
Ideas and Growth: Romer Model

EC502 Macroeconomics
Topic 3

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What Sustains Long-run Growth?

- How do countries sustain long-run growth? Why is the US constantly growing at 2%?
- Solow model: capital accumulation cannot sustain growth in the long run
- Two reasons:
 1. Decreasing returns to scale in capital
⇒ countries accumulate less and less capital as they grow
 2. Constant returns to scale in overall production
⇒ more population do not lead to higher *per capita* income
- We will attack 2

Romer Model

Investment in New Ideas

- Restaurants can use their labor (and capital) to produce a meal
- ... Or to invent a new recipe to increase its revenue

$$Y = F(A, L, K) = A^\beta L^{1-\alpha} K^\alpha$$

- More generally, investment in new ideas \Rightarrow higher productivity
- With investment in new ideas, F features increasing returns to scale (IRS):

$$F(2A, 2L, 2K) > 2F(A, L, K)$$

even though F is constant returns to scale in (K, L)

Physical Inputs vs. Ideas

- Replication argument:
 - Doubling physical inputs (K, L) should double the output
- Put differently, we really need to double physical inputs in order to double output
- But..., we don't need to double ideas (A)
- What's the difference?
 - Physical inputs are rival
 - Ideas are non-rival
- Non-rivalry of A provides a natural foundation for IRS in (A, K, L)
- Romer's favorite example: oral rehydration therapy

Oral Rehydration Therapy



Romer Model

- For simplicity, suppose there is no capital ($\alpha = 0$)

$$Y_t = A_t^\beta L_t$$

- Total population grows at rate n :

$$N_{t+1} = (1 + n)N_t, \quad n > 0$$

- Fraction $1 - s^R$ of population engages in the production of goods:

$$L_t = (1 - s^R)N_t$$

- Fraction s^R of population engages in the production of ideas (R&D):

$$A_{t+1} = A_t + s^R N_t$$

Increasing Returns to Scale of Ideas

- The key assumption is, again, increasing returns to scale
- Per-capita output:

$$\frac{Y_t}{N_t} = (1 - s^R) A_t^\beta$$

- Per-capita output is increasing in the **total** stock of knowledge
- **Not** on knowledge per capita.
- Reflects the fact that knowledge is non-rival

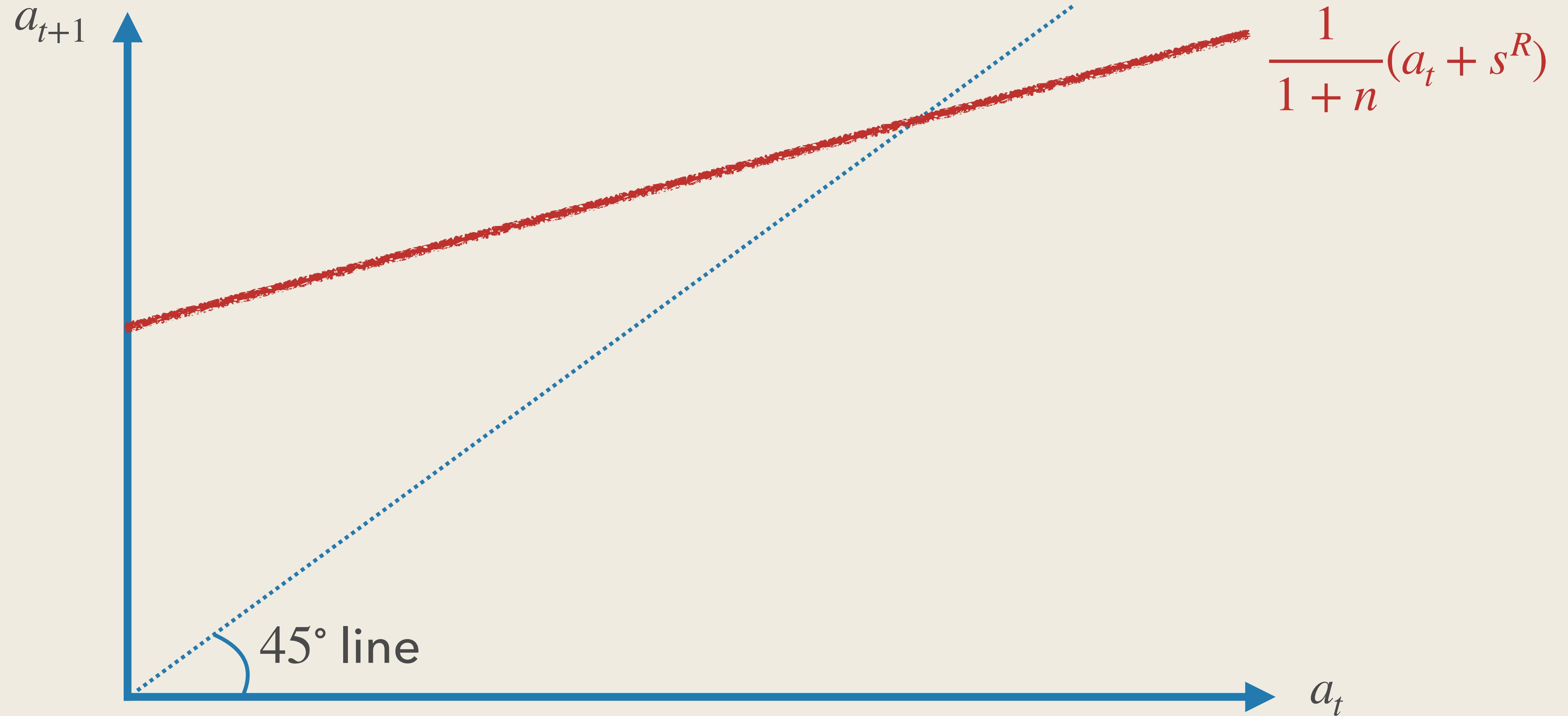
Knowledge Accumulation Process

- Define knowledge per capita: $a_t = A_t/N_t$
- Divide the knowledge accumulation equation by N_t to rewrite it as

