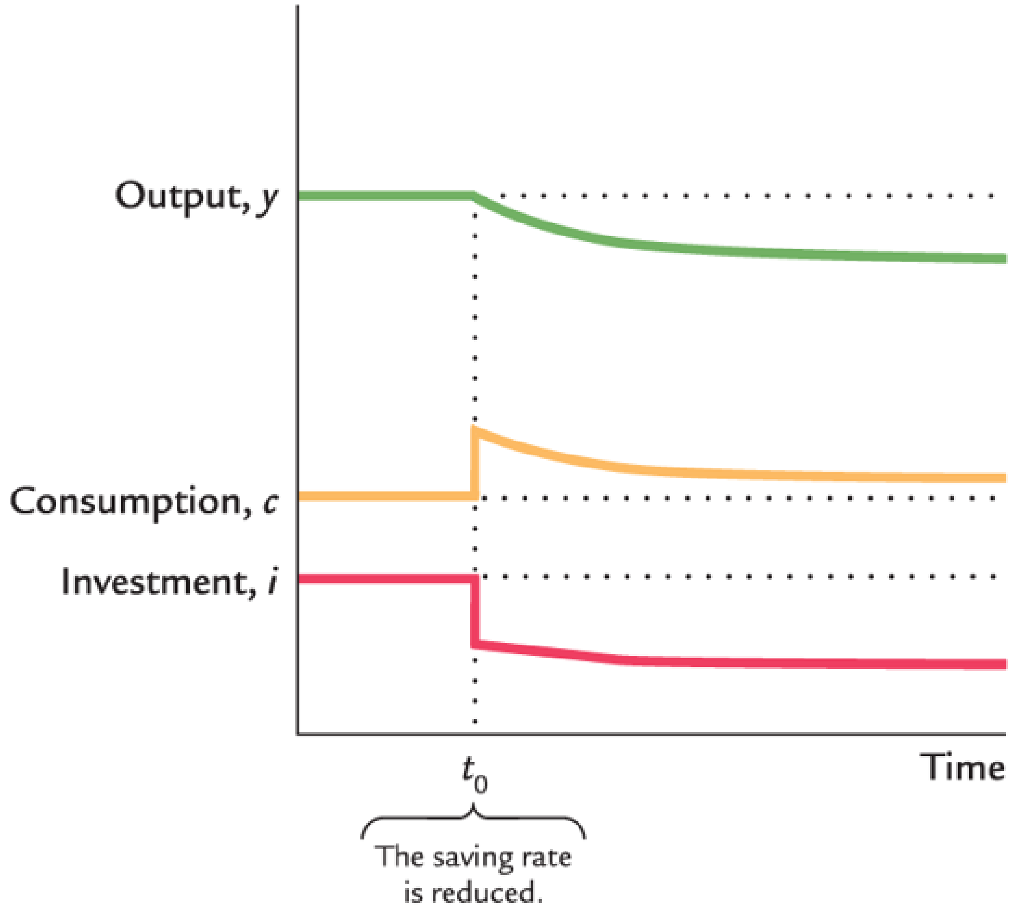
- The economy does NOT have a tendency to move toward the Golden Rule steady state.
- Achieving the Golden Rule requires that policymakers adjust ***s***.
- This adjustment leads to a new steady state with higher consumption.
- But what happens to consumption during the transition to the Golden Rule?

Starting with too much capital

If $k^* > k^*_{gold}$

then increasing c^* requires a fall in s.

In the transition to the Golden Rule, consumption is higher at all points in time.