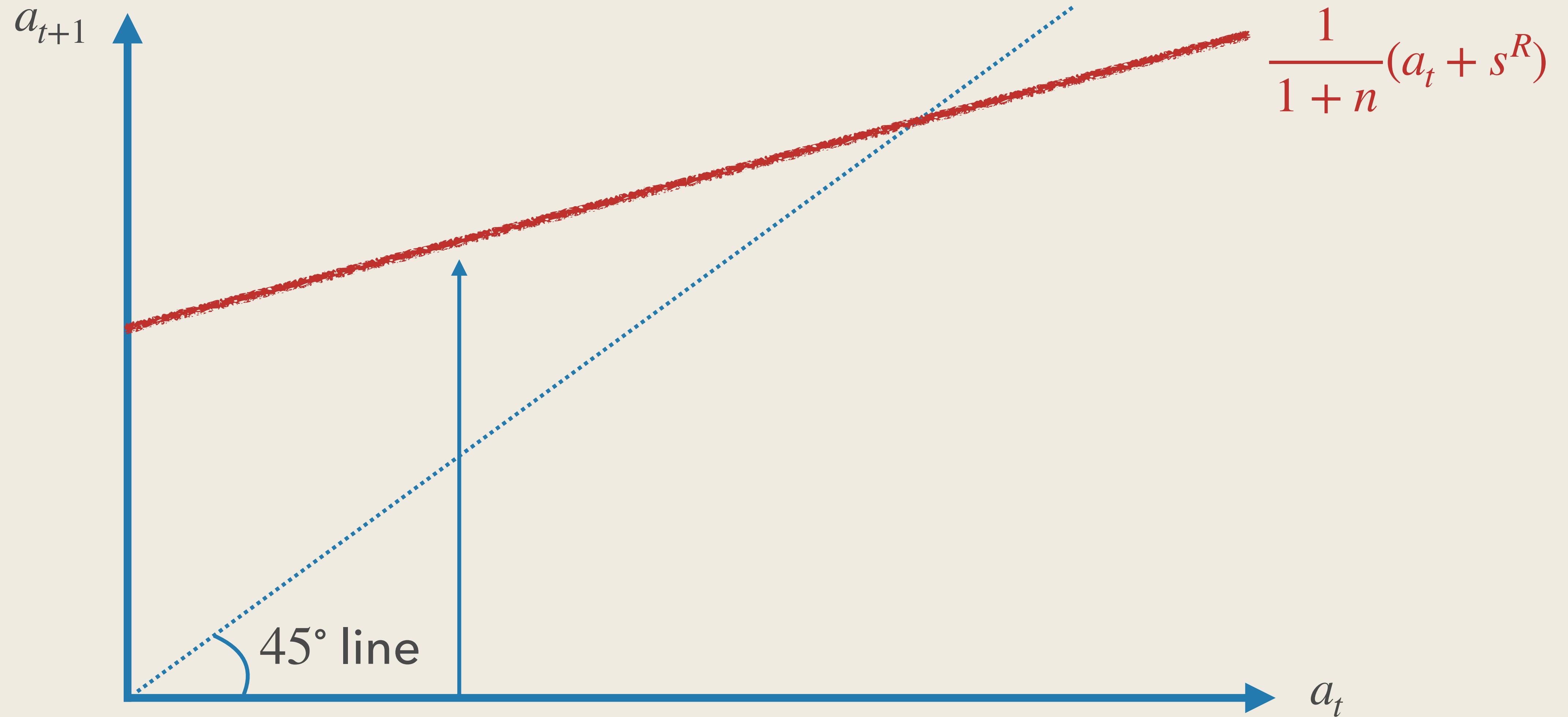
$$a_{t+1} = \frac{1}{1+n}(a_t + s^R)$$

- Given a_0 , the above equation determines $a_1, a_2, \dots,$

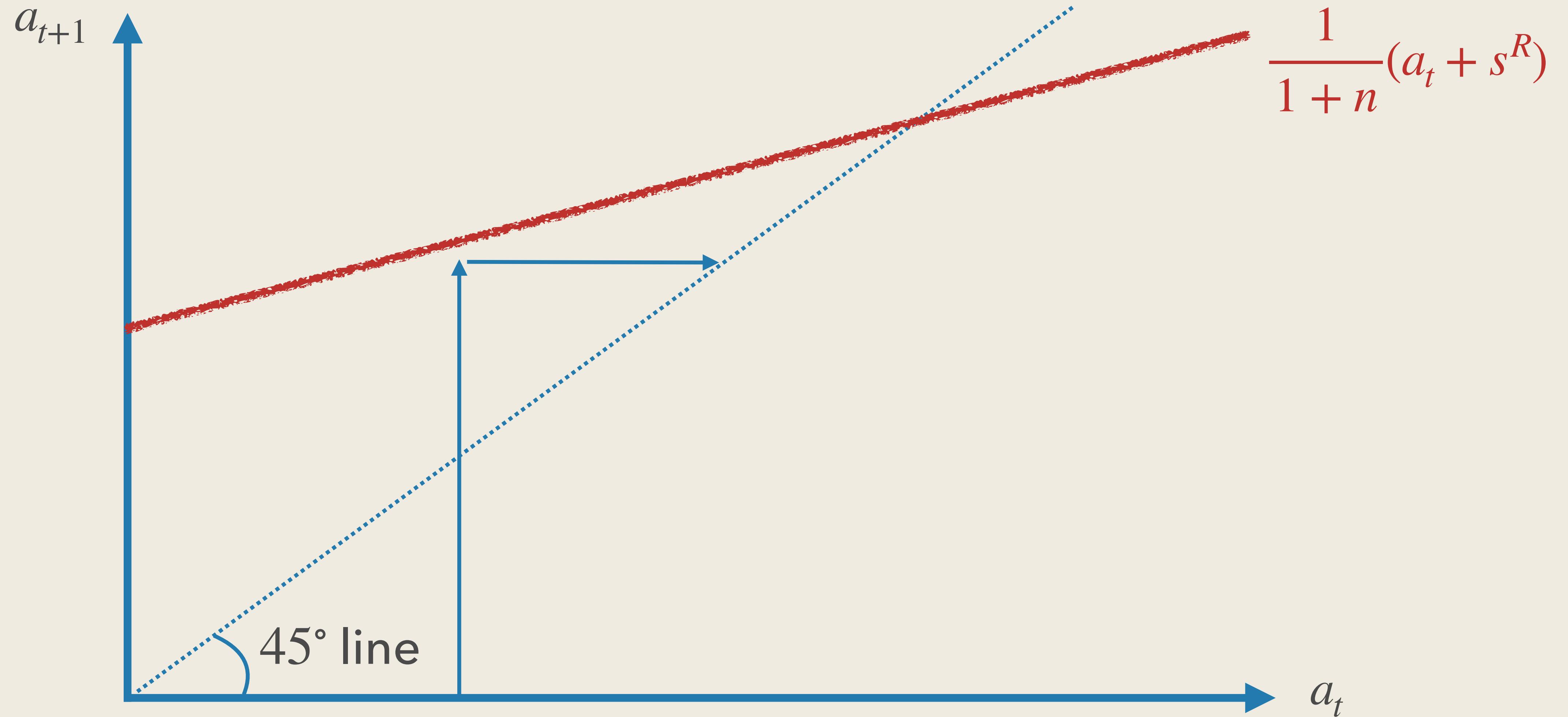
Evolution of Knowledge Stock



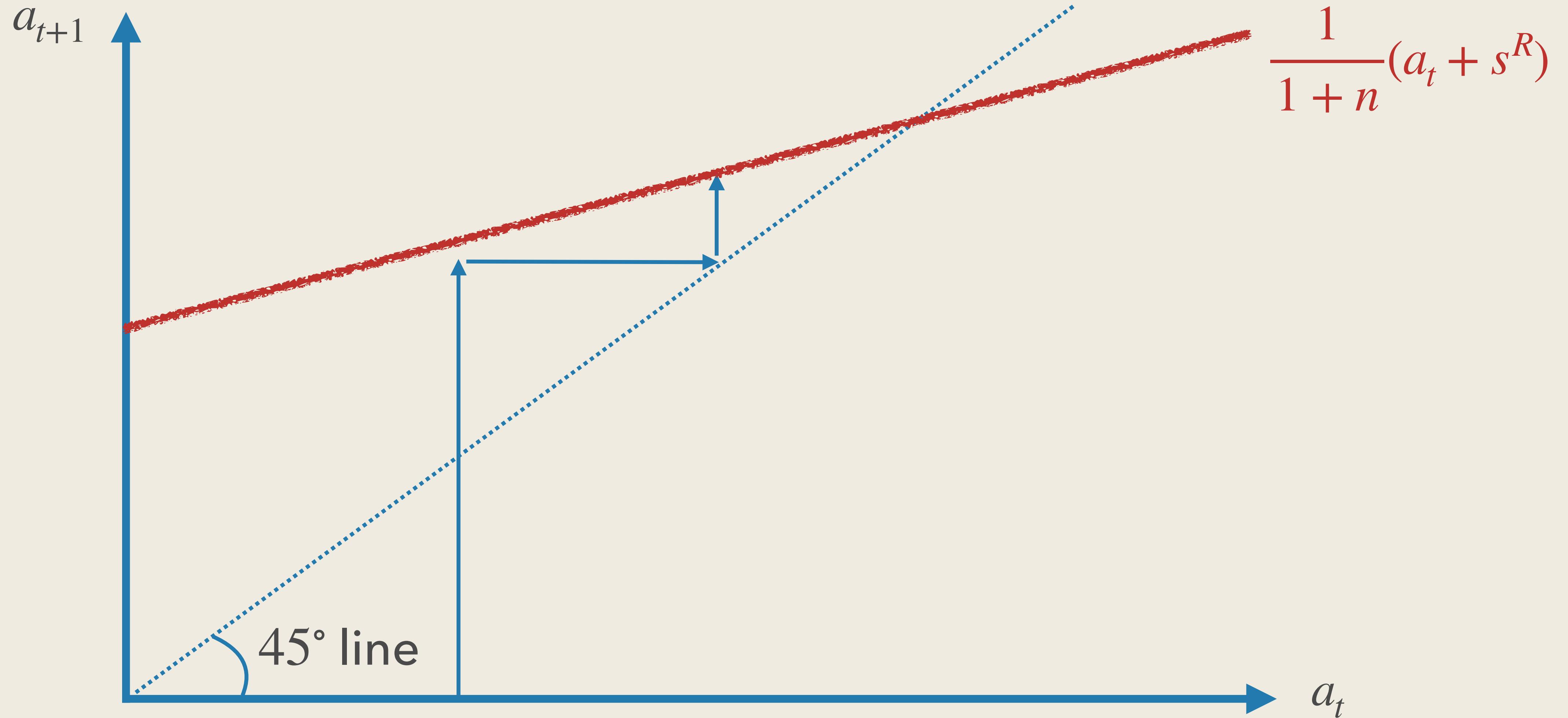
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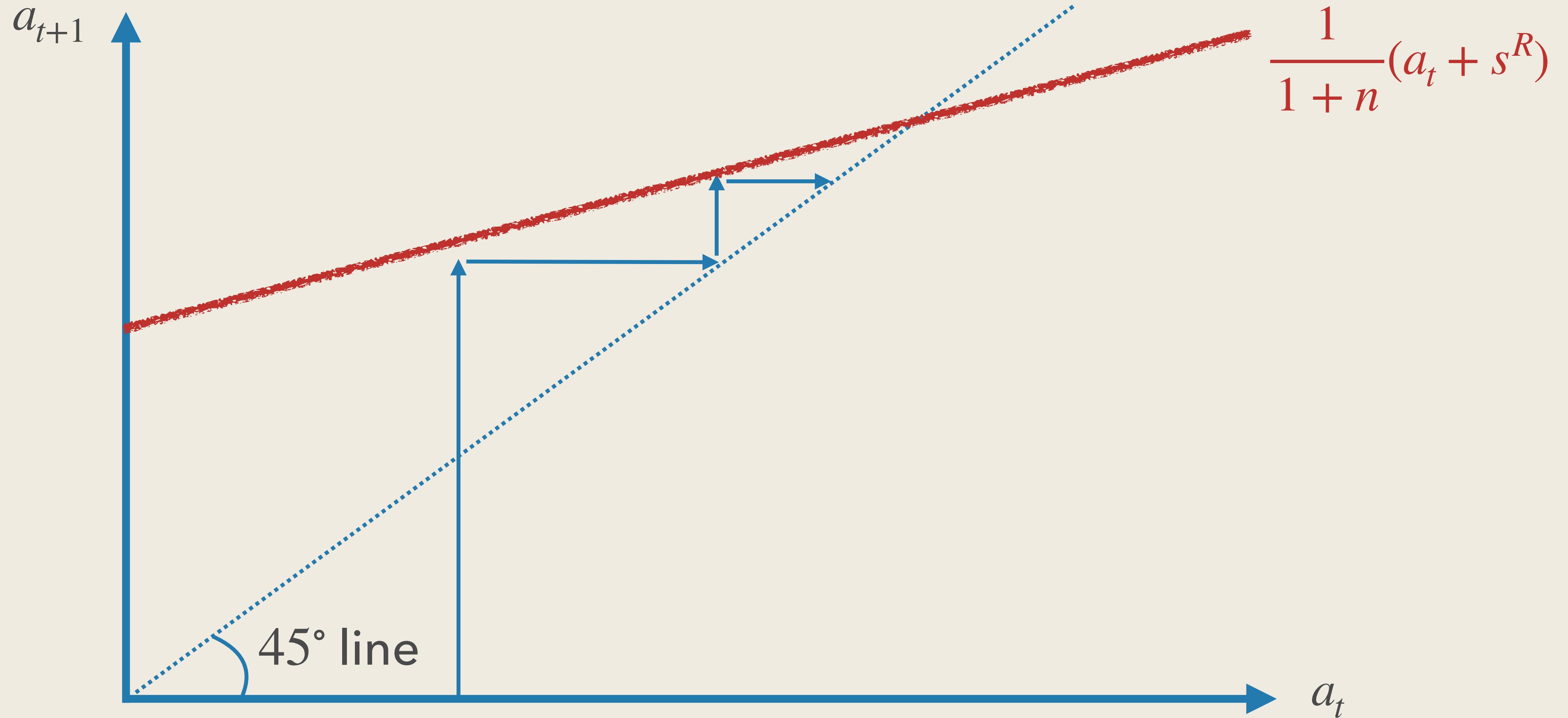
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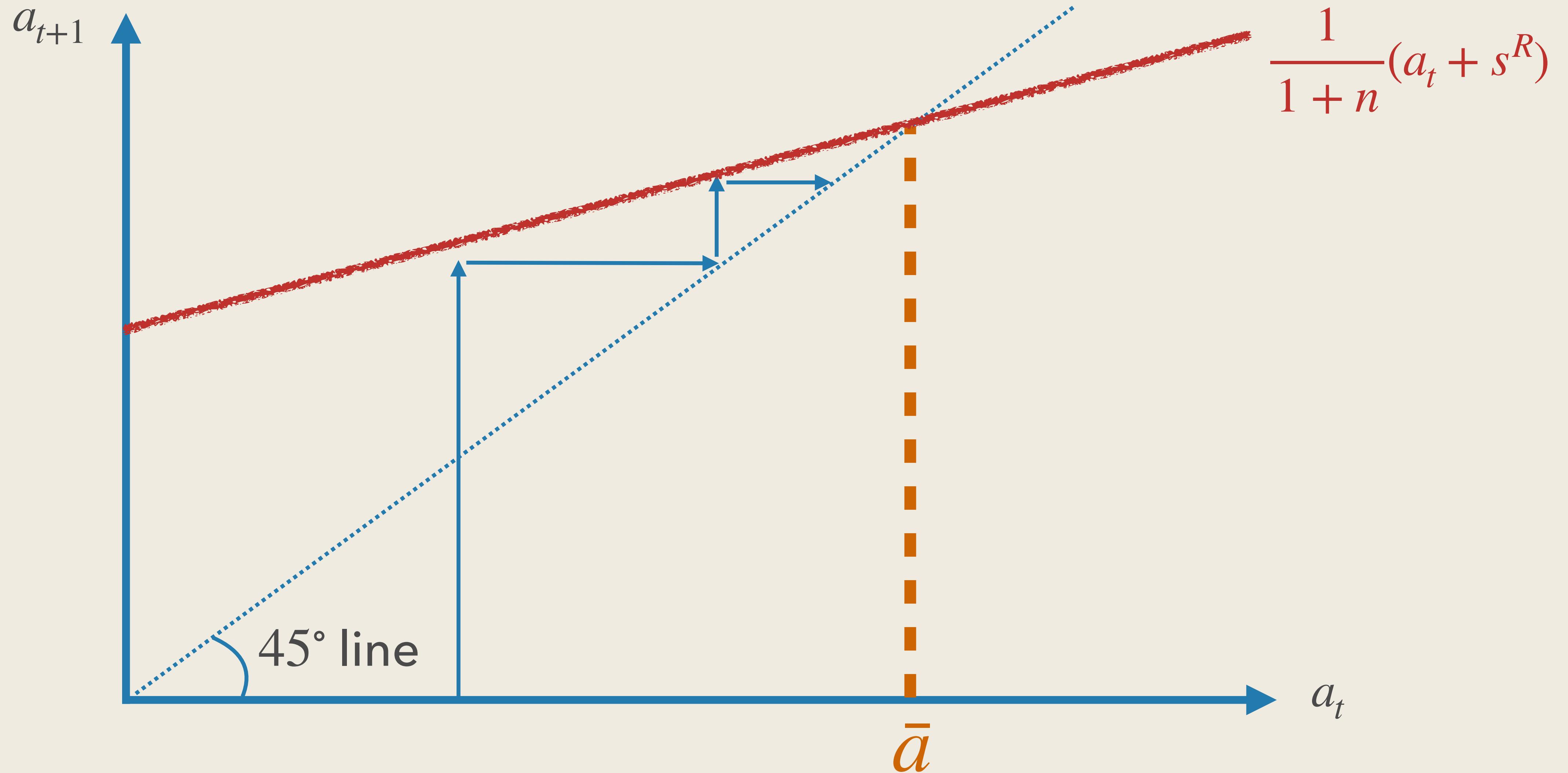
Evolution of Knowledge Stock



Evolution of Knowledge Stock



Evolution of Knowledge Stock



Long-run Growth in Knowledge

- In the long-run (**steady state**), the knowledge per capita converges to \bar{a} that satisfies

$$\bar{a} = \frac{1}{1+n}(\bar{a} + s^R)$$

- Solving for \bar{a} gives $\bar{a} = s^R/n$.
- More importantly, \bar{a} constant $\Rightarrow A_t = \bar{a}N_t \Rightarrow A_t$ keeps growing at the speed N_t grows

$$1 + g_A = \frac{A_{t+1}}{A_t} = \frac{N_{t+1}}{N_t} = 1 + n$$

- Growth rate of knowledge = growth rate of researchers = population growth

Long-run Growth in GDP per capita!

- Recall per-capita output is $Y_t/N_t = (1 - s^R)A_t^\beta$
- The growth rate of per-capita output is

$$g_{Y/N} \approx \log(Y_{t+1}/N_{t+1}) - \log(Y_t/N_t) = \log A_{t+1}^\beta - \log A_t^\beta = \beta \log(1 + n)$$

- When n is small,

$$g_{Y/N} \approx \beta n$$

- Per-capita GDP growth = importance of knowledge (β) \times population growth (n)
- A country sustains long-run growth in GDP per capita!

Where We are Going

- Appendix combines the Romer and Solow models
 - **Key insight:** growth in $A \Rightarrow$ growth in k even in the long-run
- Now we confront the predictions from Romer model with data:
 1. Is the process of idea creation consistent with data?
 2. Does a larger population size lead to economic growth?
 3. What happens if population growth is negative?

1. Are Ideas Getting Harder to Find? – Bloom, Jones, Van Reenen, Webb (2020)

Are Ideas Getting Harder to Find?

$$\frac{A_{t+1} - A_t}{A_t} = \frac{1}{A_t} \times s^R N_t$$

Are Ideas Getting Harder to Find?

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Growth rate of knowledge

Are Ideas Getting Harder to Find?

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Growth rate of knowledge

Research productivity

Are Ideas Getting Harder to Find?

$$\frac{A_{t+1} - A_t}{A_t} = \frac{1}{A_t} \times S^R N_t$$

Growth rate of knowledge Research productivity Number of researchers

The equation illustrates the relationship between the growth rate of knowledge ($A_{t+1} - A_t$), research productivity ($\frac{1}{A_t}$), and the number of researchers ($S^R N_t$). The terms $A_{t+1} - A_t$ and $\frac{1}{A_t}$ are circled in red, while $S^R N_t$ is circled in green. Below the equation, the labels 'Growth rate of knowledge', 'Research productivity', and 'Number of researchers' are aligned with their respective circled terms.

Are Ideas Getting Harder to Find?

$$\frac{A_{t+1} - A_t}{A_t} = \frac{1}{A_t} \times s^{RN}_t$$

- The Romer model strongly ties TFP growth to the growth of researchers
 - If the number of researchers does not grow, no economic growth
 - In order to sustain TFP growth, we need more and more researchers
 - Research productivity keeps falling over time
 - This means ideas get harder and harder to find as a country grows

Original Romer Model

- Romer (1990) originally developed a slightly different version of the model

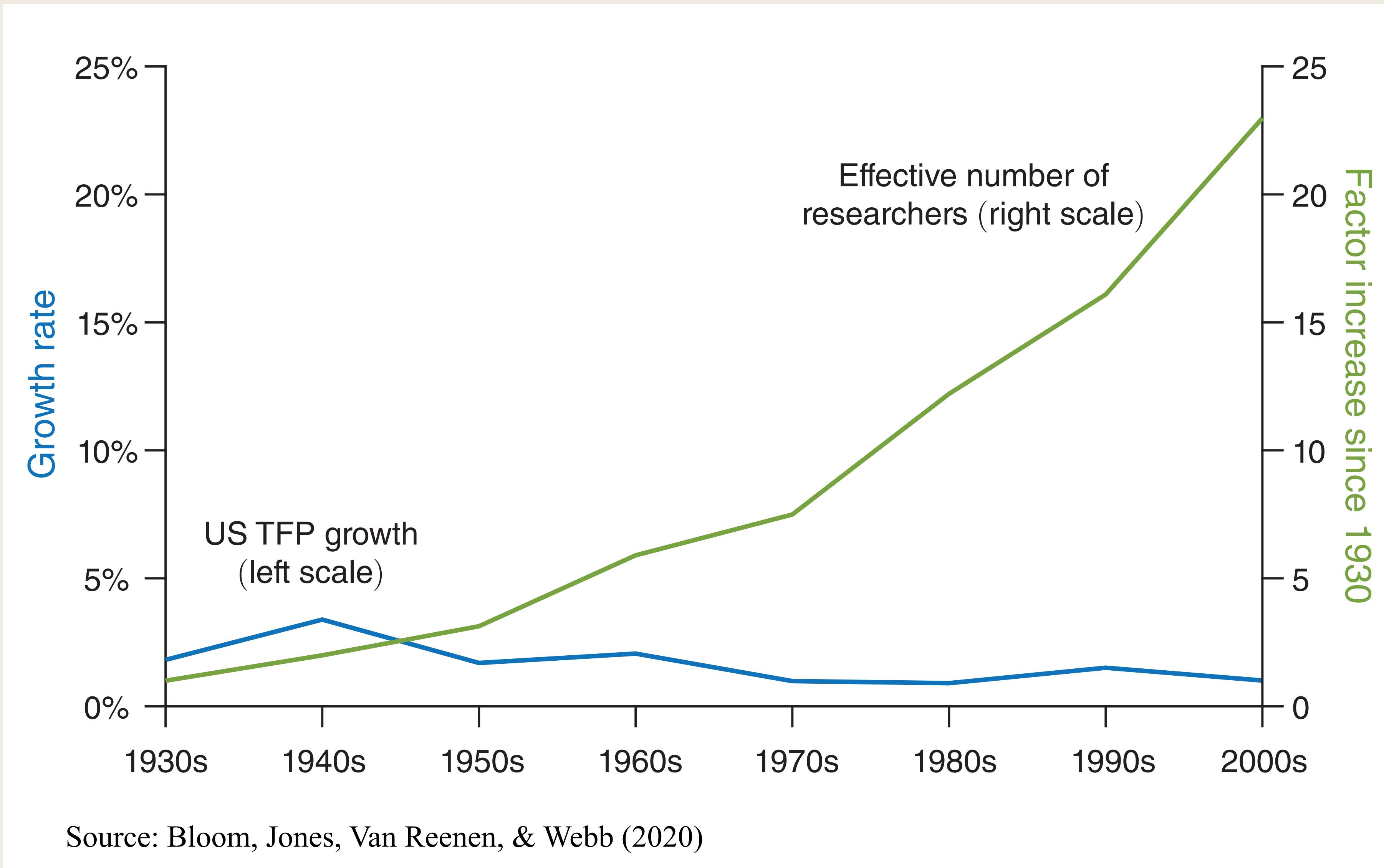
$$A_{t+1} = A_t + s^R N_t \times A_t$$

- This captures the notion of “standing on the shoulders of giants”
- In this case,

$$\frac{A_{t+1} - A_t}{A_t} = s^R N_t$$

- Research productivity remains constant with economic growth
⇒ ideas don't get harder to find
- Who's right?

Researchers and TFP Growth: Aggregate Data



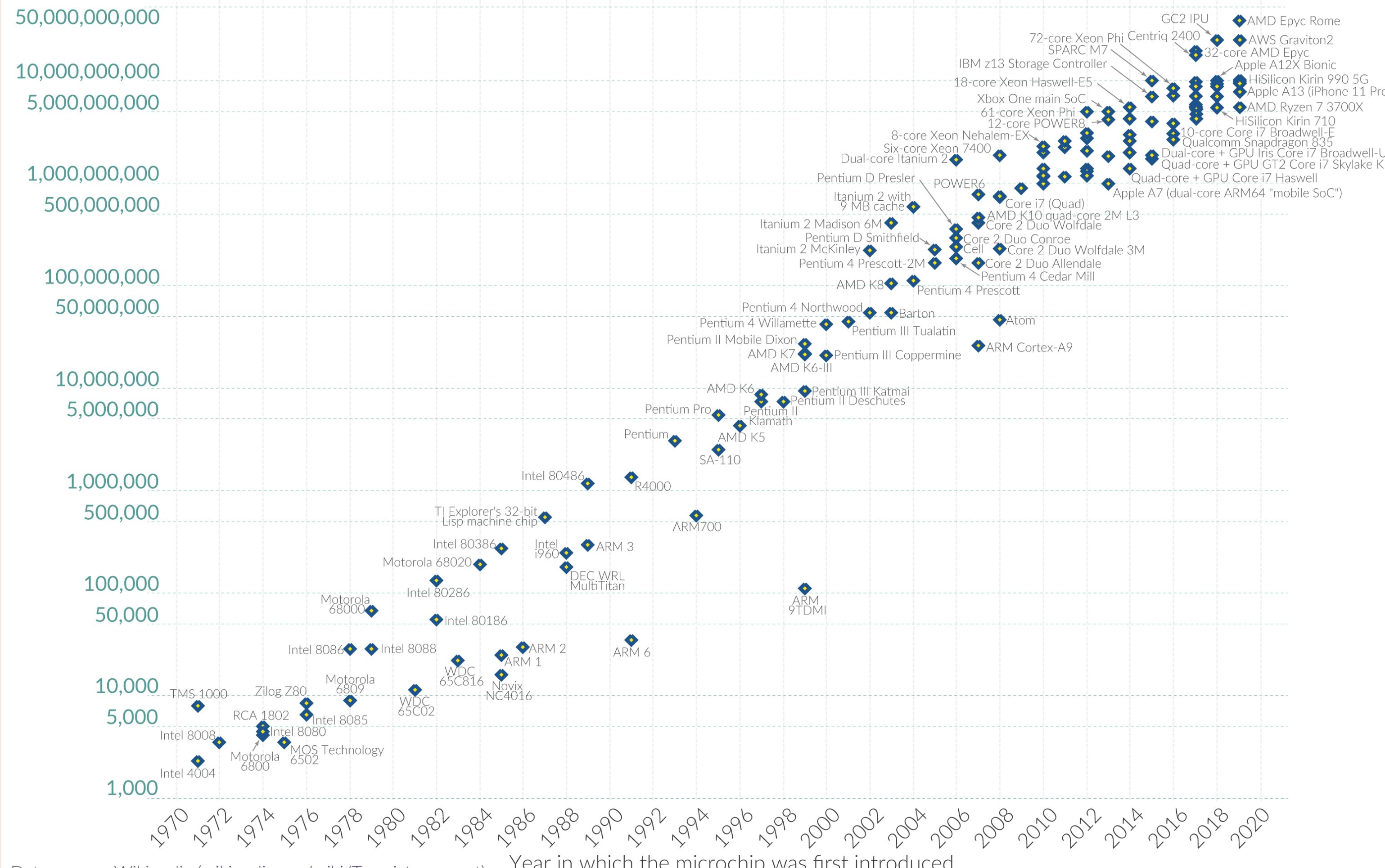
Moore's Law

Moore's Law: The number of transistors on microchips doubles every two years

Our World
in Data

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.

Transistor count

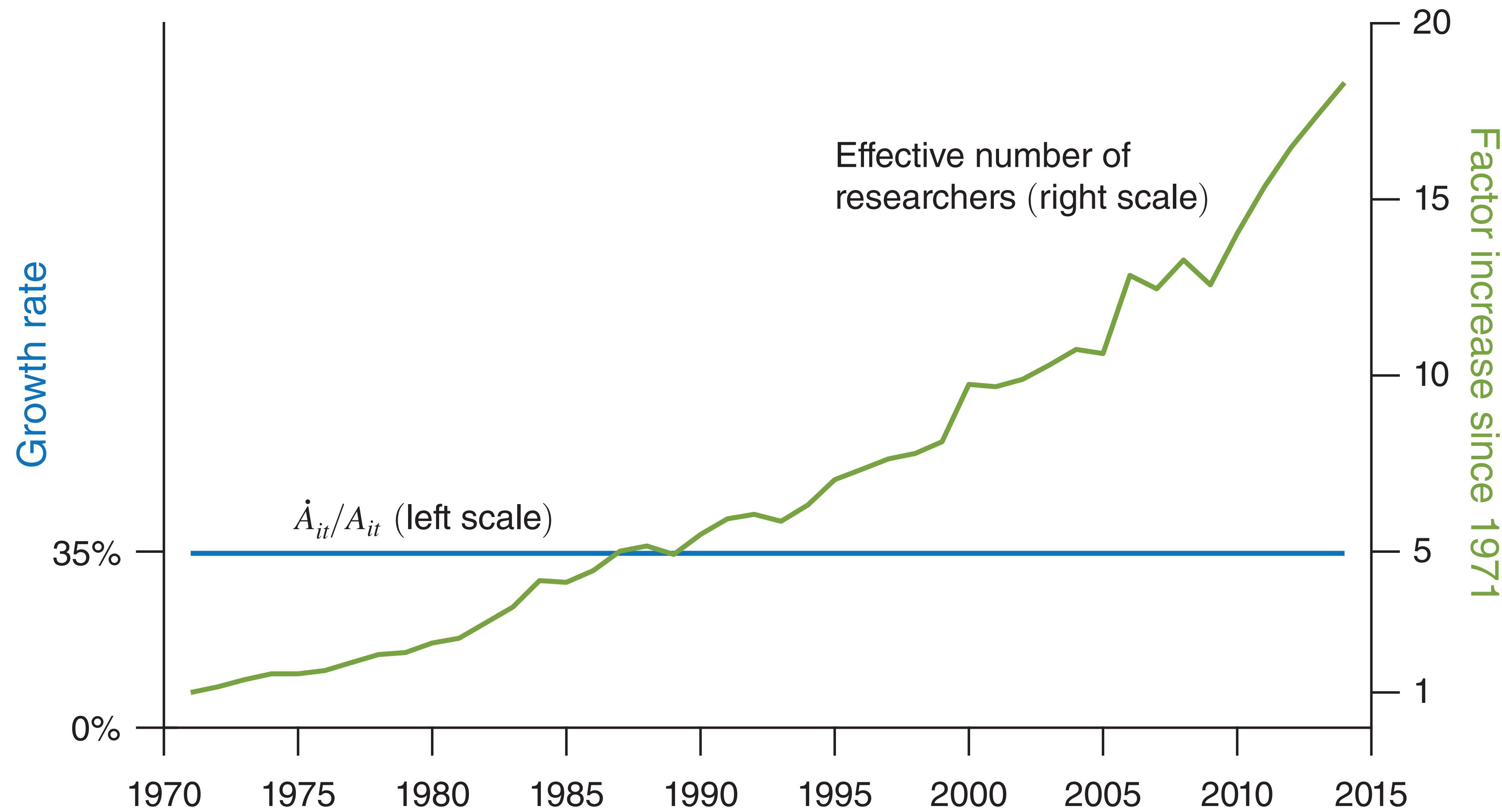


Data source: Wikipedia ([wikipedia.org/w/index.php?title=Transistor_count&oldid=913111000](https://en.wikipedia.org/w/index.php?title=Transistor_count&oldid=913111000))

OurWorldInData.org – Research and data to make progress against the world's largest problems.