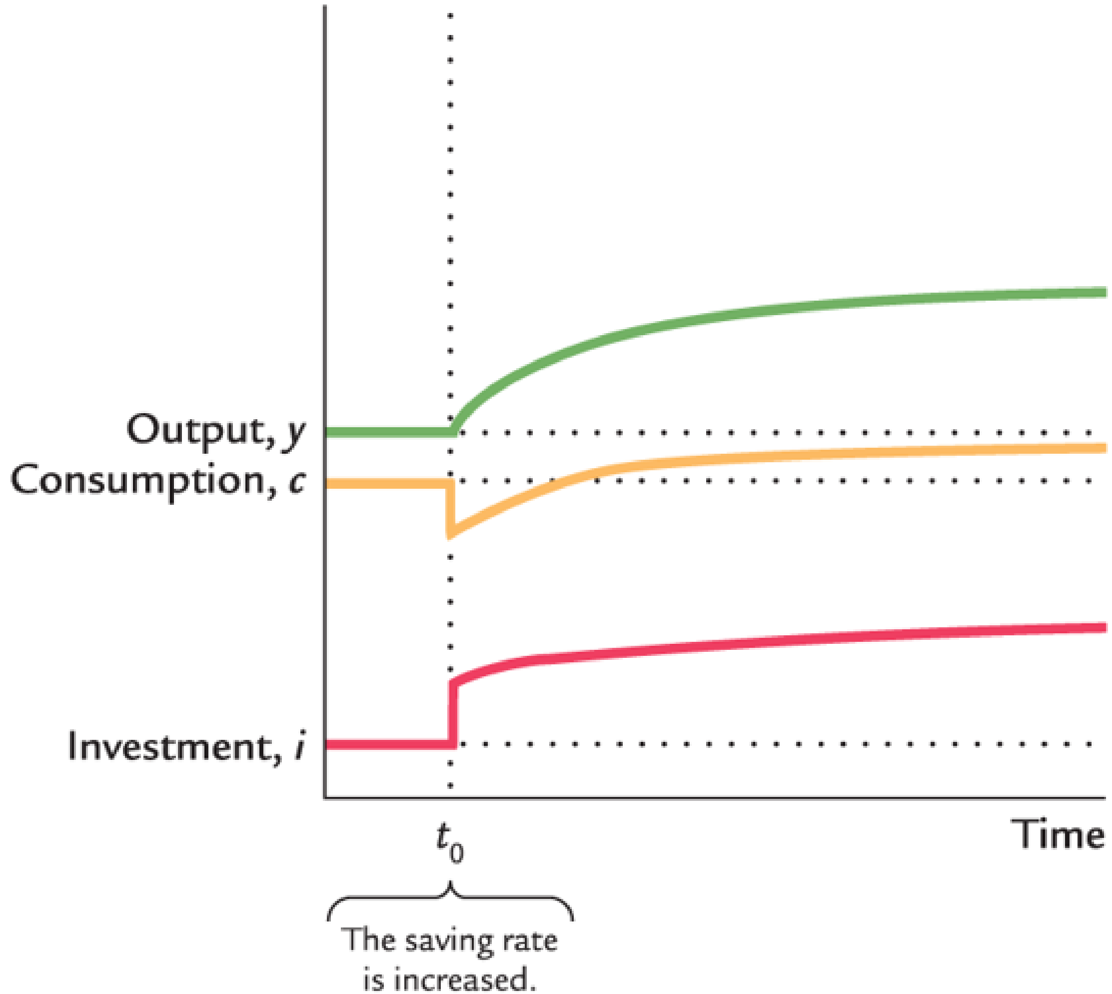


Starting with too little capital

If $k^* < k^*_{gold}$

then increasing c^* requires an increase in s.

Future generations enjoy higher consumption, but the current one experiences an initial drop in consumption.



Population growth

- Assume that the population and labor force grow at rate ***n*** (exogenous):

$$\frac{\Delta L}{L} = n$$

- Example: Suppose ***L*** = 1,000 in year 1 and the population is growing at 2% per year (***n*** = 0.02).
- Then $\Delta L = n\, L = 0.02 \times 1{,}000 = 20$, so ***L*** = 1,020 in year 2.

Break-even investment

- $(\delta + n)k$ = **break-even investment**, the amount of investment necessary to keep k constant.
- Break-even investment includes:
  - δk to replace capital as it wears out
  - $n k$ to equip new workers with capital

  (Otherwise, k would fall as the existing capital stock is spread more thinly over a larger population of workers.)

The equation of motion for *k* with population growth

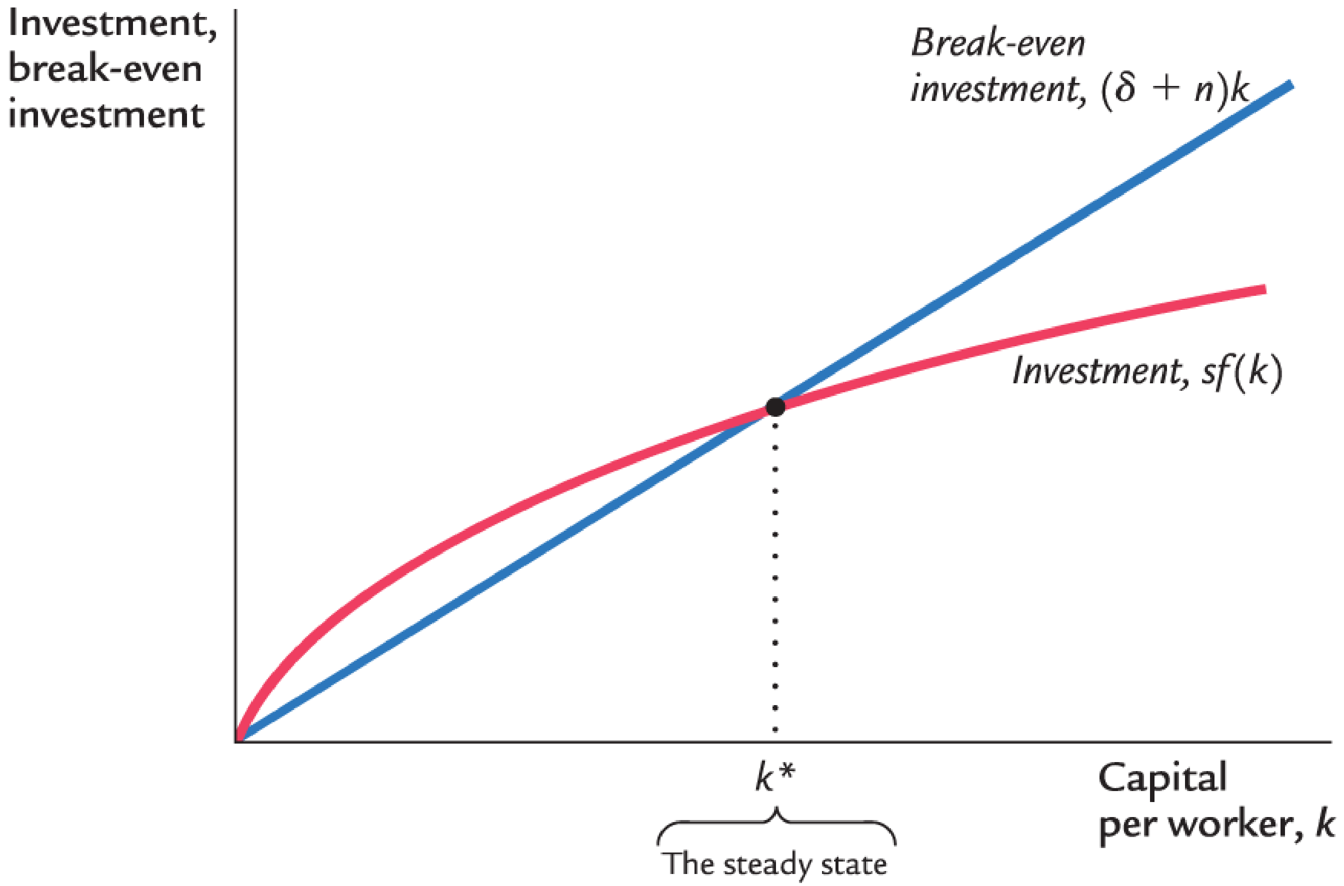
- With population growth, the equation of motion for ***k*** is:

$$\Delta k = s\,f(k) - (\delta + n)\,k$$

actual investment

break-even investment

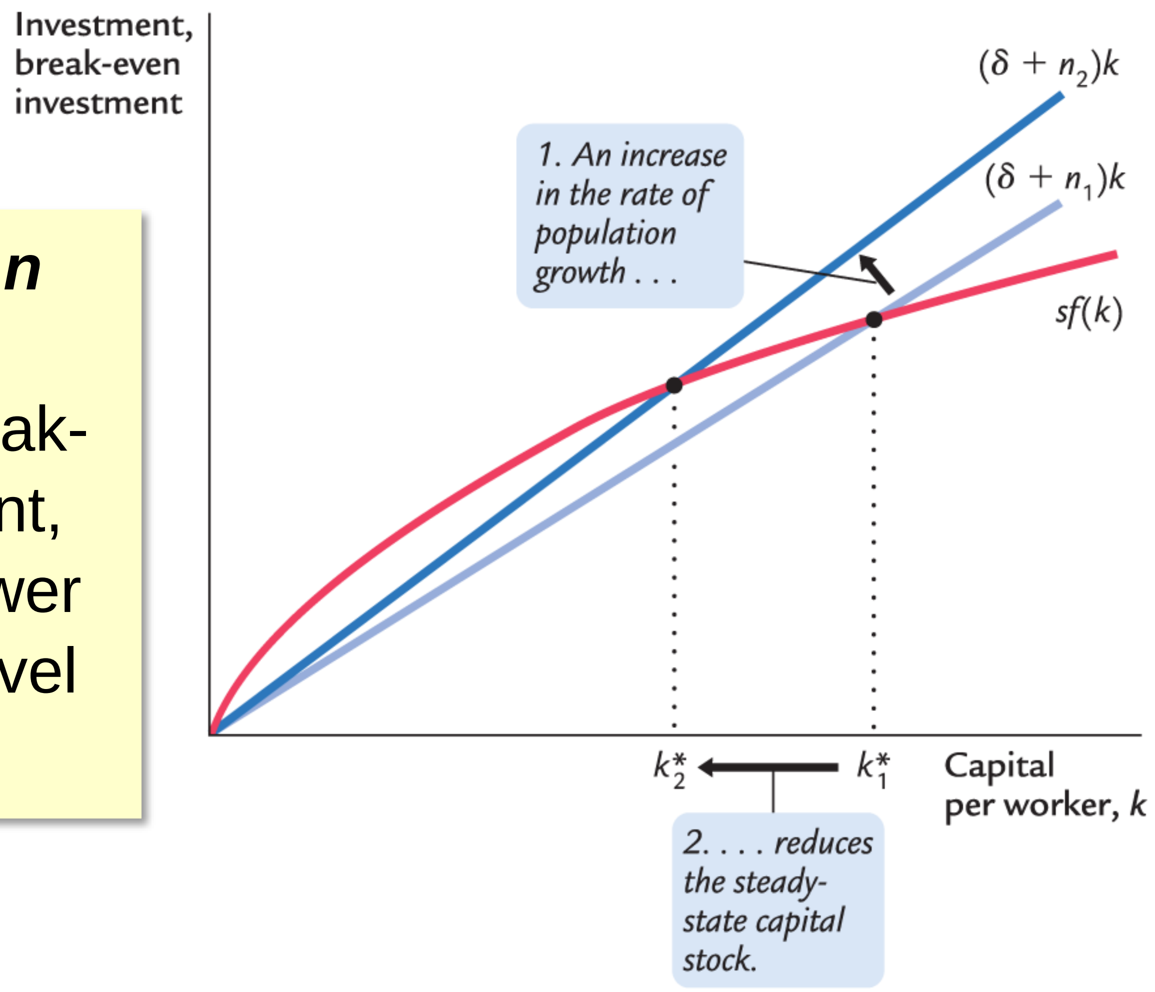
The Solow model diagram



Mankiw, *Macroeconomics*, 10e, © 2019 Worth Publishers

The impact of population growth

An increase in ***n*** causes an increase in break-even investment, leading to a lower steady-state level of ***k***.



Mankiw, *Macroeconomics*, 10e, © 2019 Worth Publishers

Prediction

- The Solow model predicts that countries with higher population growth rates will have lower levels of capital and income per worker in the long run.
- Are the data consistent with this prediction?

The Golden Rule with population growth

To find the Golden Rule capital stock, express c^* in terms of k^*:

$$c^* = y^* - i^*$$

$$= f(k^*) - (\delta + n)\,k^*$$

c^* is maximized when

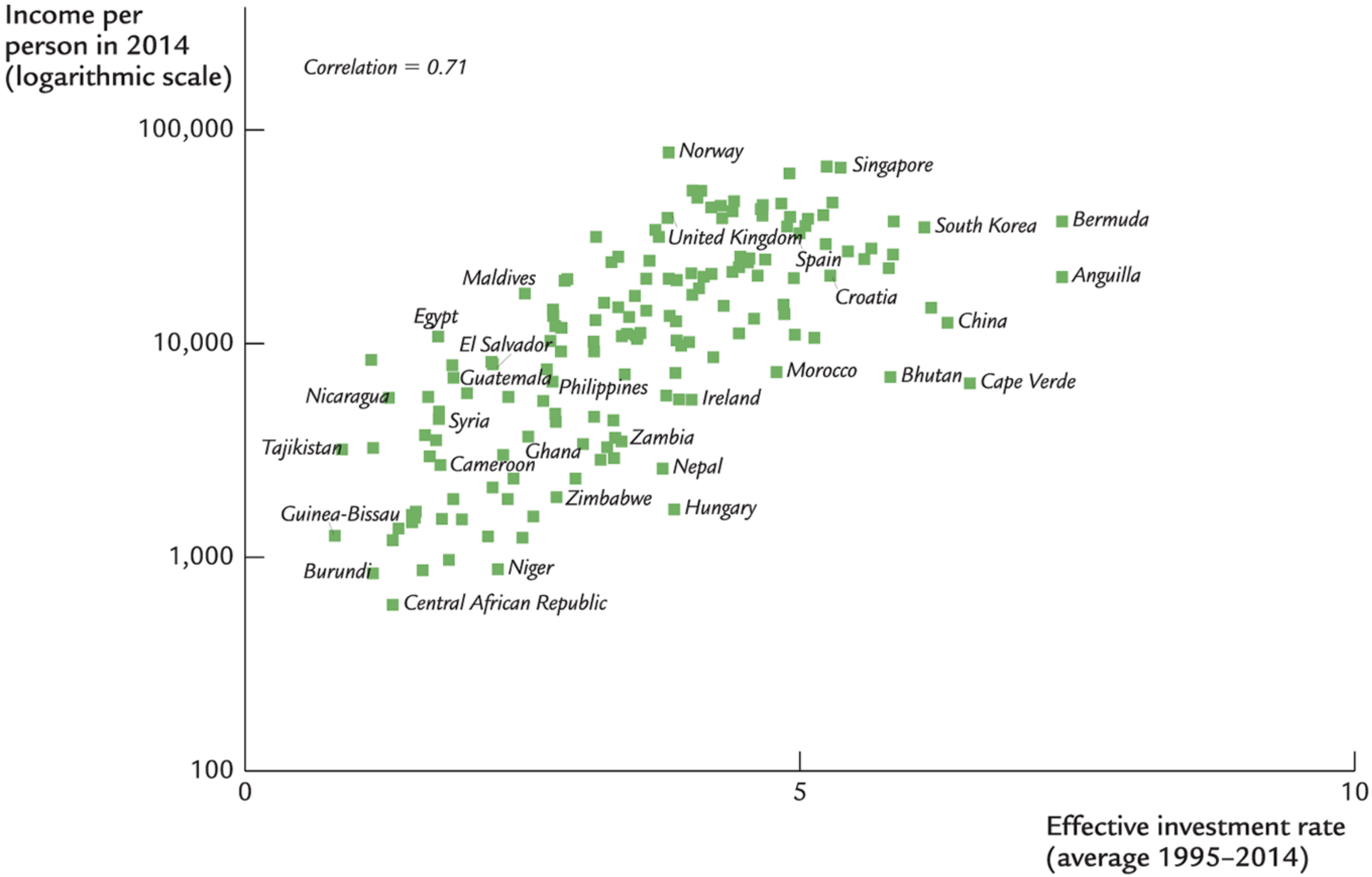
$$\text{MPK} = \delta + n$$

Or, equivalently,

$$\text{MPK} - \delta = n$$

In the Golden Rule steady state, the marginal product of capital net of depreciation equals the population growth rate.

International evidence on investment rates and income per person



Alternative perspectives on population growth, part 1

The Malthusian model (1798)

- Predicts population growth will outstrip the Earth's ability to produce food, leading to the impoverishment of humanity.
- Since the time of Malthus, world population has increased sixfold, yet living standards are higher than ever.
- Malthus neglected the effects of technological progress.

Alternative perspectives on population growth, part 2

The Kremerian model (1993)

- Posits that population growth contributes to economic growth.
- More people = more geniuses, scientists, and engineers, so faster technological progress.
- Evidence, from very long historical periods:
  - As world population growth rate increased, so did the rate of growth in living standards.
  - Historically, regions with larger populations have enjoyed faster growth.

Technological progress in the Solow model

So far, in the Solow model we have kept these assumptions:

- the production technology is held constant.
- income per capita is constant in the steady state.

Neither point is true in the real world:

- 1900–2016: U.S. real GDP per person grew by a factor of 8.58, or 1.9% per year.
- examples of technological progress abound (see the next slide).

Examples of technological progress

- U.S. farm sector productivity nearly tripled from 1950 to 2012.
- The real price of computer power has fallen an average of 30% per year over the past three decades.
- 2000: 361 million Internet users, 740 million cell phone users

  2016: 3.4 billion Internet users, 5.0 billion cell phone users
- 2001: iPod capacity = 5GB, 1,000 songs. Not capable of playing episodes of *Game of Thrones*.

  2018: iPod touch capacity = 64GB, 30,000 songs. Can play episodes of *Game of Thrones*.

Technological progress in the Solow model, part 1

- A new variable: $\boldsymbol{E}$ = labor efficiency
- Assume:
  Technological progress is **labor-augmenting**:
  it increases labor efficiency at the exogenous rate $\boldsymbol{g}$:

$$g = \frac{\Delta E}{E}$$

Technological progress in the Solow model, part 2

We now write the production function as:

$$Y = F(K, L \times E)$$

- where $L \times E$ = number of effective workers
  - Increases in labor efficiency have the same effect on output as increases in the labor force.