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Researchers and TFP Growth: Moore's Law



Source: Bloom, Jones, Van Reenen, & Webb (2020)

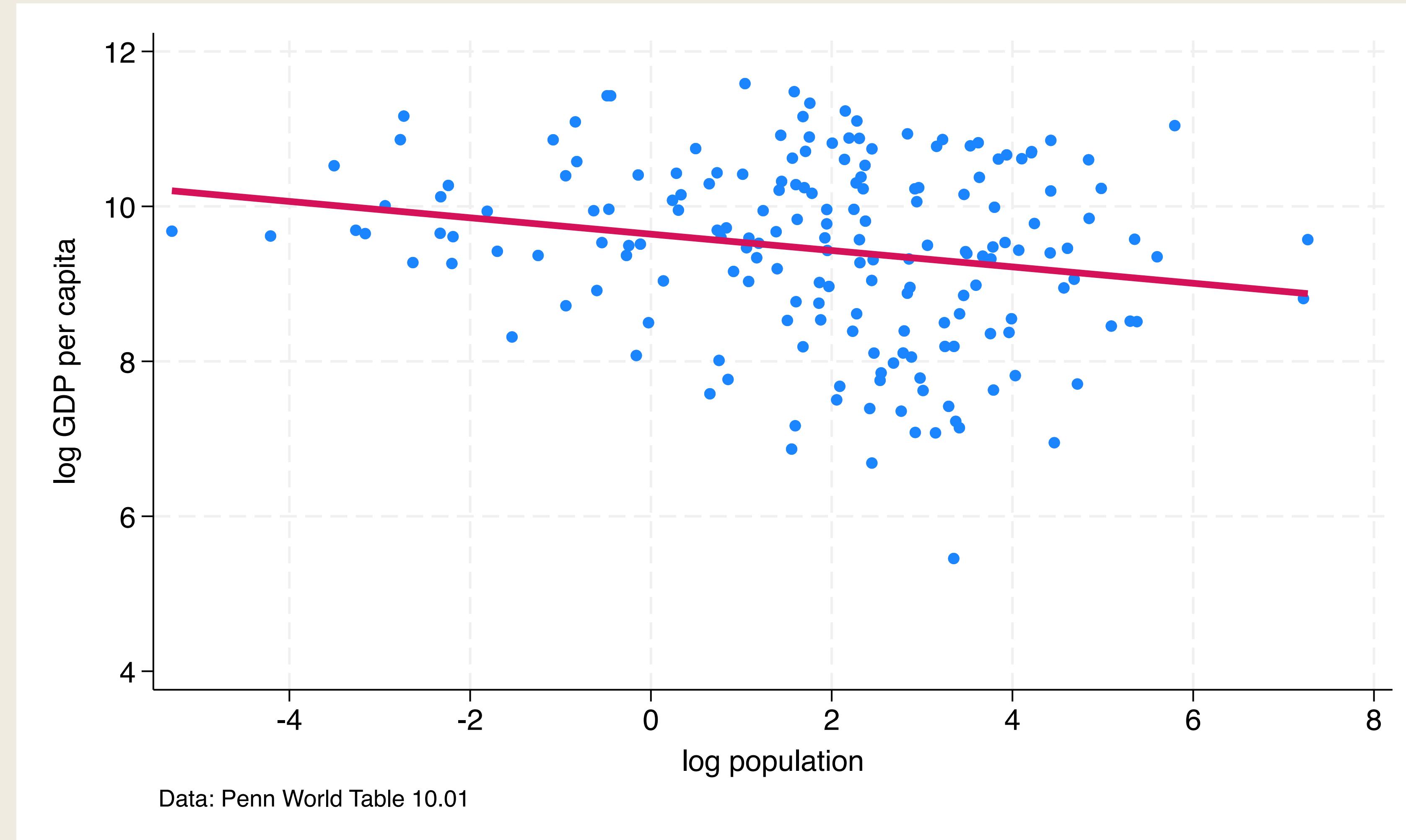
2. Does a Larger Population Size Raise Per-capita Income? – Peters (2022)

Population and Productivity

- Romer model strongly ties GDP to population
 - GDP grows faster if the population grows faster, $g_{Y/N} = \beta n$
 - GDP level is higher if the population is larger, $Y_t/N_t = A_t^\beta(1 - s^R)$ and $A_t = s^R N_t/n$
- An increase in population raises productivity and income per capita
... holding everything else constant
- Do we have any evidence?

Naive Idea

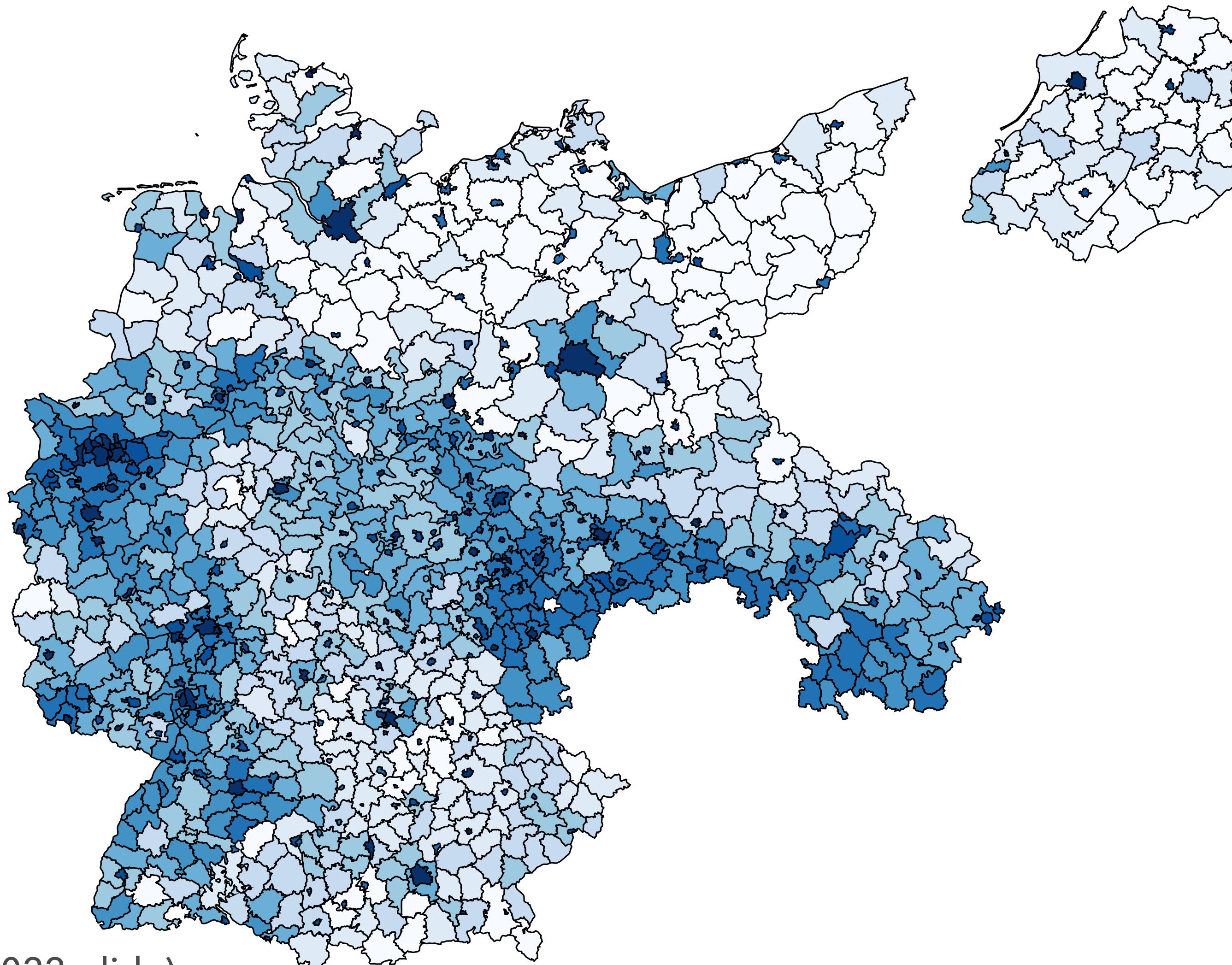
- What if we see the relationship between Y/N and N using cross-country data?



How Do We Isolate Population Size?

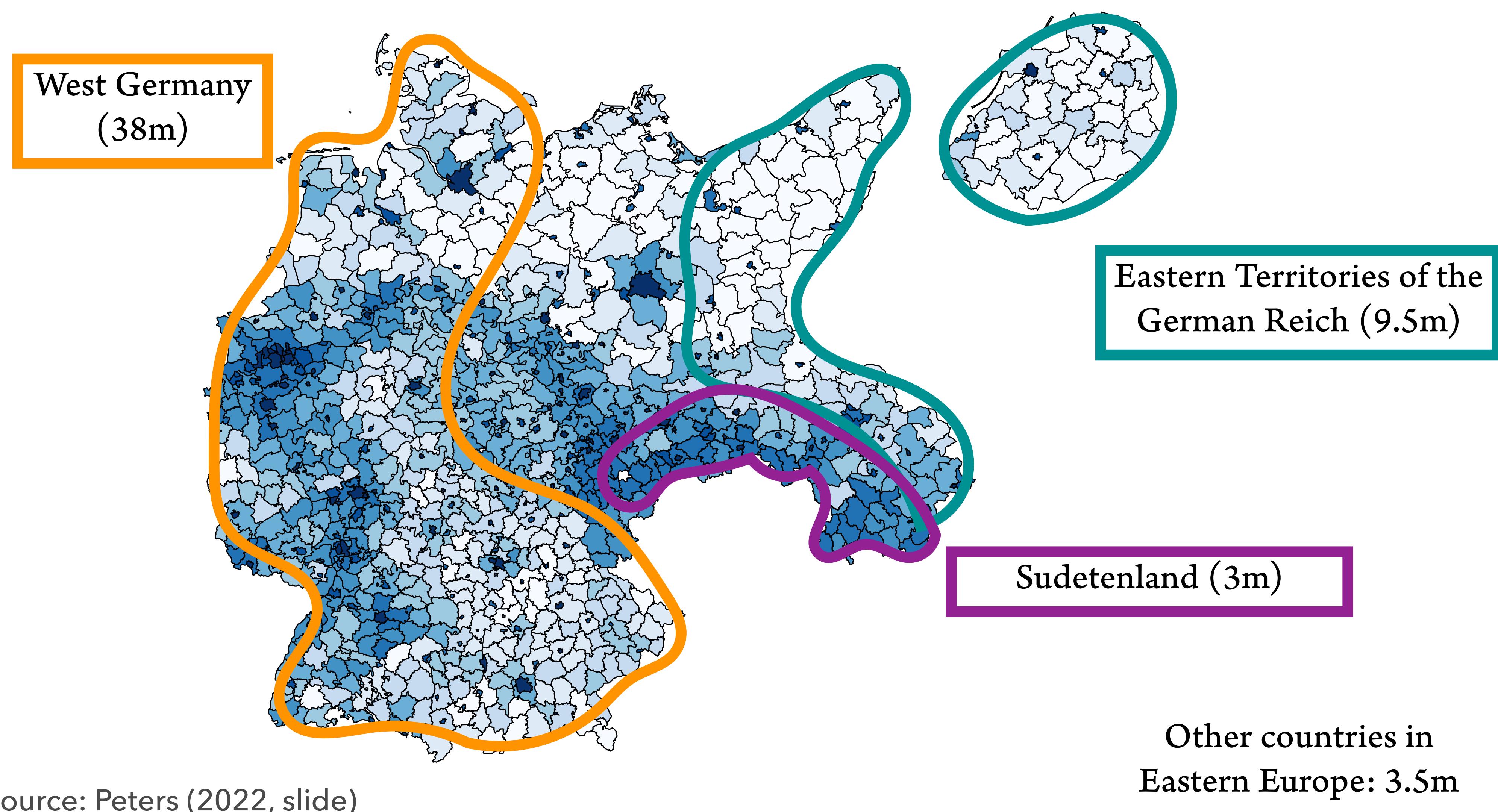
- The ideal thought experiment is that we **only** change the population size
- Countries differ not only in population size but a lot of other things...
- Peters (2022):
Population expulsions in Germany after WW2 provide an ideal experiment