Technological progress in the Solow model, part 3

- Notation:

  $\boldsymbol{y = Y / LE}$ = output per effective worker

  $\boldsymbol{k = K / LE}$ = capital per effective worker

- Production function per effective worker:

  $$y = f(k)$$

- Saving and investment per effective worker:

  $$s\,y = s\,f(k)$$

Technological progress in the Solow model, part 4

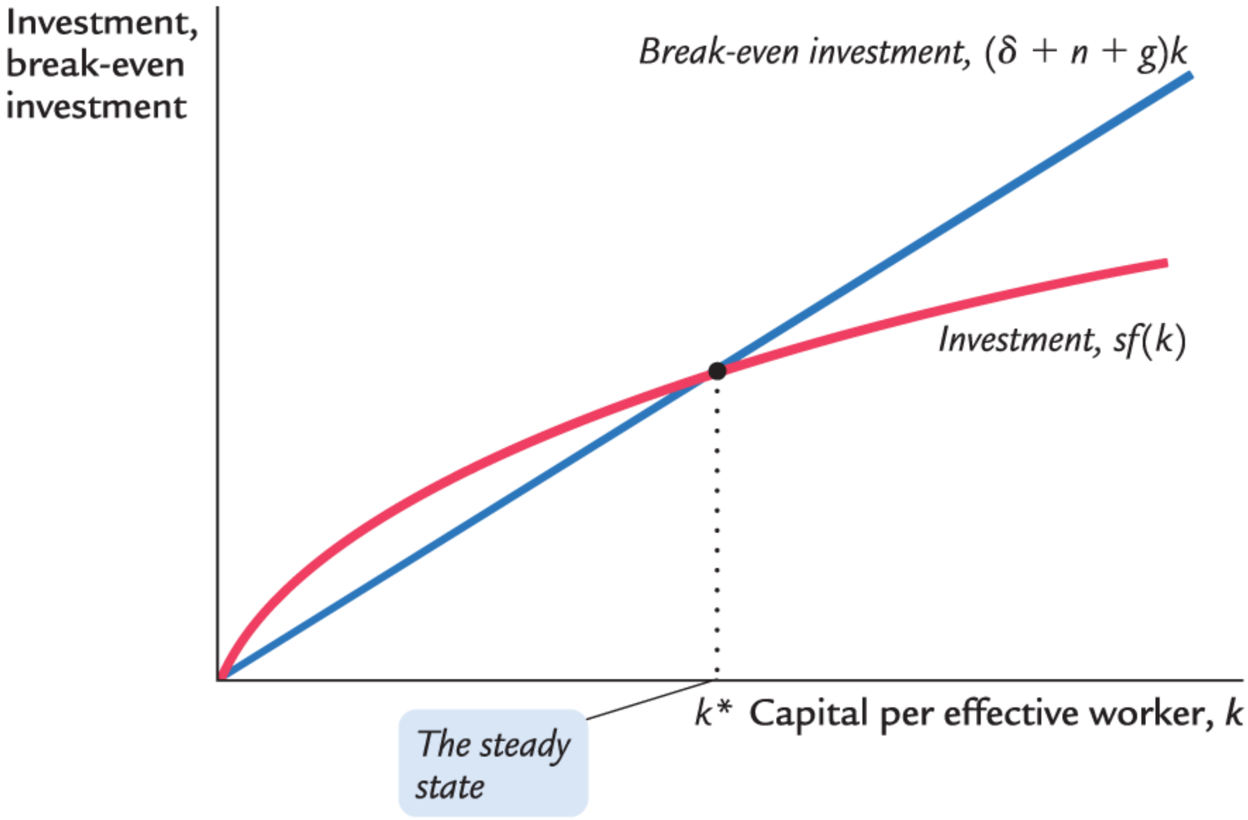
$(\delta + n + g)\, k$ = break-even investment:
the amount of investment necessary to keep k constant.

Consists of:

- δk to replace depreciating capital
- $n k$ to provide capital for new workers
- $g k$ to provide capital for the new "effective" workers created by technological progress

Technological progress in the Solow model

$$\Delta k = s\,f(k) - (\delta + n + g)k$$



Mankiw, *Macroeconomics*, 10e, © 2019 Worth Publishers

Steady-state growth rates in the Solow model with tech. progress

Variable	Symbol	Steady-State Growth Rate
Capital per effective worker	$k = K/(E \times L)$	0
Output per effective worker	$y = Y/(E \times L) = f(k)$	0
Output per worker	$Y/L = y \times E$	g
Total output	$Y = y \times (E \times L)$	$n + g$

The Golden Rule with technological progress

To find the Golden Rule capital stock, express c^* in terms of k^*:

$$c^* = y^* - i^*$$

$$= f(k^*) - (\delta + n + g)\, k^*$$

c^* is maximized when

$$MPK = \delta + n + g$$

Or, equivalently,

$$MPK - \delta = n + g$$

In the Golden Rule steady state, the marginal product of capital net of depreciation equals the population growth rate plus the rate of tech progress.

Growth empirics: Balanced growth

- The Solow model's steady state exhibits **balanced growth**: many variables grow at the same rate.
  - The Solow model predicts that ***Y*/*L*** and ***K*/*L*** grow at the same rate (***g***), so ***K*/*Y*** should be constant. This is true in the real world.
  - The Solow model predicts that real wage grows at the same rate as ***Y*/*L***, while real rental price is constant. Also true in the real world.

Growth empirics: Convergence, part 1

- Solow model predicts that, other things equal, poor countries (with lower ***Y***/***L*** and ***K***/***L***) should grow faster than rich ones.
- If true, then the income gap between rich and poor countries would shrink over time, causing living standards to *converge*.
- In the real world, many poor countries do NOT grow faster than rich ones. Does this mean the Solow model fails?

Growth empirics: Convergence, part 2

- No, the Solow model does not fail because it predicts that, other things equal, poor countries (with lower ***Y***/***L*** and ***K***/***L***) should grow faster than rich ones.
  - In samples of countries with similar savings and population growth rates, income gaps shrink about 2% per year.
  - In larger samples, after controlling for differences in saving, population growth, and human capital, incomes converge by about 2% per year.

Growth empirics: Convergence, part 3

- What the Solow model really predicts is **conditional convergence**: countries converge to their own steady states, which are determined by saving, population growth, and education.
- Each country’s steady state depends on its structural characteristics:
  - 💰 **Saving rate**
  - 👶 **Population growth**
  - 🎓 **Human capital (education, skills)**

Therefore countries with **similar characteristics** will converge to **similar income levels.**

Countries with **different characteristics** will converge to **different levels**

Growth empirics: Convergence, part 3

Example of conditional convergence:

- Let's assume 2 countries **A** and **B**: they have the same saving rate, same population growth, same education level
  - If A starts poorer than B, it will grow faster
  - Over time, A will catch up with B

Growth empirics: Convergence, part 3

Example of conditional convergence:

If country A has: lower saving, higher population growth, and lower human capital than B

- It may remain poorer in the long run because its steady state is lower

- This prediction comes true in the real world.

Growth empirics: Factor accumulation vs. production efficiency, part 1

- Differences in income per capita among countries can be due to differences in:
  1. capital—physical or human—per worker
  2. the efficiency of production (the height of the production function)
- Studies:
  - Both factors are important.
  - The two factors are correlated: countries with higher physical or human capital per worker also tend to have higher production efficiency.

Growth empirics: Factor accumulation vs. production efficiency, part 2

- Possible explanations for the correlation between capital per worker and production efficiency:
  - Production efficiency encourages capital accumulation.
  - Capital accumulation has externalities that raise efficiency.
  - A third, unknown variable causes capital accumulation and efficiency to be higher in some countries than others.

Policy issues

- Are we saving enough? Too much?
- What policies might change the saving rate?
- How should we allocate our investment between privately owned physical capital, public infrastructure, and human capital?
- How do a country's institutions affect production efficiency and capital accumulation?
- What policies might encourage faster technological progress?

Policy issues: Evaluating the rate of saving, part 1

- Use the Golden Rule to determine whether the U.S. saving rate and capital stock are too high, too low, or about right.
  - If $(MPK - \boldsymbol{\delta}) > (\boldsymbol{n} + \boldsymbol{g})$, the U.S. economy is below the Golden Rule steady state and should increase $\boldsymbol{s}$.
  - If $(MPK - \boldsymbol{\delta}) < (\boldsymbol{n} + \boldsymbol{g})$, the U.S. economy is above the Golden Rule steady state and should reduce $\boldsymbol{s}$.

Policy issues: Evaluating the rate of saving, part 2

To estimate ($MPK - \delta$), use three facts about the U.S. economy:

1. $\boldsymbol{k} = 2.5\ \boldsymbol{y}$
   The capital stock is about 2.5 times one year's GDP.
2. $\boldsymbol{\delta k} = 0.1\ \boldsymbol{y}$
   About 10% of GDP is used to replace depreciating capital.
3. $MPK \times \boldsymbol{k} = 0.3\ \boldsymbol{y}$
   Capital income is about 30% of GDP.

Policy issues: Evaluating the rate of saving, part 3

1. $\boldsymbol{k} = 2.5\, \boldsymbol{y}$
2. $\boldsymbol{\delta k} = 0.1\, \boldsymbol{y}$
3. $MPK \times \boldsymbol{k} = 0.3\, \boldsymbol{y}$

To determine $\boldsymbol{\delta}$, divide **2** by **1**:

$$\frac{\delta \boldsymbol{k}}{\boldsymbol{k}} = \frac{0.1\boldsymbol{y}}{2.5\,\boldsymbol{y}} \Rightarrow \delta = \frac{0.1}{2.5} = 0.04$$

Policy issues: Evaluating the rate of saving, part 4

1. $\boldsymbol{k} = 2.5\,\boldsymbol{y}$
2. $\boldsymbol{\delta k} = 0.1\,\boldsymbol{y}$
3. $MPK \times \boldsymbol{k} = 0.3\,\boldsymbol{y}$

To determine *MPK,* divide **3** by **1**:

$$\frac{\text{MPK} \times \boldsymbol{k}}{\boldsymbol{k}} = \frac{0.3\,\boldsymbol{y}}{2.5\,\boldsymbol{y}} \Rightarrow \text{MPK} = \frac{0.3}{2.5} = 0.12$$

Hence, $MPK - \boldsymbol{\delta} = 0.12 - 0.04 = \underline{0.08}$

Policy issues: Evaluating the rate of saving, part 5

- From the last slide: $MPK - \boldsymbol{\delta} = 0.08$
- U.S. real GDP grows an average of 3% per year (in the long-run GDP growth = n + g) so $\boldsymbol{n} + \boldsymbol{g} = 0.03$
- Thus,

$$MPK - \boldsymbol{\delta} = 0.08 > 0.03 = \boldsymbol{n} + \boldsymbol{g}$$

- Conclusion:

The U.S. is below the Golden Rule steady state: Increasing the U.S. saving rate would increase consumption per capita in the long run.

Policy issues: How to increase the saving rate

- Reduce the government budget deficit (or increase the budget surplus).
- Increase incentives for private saving:
  - Reduce capital gains tax, corporate income tax, and estate tax, as they discourage saving.
  - Replace federal income tax with a consumption tax.
  - Expand tax incentives for IRAs (individual retirement accounts) and other retirement savings accounts.

Policy issues: Allocating the economy's investment, part 1

- In the Solow model, there's one type of capital.
- In the real world, there are many types, which we can divide into three categories:
  - private capital stock
  - public infrastructure
  - **human capital:** the knowledge and skills that workers acquire through education
- How should we allocate investment among these types?

Policy issues: Allocating the economy's investment, part 2

Two viewpoints:

1. Equalize tax treatment of all types of capital in all industries and let the market allocate investment to the type with the highest marginal product.
2. **Industrial policy**:
   Government should actively encourage investment in capital of certain types or in certain industries because it may have positive externalities that private investors don't consider.