Germany in 1939



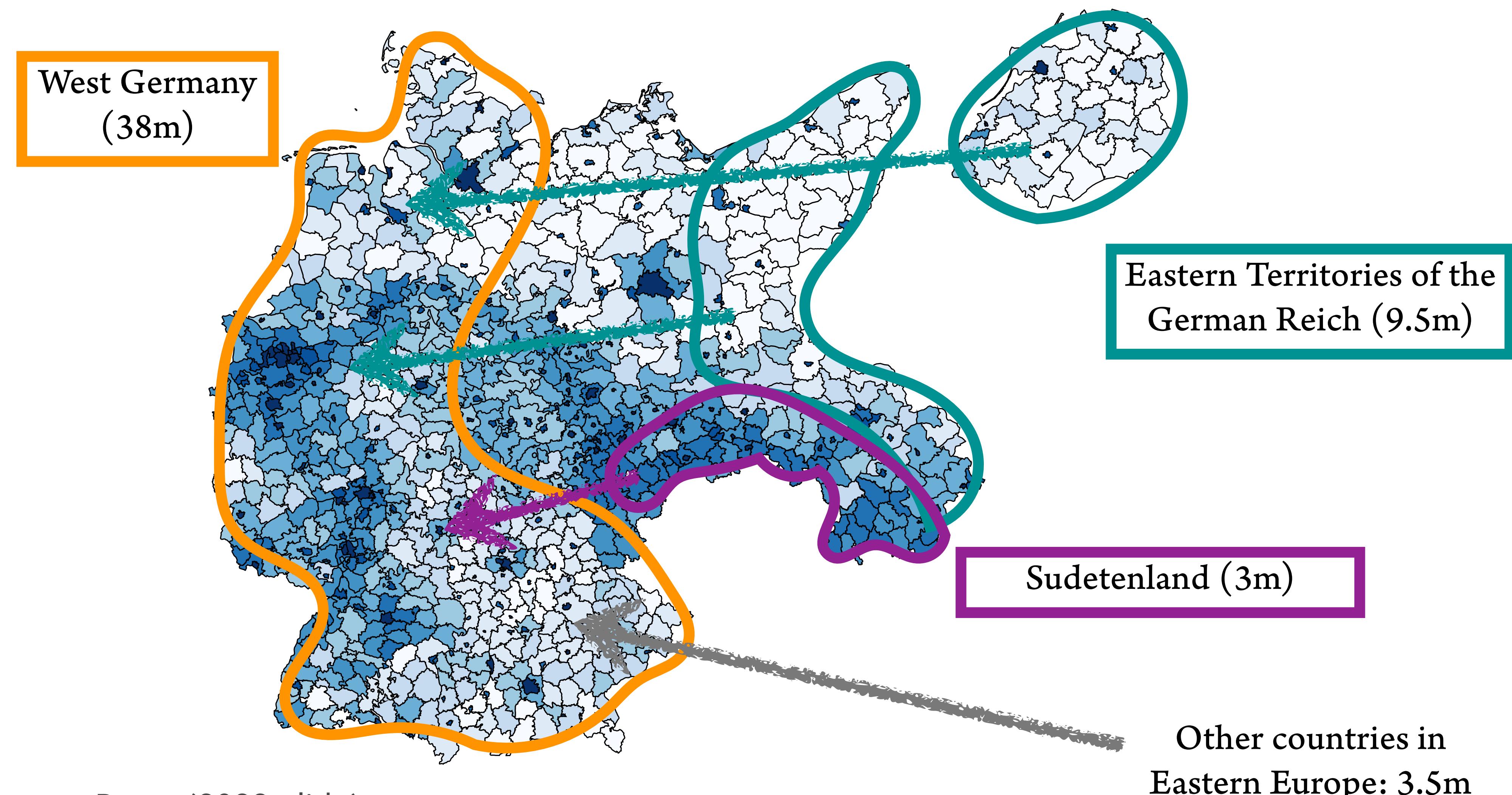
Source: Peters (2022, slide)

Distribution of German Ethnicity



Source: Peters (2022, slide)

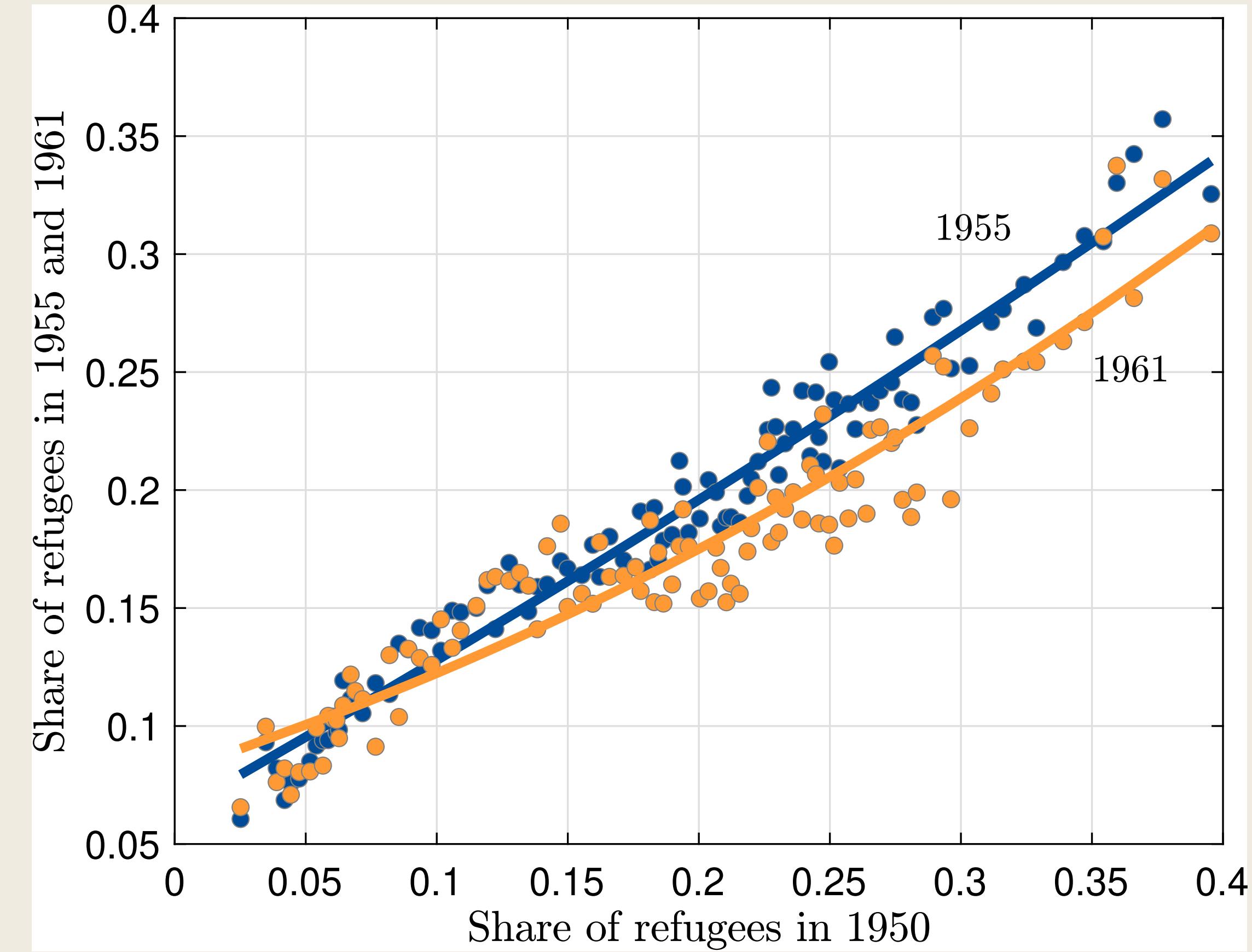
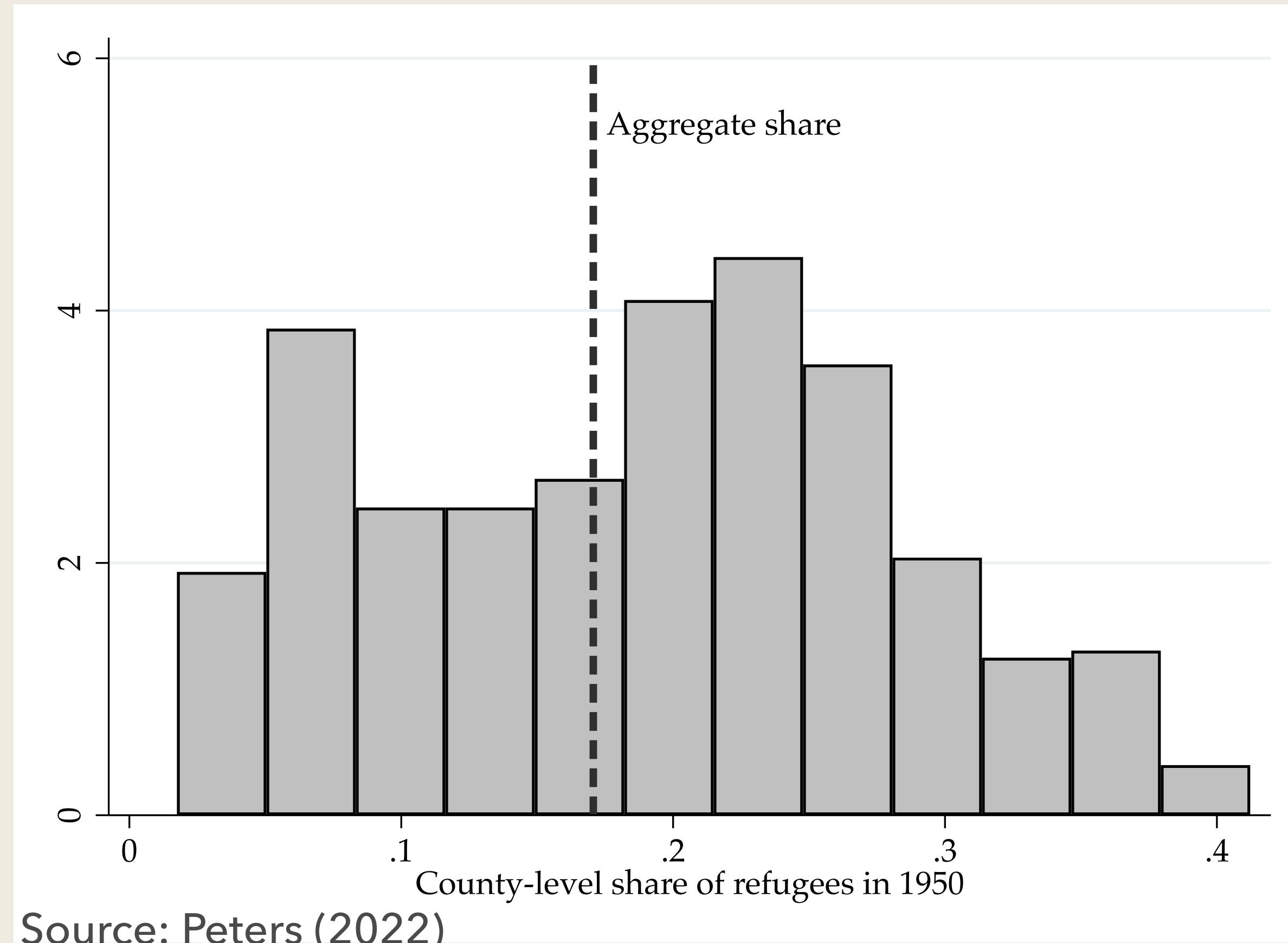
The Expulsions: 1945 - 1949



The Expulsions: 1945 - 1949

- Phase 1 (Nov 44 - Oct 45): **2m**
 - Expulsions / flight during the war
 - “Wild expulsions” after armistice
- Phase 2 (Jan 46 - July 1949): **6m**
 - Organized population transfers (Potsdam conference)
- West German population increased by 20% between 1939 and 1950