Possible problems with industrial policy

- The government may not have the ability to “pick winners” (choose industries with the highest return to capital or biggest externalities).
- Politics (e.g., campaign contributions) rather than economics may influence which industries get preferential treatment.

Policy issues: Establishing the right institutions

- Creating the right institutions is important for ensuring that resources are allocated to their best use. Examples:
  - Legal institutions, to protect property rights.
  - Capital markets, to help financial capital flow to the best investment projects.
  - A corruption-free government, to promote competition, enforce contracts, etc.

Establishing the right institutions: North versus South Korea

After WW2, Korea split into:

- North Korea with institutions based on authoritarian communism
- South Korea with Western-style democratic capitalism

Today, GDP per capita is over 10 times higher in S. Korea than in N. Korea.

Jason Reed/Reuters/Newscom

Policy issues: Encouraging technological progress

- Patent laws:
  encourage innovation by granting temporary monopolies to inventors of new products
- Tax incentives for R&D
- Grants to fund basic research at universities
- Industrial policy:
  encourages specific industries that are key for rapid technological progress *(subject to the preceding concerns).*

CASE STUDY: Is free trade good for economic growth? Part 1

- Since Adam Smith, economists have argued that free trade can increase production efficiency and living standards.
- Research by Sachs & Warner:

Average annual growth rates, 1970–89

	Open	**Closed**
Developed nations	2.3%	0.7%
Developing nations	4.5%	0.7%

CASE STUDY: Is free trade good for economic growth? Part 2

- To determine causation, Frankel and Romer exploit geographic differences among countries:
  - Some nations trade less because they are farther from other nations or landlocked.
  - Such geographic differences are correlated with trade but not with other determinants of income.
  - Hence, they can be used to isolate the impact of trade on income.
- Findings: increasing trade/GDP by 2% causes GDP per capita to rise 1%, other things equal.

CASE STUDY: Is free trade good for economic growth? Part 2

- A common answer is that the gains from international trade are unequal;
- although a country as a whole sees its income rise, some workers permanently lose their jobs and see a large decrease in their income.

  The basic idea is:

  - International trade **increases the overall size of the economy**:
    - the country becomes more efficient
    - total GDP rises

CASE STUDY: Is free trade good for economic growth? Part 2

- ⚖ But the benefits are not equally distributed

Not everyone gains in the same way:

- Some sectors expand (export industries)
- Other sectors shrink (due to import competition)

What happens to workers?
Workers in expanding sectors → will **gain**
Workers in declining sectors → **lose their jobs** or earn less and these losses can be permanent

Endogenous growth theory

- Solow model:
  - Sustained growth in living standards is due to technological progress.
  - The rate of technological progress is exogenous.

How do we incorporate the process of technological change into a growth model?

- Endogenous growth theory:
  - In this set of models, the growth rate of productivity and living standards is endogenous.

Endogenous growth theory

In the Solow model, the long-run economic growth rate equals the rate of technological progress, which is exogenous in the model.

Hence, the Solow model is basically saying, “all I can tell you is that growth in living standards depends on technological progress. I have no idea what drives technological progress.”

Endogenous growth theory tries to explain the behavior of the rates of technological progress and/or productivity growth rather than merely taking these rates as given.

The basic model, (the AK model)

The **AK** model is a simple model of economic growth where:

- Output depends directly on capital
- $Y = A \cdot K$
- where:
- Y = output (GDP)
- K = capital (machines, skills, infrastructure)
- A = productivity (technology) = the amount of output produced for each unit of capital (***A*** is exogenous and constant)

The basic model, (the AK model)

- Production function: $\boldsymbol{Y = A\,K}$
- The **production function does not exhibit diminishing** returns to capital. This means: every extra unit of capital is just as productive as the previous one
- Key difference between this model and Solow: *MPK* is constant here, diminishes in Solow
- Investment: $\boldsymbol{sY}$
- Depreciation: $\boldsymbol{\delta K}$
- Equation of motion for total capital:
  - $\Delta \boldsymbol{K} = \boldsymbol{sY - \delta K}$

The basic model

$\Delta \boldsymbol{K} = \boldsymbol{sY} - \boldsymbol{\delta K}$

Divide through by $\boldsymbol{K}$ and use $\boldsymbol{Y} = \boldsymbol{A}\,\boldsymbol{K}$ to get:

$$\frac{\Delta \boldsymbol{Y}}{\boldsymbol{Y}} = \frac{\Delta \boldsymbol{K}}{\boldsymbol{K}} = \boldsymbol{sA} - \delta$$

- If $\boldsymbol{s}\,\boldsymbol{A} > \boldsymbol{\delta}$, then income will grow forever, and investment is the "engine of growth."
- Note that this does not require the assumption of exogenous technological progress.
- Here, the permanent growth rate depends on $\boldsymbol{s}$. In Solow model, it does not.

Assumption on diminishing returns of capital

Y and K grow at the same rate because A is constant.
Discussion:

The return to capital is the incentive to invest. If capital exhibits diminishing returns, then the incentive to invest decreases as the economy grows.

Hence, investment cannot be a source of sustained growth.

However, in this model, MPK does not fall as K rises, so the incentive to invest never declines; people will always find it worthwhile to save and invest over and above depreciation, so investment becomes an engine of growth. In the AK model, capital keeps generating growth without limits, so economies can grow indefinitely if they keep investing.

Endogenous model vs Solow

In the endogenous AK model

1. Endless growth is possible

If a country keeps investing, it can **grow forever**

Growth does **not slow down**

2. Saving matters a lot

Higher saving → more investment → more capital → faster growth

So policies that increase saving or investment **permanently increase growth**

3. No convergence (unlike Solow)

In the Solow model: poor countries catch up (convergence)

In the AK model: **countries can diverge**

- countries that invest more → grow faster forever
- countries that invest less → fall behind

Assumption on diminishing returns of capital

Does capital exhibit diminishing or constant marginal returns? The answer is critical, for it determines whether investment explains sustained (i.e. steady-state) growth in productivity and living standards.