Heterogeneity and Persistence of Settlement



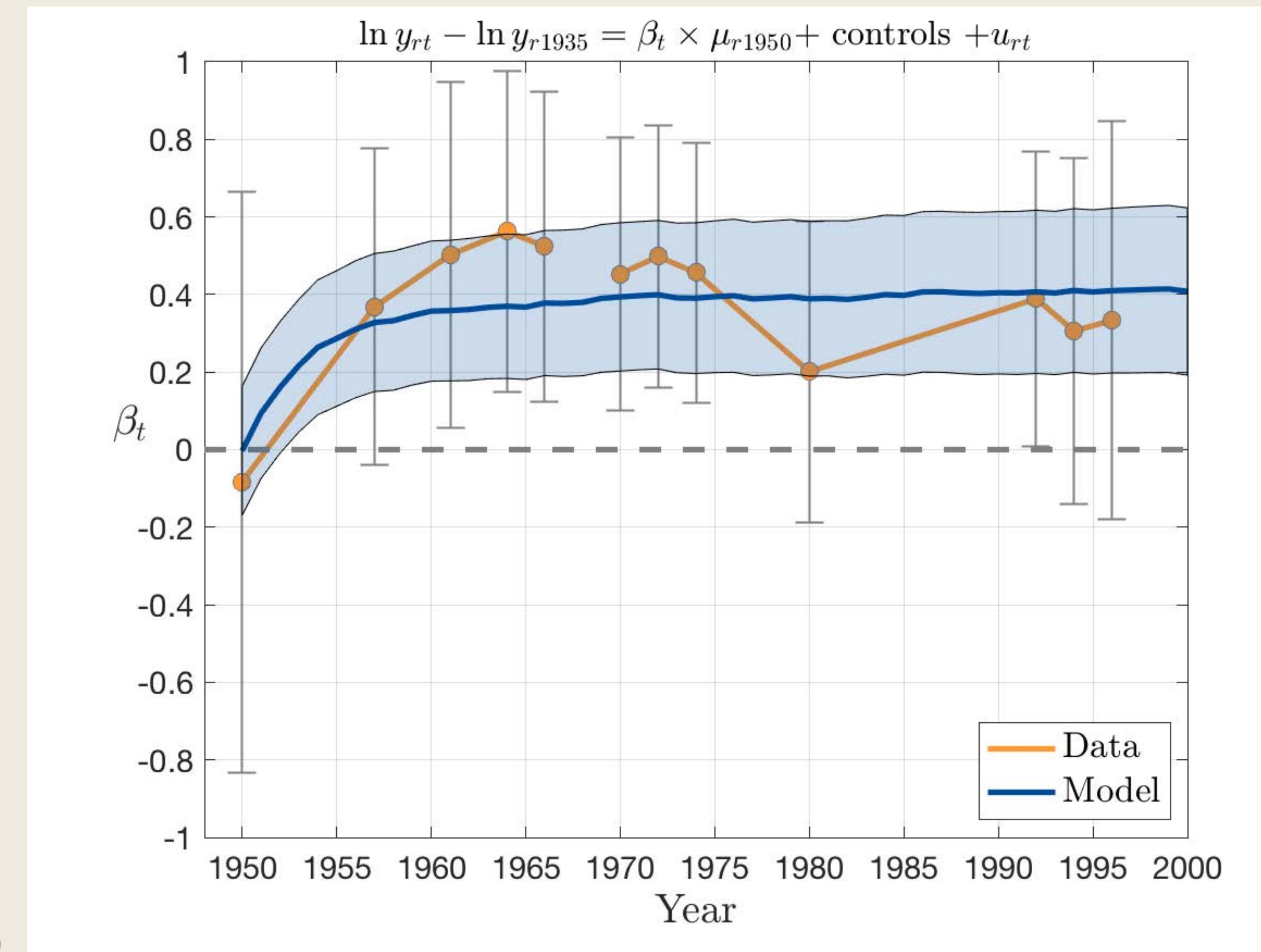
- The allocation of initial settlement of refugees

1. varied dramatically across counties
2. had a persistent effect

Question

- Allocation of refugees is mostly based on housing and food availability
- Ask:
Did a country receiving a lot of refugees grow more
... compared to a country receiving no (or few) refugees?

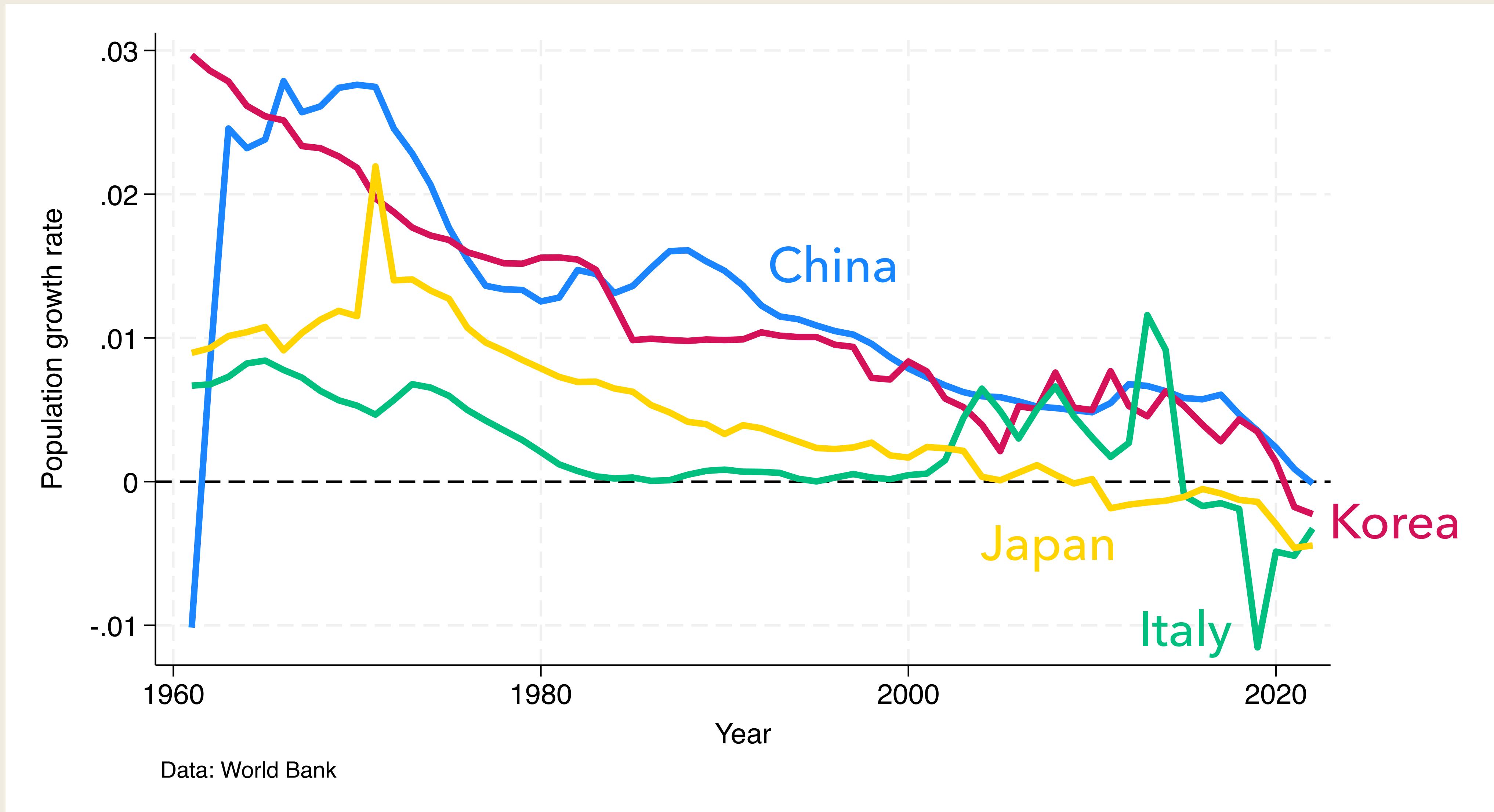
GDP Per Capita Increases with More Refugees



Source: Peters (2022, slide)

3. End of Economic Growth? – Jones (2022)

Negative Population Growth



Future of Economic Growth

- Romer model predicts population growth is the engine of long-run growth
- Many countries already have negative population growth
... and many others are predicted to be so in the next decades
- What do they mean for economic growth?

Negative Population Growth in Romer Model

- Let us go back to Romer model in the very beginning

$$A_{t+1} = A_t + s^R N_t \quad (a)$$

- Population has a negative growth rate:

$$N_{t+1} = (1 - \eta)N_t, \quad \eta > 0 \quad (b)$$

- Iterating (b),

$$N_t = (1 - \eta)^t N_0 \quad (c)$$

- Plugging (b) into (c),

$$A_{t+1} = A_t + s^R (1 - \eta)^t N_0 \quad (d)$$

What Happens in the Long-run?

- Iterating (d),

$$A_{t+1} = A_0 + s^R N_0 \sum_{s=0}^t (1 - \eta)^s$$

- In the long-run (as $t \rightarrow \infty$),

$$A_t \rightarrow A = A_0 + \frac{s^R}{\eta} N_0$$

- Since $Y_t = A_t^\beta L_t$ and $L_t = (1 - s^R)N_t$, GDP per capita is

$$Y_t/N_t = A_t^\beta (1 - s^R) \rightarrow A^\beta (1 - s^R) \quad \text{as } t \rightarrow \infty$$

Empty Planet?

With negative population growth...

1. Knowledge stock converges to a constant
2. GDP per capita converges to a constant as well
⇒ no economic growth
3. Population keeps declining, so total GDP keeps declining and converges to zero

Appendix: Combining Romer and Solow Model

Solow + Romer

- Now we put back capital

$$Y_t = A_t^\beta L_t^{1-\alpha} K_t^\alpha$$

$$N_{t+1} = (1+n)N_t$$

$$L_t = (1 - s^R)N_t$$

$$A_{t+1} = A_t + s^R N_t$$

$$K_{t+1} = K_t(1 - \delta) + s Y_t$$

Solow + Romer

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Convenient Normalization

- Educated trick: we normalize all variables with $A_t^{\frac{\beta}{1-\alpha}}N_t$
 - This makes all variables stationary, as we will see
- Define $y_t = Y_t/(A_t^{\frac{\beta}{1-\alpha}}N_t)$ and $k_t = K_t/(A_t^{\frac{\beta}{1-\alpha}}N_t)$. Then

$$y_t = (1 - s_R)^{1-\alpha} k_t^\alpha \tag{1}$$

$$k_{t+1} = \frac{1}{(1 + g_{At})^{\frac{\beta}{1-\alpha}}} \frac{1}{(1 + n)} [k_t(1 - \delta) + s(1 - s_R)^{1-\alpha} k_t^\alpha] \tag{2}$$

$$A_{t+1}/N_{t+1} = \frac{1}{1 + n} [A_t/N_t + s^R] \tag{3}$$

where $1 + g_{At} = A_{t+1}/A_t$

Derivations of (1)

- Production function:

$$Y_t = A_t^\beta L_t^{1-\alpha} K_t^\alpha$$

- Divide both sides by $A_t^{\frac{\beta}{1-\alpha}} N_t$:

$$\begin{aligned}\frac{Y_t}{A_t^{\frac{\beta}{1-\alpha}} N_t} &= \frac{A_t^\beta}{A_t^{\frac{\beta}{1-\alpha}}} \left(\frac{L_t}{N_t} \right)^{1-\alpha} \left(\frac{K_t}{N_t} \right)^\alpha \\ &= \frac{1}{A_t^{\frac{\beta\alpha}{1-\alpha}}} (1 - s^R)^{1-\alpha} \left(\frac{K_t}{N_t} \right)^\alpha \\ &= (1 - s^R)^{1-\alpha} \left(\frac{K_t}{A_t^{\frac{\beta}{1-\alpha}} N_t} \right)^\alpha\end{aligned}$$

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Derivation of (2)

$$K_{t+1} = K_t(1 - \delta) + sY_t$$

- Divide both sides by $A_t^{\frac{\beta}{1-\alpha}}N_t$:

$$\frac{K_{t+1}}{A_t^{\frac{\beta}{1-\alpha}}N_t} = k_t(1 - \delta) + sy_t$$

- Multiply and divide the left-hand side by $A_{t+1}^{\frac{\beta}{1-\alpha}}N_{t+1}$

$$\frac{K_{t+1}}{A_{t+1}^{\frac{\beta}{1-\alpha}}N_{t+1}} \frac{A_{t+1}^{\frac{\beta}{1-\alpha}}N_{t+1}}{A_t^{\frac{\beta}{1-\alpha}}N_t} = k_t(1 - \delta) + sy_t$$

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$$\frac{K_{t+1}}{A_{t+1}^{\frac{\beta}{1-\alpha}}N_{t+1}} \cdot \frac{A_{t+1}^{\frac{\beta}{1-\alpha}}N_{t+1}}{A_t^{\frac{\beta}{1-\alpha}}N_t} = k_t(1 - \delta) + sy_t$$

k_{t+1}

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k_{t+1} $1 + n$

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$$\frac{K_{t+1}}{A_{t+1}^{\frac{\beta}{1-\alpha}}N_{t+1}} \cdot \frac{A_{t+1}^{\frac{\beta}{1-\alpha}}N_{t+1}}{A_t^{\frac{\beta}{1-\alpha}}N_t} = k_t(1 - \delta) + sy_t$$
$$k_{t+1} \cdot \frac{(1 + g_{At})^{\frac{\beta}{1-\alpha}}}{1 + n}$$

Solow + Romer in the Long-run

- The previous equations dictate the dynamics of $a_t = A_t/N_t$ and k_t
- Let us focus on the long-run
- In the long-run, as we have seen already, (3) implies $a_t = A_t/N_t$ is a constant, and

$$g_{At} = g_A = n$$

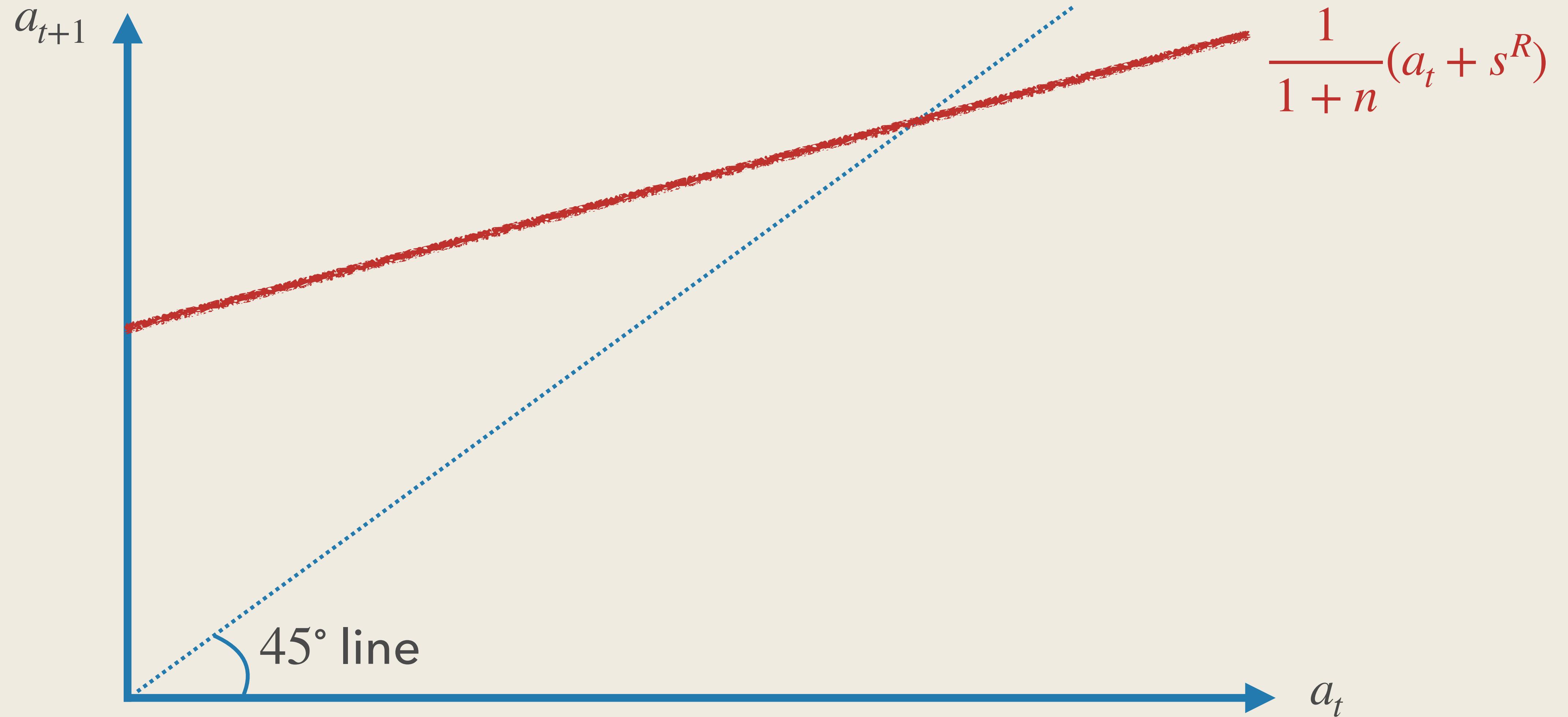
- Putting $g_A = n$ into (2), we now obtain a nearly identical equation as in Solow model:

$$k_{t+1} = \frac{1}{(1+n)^{1+\beta/(1-\alpha)}} [k_t(1-\delta) + s(1-s^R)^{1-\alpha} k_t^\alpha]$$

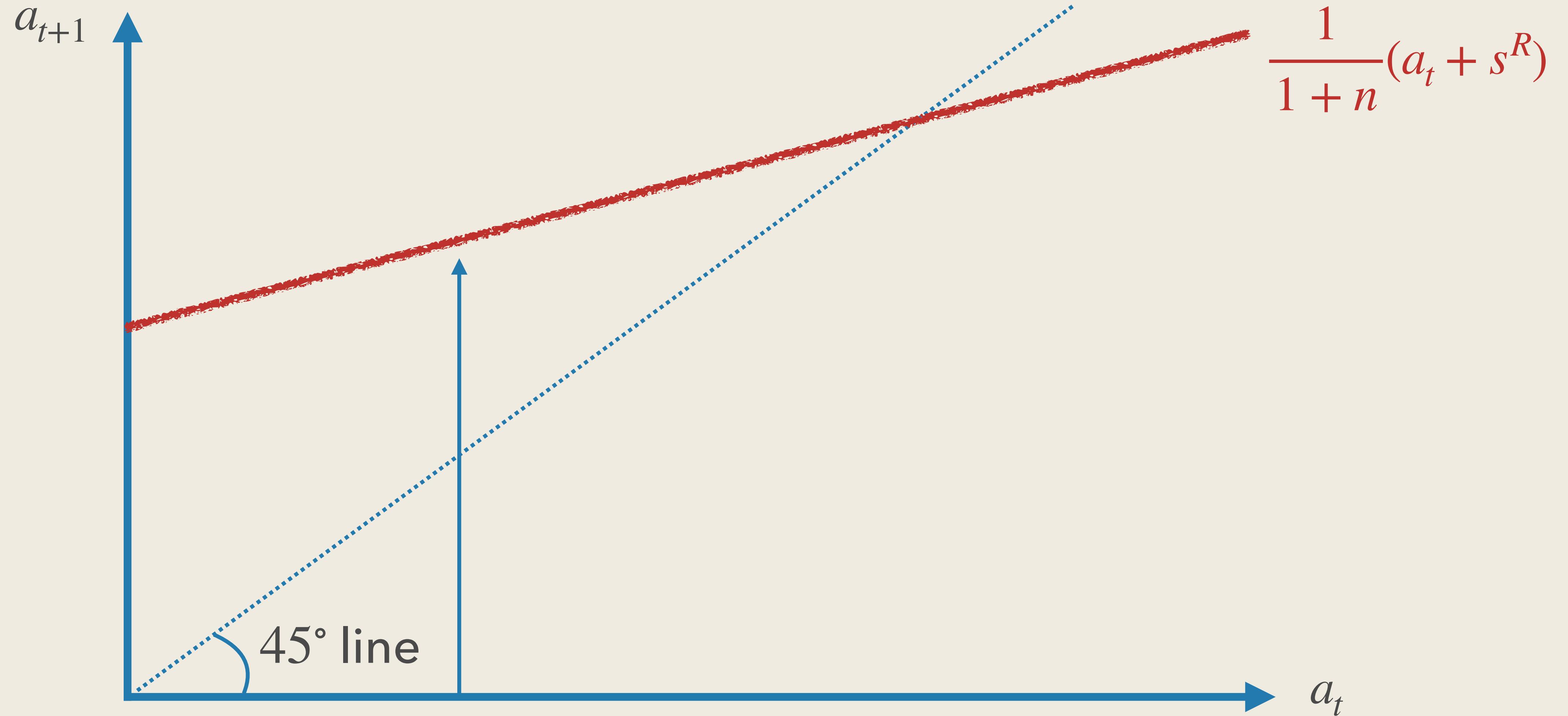
- In the long-run with $k_t = k$,

$$k = \left(\frac{s(1-s^R)^{1-\alpha}}{(1+n)^{1+\beta/(1-\alpha)} - (1-\delta)} \right)^{\frac{1}{1-\alpha}}, \quad y = (1-s^R)^{1-\alpha} k^\alpha$$