Assumption on diminishing returns of capital

Does it make sense that capital does not show diminishing returns?

No, if capital is defined as the stock of plants and equipment.

Yes, if capital is broadly interpreted to include the stock of knowledge. Knowledge is a type of capital.

Some economists argue that there are increasing returns to knowledge.

If so, then constant returns to capital is more plausible, and this model may be a good description of economic growth.

A two-sector model, part 1

The AK model developed above is the simplest example of an endogenous growth model. It is an endogenous growth model because growth is generated internally through capital accumulation rather than imposed from outside.

Economic growth arises directly from the accumulation of capital, which is a variable determined within the model.

Savings and investment decisions made by agents determine growth, not some outside technological shock.

This is the distinctive feature of endogenous growth theory.

A two-sector model, part 1

A more sophisticated version of endogenous model incorporates two sectors:

a manufacturing sector that produces goods and services for either consumption or investment in physical capital K and,

a research sector composed of universities that produce knowledge, E, which is used in both sectors.

A two-sector model

Two sectors:

that it is an extension of the Solow model with technological progress.

There are two differences:

First, a **fraction of the labor force** does not produce goods and services but rather produces “knowledge” by doing research in universities.

Second, **the rate of tech progress is not exogenous** but rather depends on how fast the stock of knowledge grows, which in turn depends on how much labor the economy has allocated to research.

A two-sector model

Two sectors:

- manufacturing firms produce goods.
- research universities produce knowledge that increases labor efficiency in manufacturing.

- u = fraction of labor in research (u is exogenous)

The economy can be described by three equations:

1) Manufacturing production function:

$$Y = F\,[K, (1 - u)E\,L]$$

1) Research production function: $\Delta E = g\,(u)E$

2) Capital accumulation: $\Delta K = s\,Y - \delta K$

A two-sector model

Manufacturing production function:

Just as in the Solow model with exogenous technological progress, output of manufacturers depends on capital and the effective labor force employed in the manufacturing sector, $(1 - u)EL$.

Research production function: The "output" is increases in knowledge and labor efficiency.

A two-sector model

The "inputs" are labor and current knowledge.

The function g( ) shows **how changes in the amount of labor devoted to research affect the creation of new knowledge**.

All we need is for g( ) to be an increasing function. It does not matter whether a doubling of scientists causes the creation of knowledge to double, more than double, or less than double.

Capital accumulation: As in the previous model, net investment equals gross investment (sY) minus depreciation.

A two-sector model

- In the steady state, manufacturing output per worker and the standard of living grow at rate $\Delta \boldsymbol{E} / \boldsymbol{E} = \boldsymbol{g}(\boldsymbol{u})$.

- Key variables: s and u

s determines the steady-state stock of physical capital,
u determines the growth in the stock of knowledge,
s and ***u*** determine the level of income, and
u determines the steady-state growth rate of income.

A two-sector model, part 1

In this model, **the steady state growth rate of the standard of living equals the growth rate of labor efficiency**, just like in the Solow model with tech progress, covered at the beginning of this chapter.

The difference here is that the rate of tech progress, g, is not exogenous: it depends on how much labor the economy has allocated to research.

A two-sector model, part 1

This model is similar to the basic *AK* model in that capital exhibits constant returns to scale since capital includes both physical capital and human capital (knowledge).

DISCUSSION QUESTION The merits of raising *u*

Questions:

In what ways would raising ***u*** (that is, devoting more labor to research) benefit the economy?

What are the costs of raising ***u***?

DISCUSSION QUESTION The merits of raising *u*

Increasing u means devoting more resources to R&D.

In the short run, output of goods and services per capita will fall. However, **the pace of technological progress will rise**, so growth will speed up, and output per capita will eventually be higher than it would have been at the initial value of u.

Of course, if we increase u to its maximum possible value, 1, then no goods and services would be produced.

DISCUSSION QUESTION The merits of raising *u*

This tradeoff suggests that there must be some kind of golden rule for u -a value of u that maximizes well-being per capita in the steady state.

At low enough values of u (values lower than this golden rule level), increases in u would, on balance, benefit the economy.

At high enough values, increases in u would likely harm the economy.

Facts about R&D

1. Much research is done by firms seeking profits.
2. Firms profit from research:

   Patents create a stream of monopoly profits.

   There is extra profit in being first on the market with a new product.
3. Innovation produces externalities that reduce the cost of subsequent innovation.

Much of the new endogenous growth theory attempts to incorporate these facts into models to better understand technological progress.

Is the private sector doing enough R&D?

- The existence of positive externalities in the creation of knowledge suggests that the private sector is not doing enough R&D.

- But there is much duplication of R&D effort among competing firms.

- Thus, many believe the government should encourage R&D.

Economic growth as "creative destruction"

- Schumpeter (1942) coined term "creative destruction" to describe displacements resulting from technological progress:
  - The introduction of a new product is good for consumers but often bad for incumbent producers, who may be forced out of the market.
- Examples:
  - Luddites (1811–1812) destroyed machines that displaced skilled mill workers in England.
  - Walmart displaces many small retail stores.

Economic growth as “creative destruction”

Focus:

Joseph Schumpeter proposed that economic growth occurs through a process known as “creative destruction.”

His theory viewed **new firms as continually entering the marketplace**, having monopoly power over their innovations, and reaping the profits that induced the firms to enter the market in the first place.

Consumers benefit from the greater choice of products, **but existing firms now face competition**. Some of these established firms cannot compete, and they go out of business.

This process continues over time, with new firms entering and established firms exiting—a process of “creative destruction.”