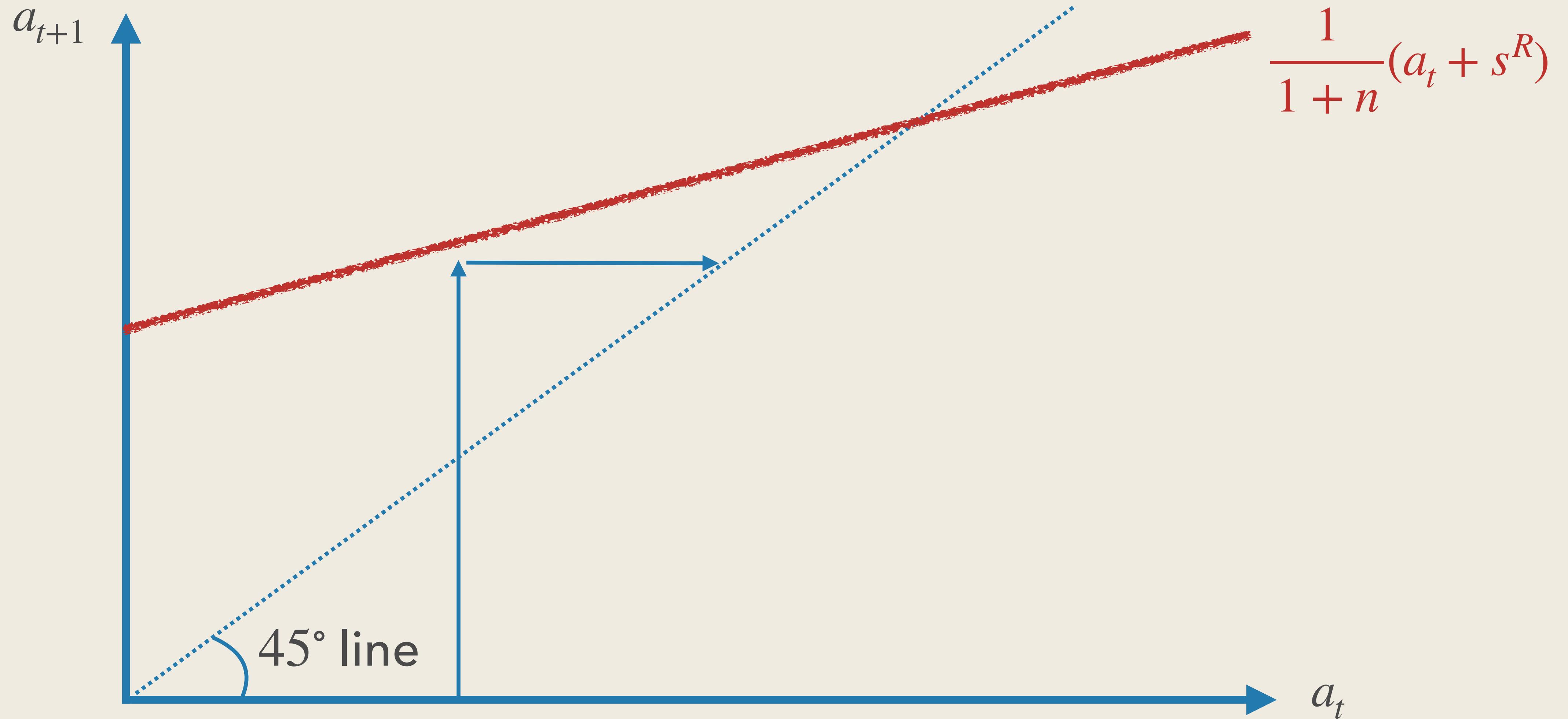
Evolution of Knowledge Stock



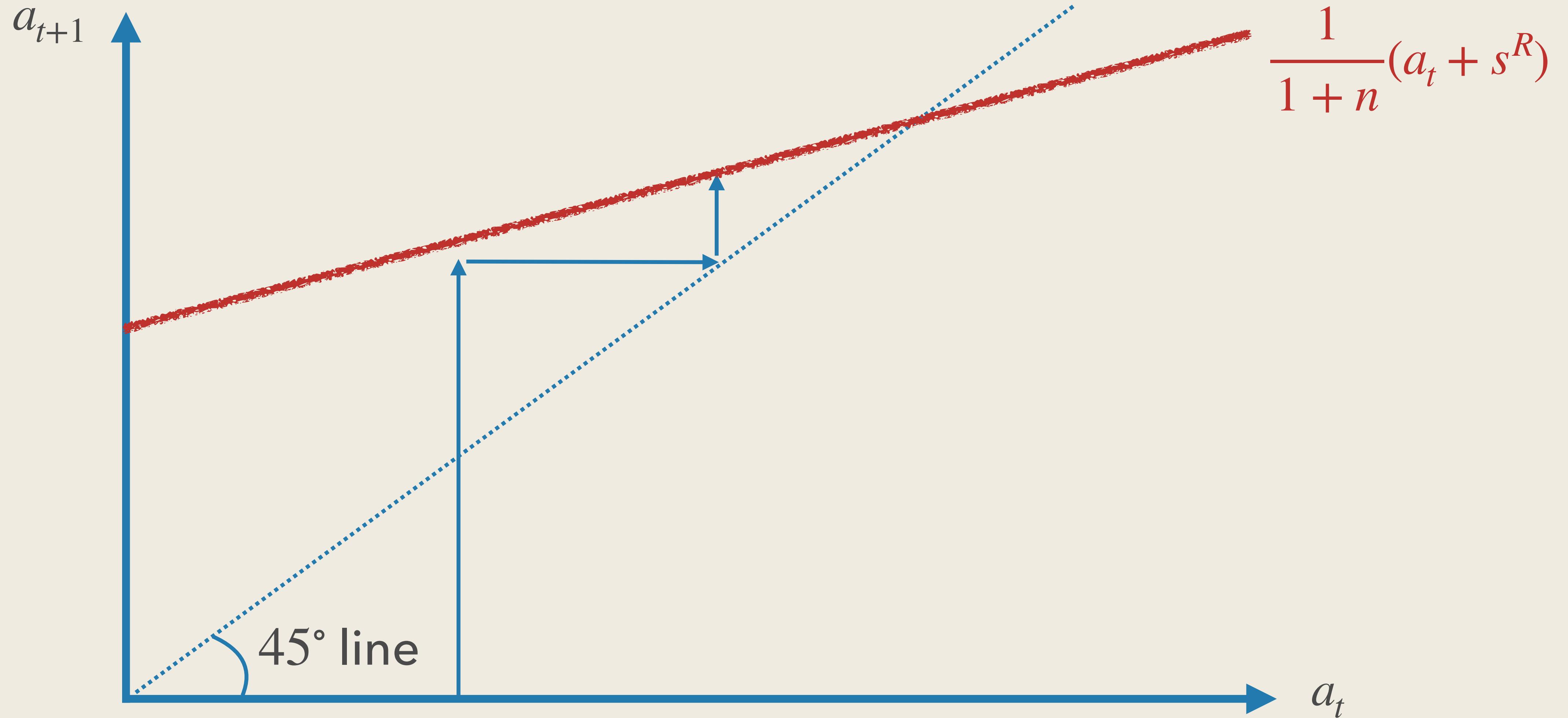
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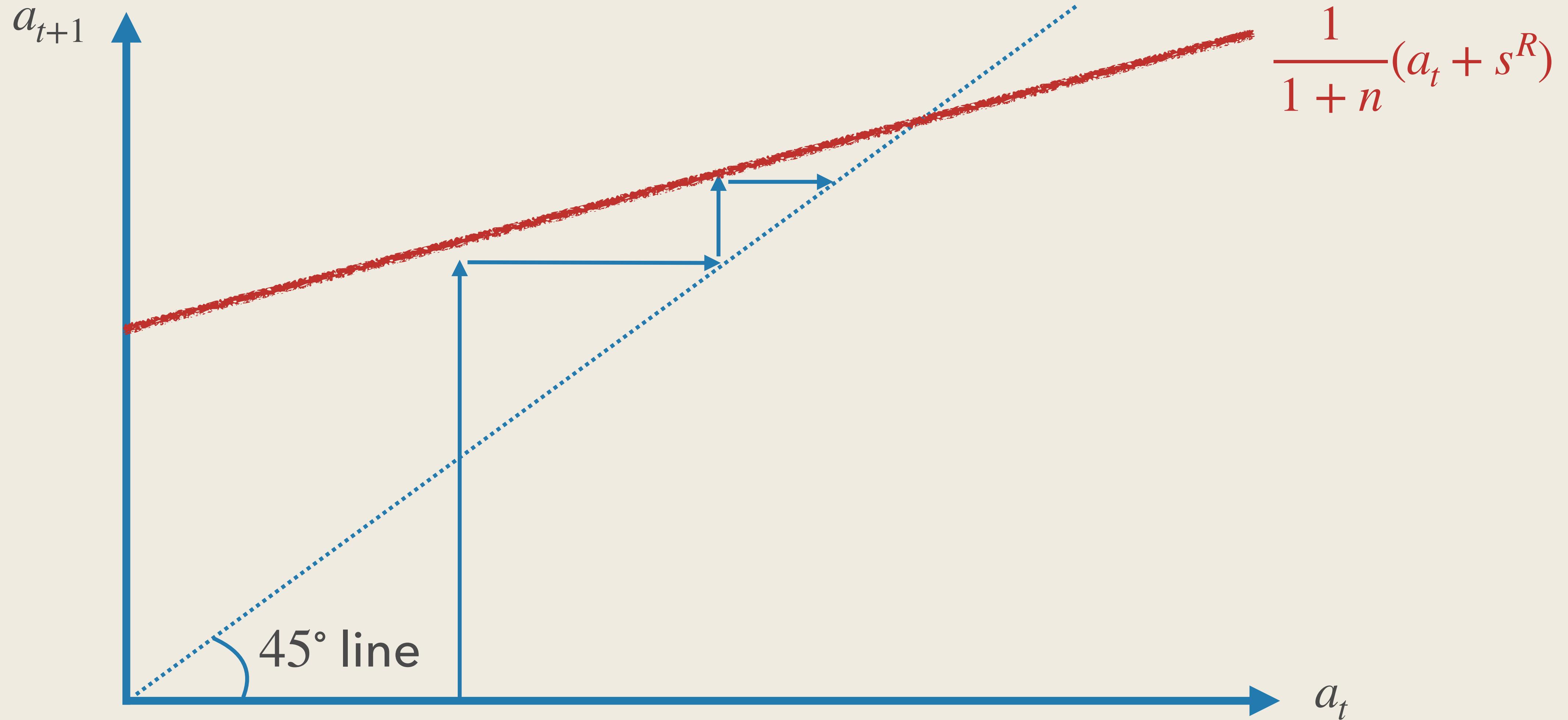
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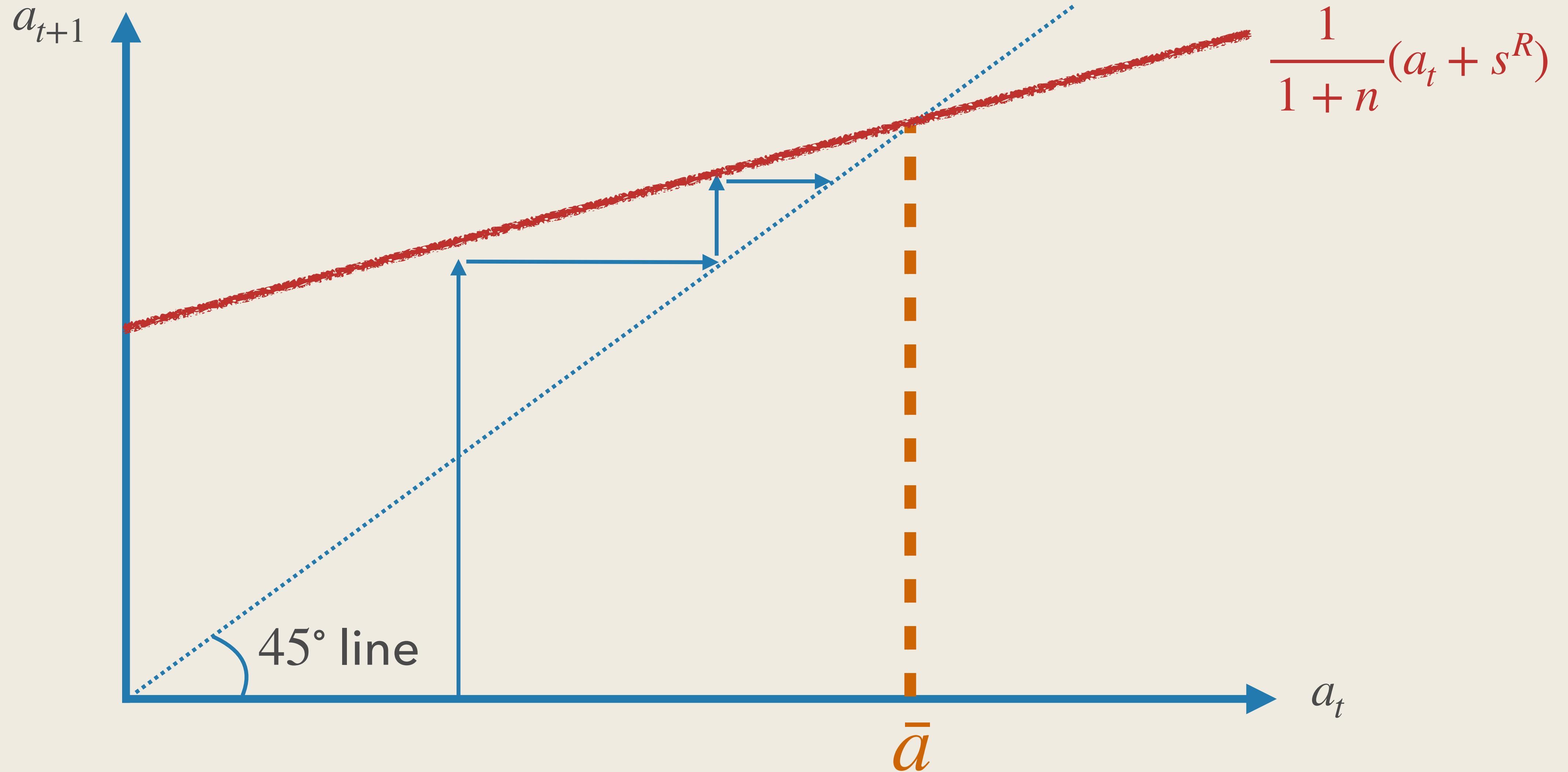
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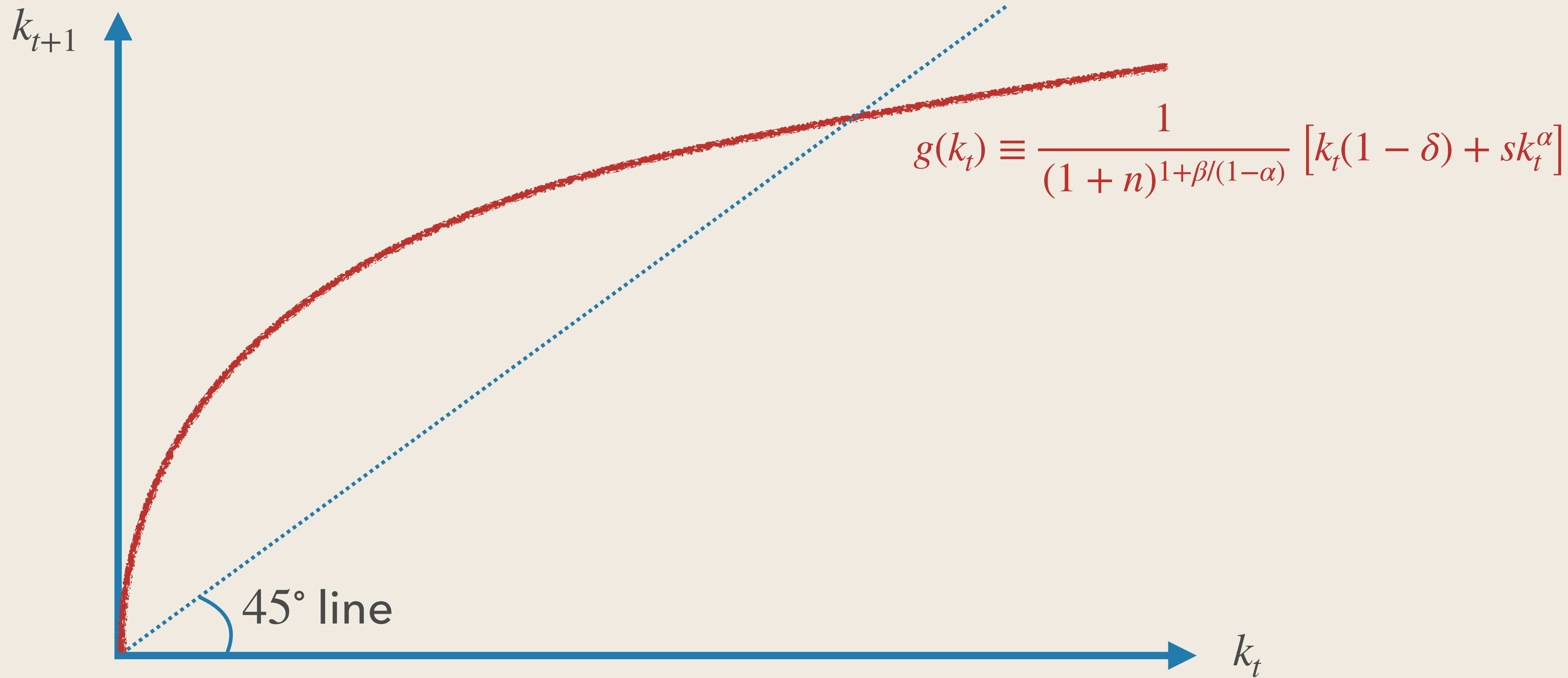
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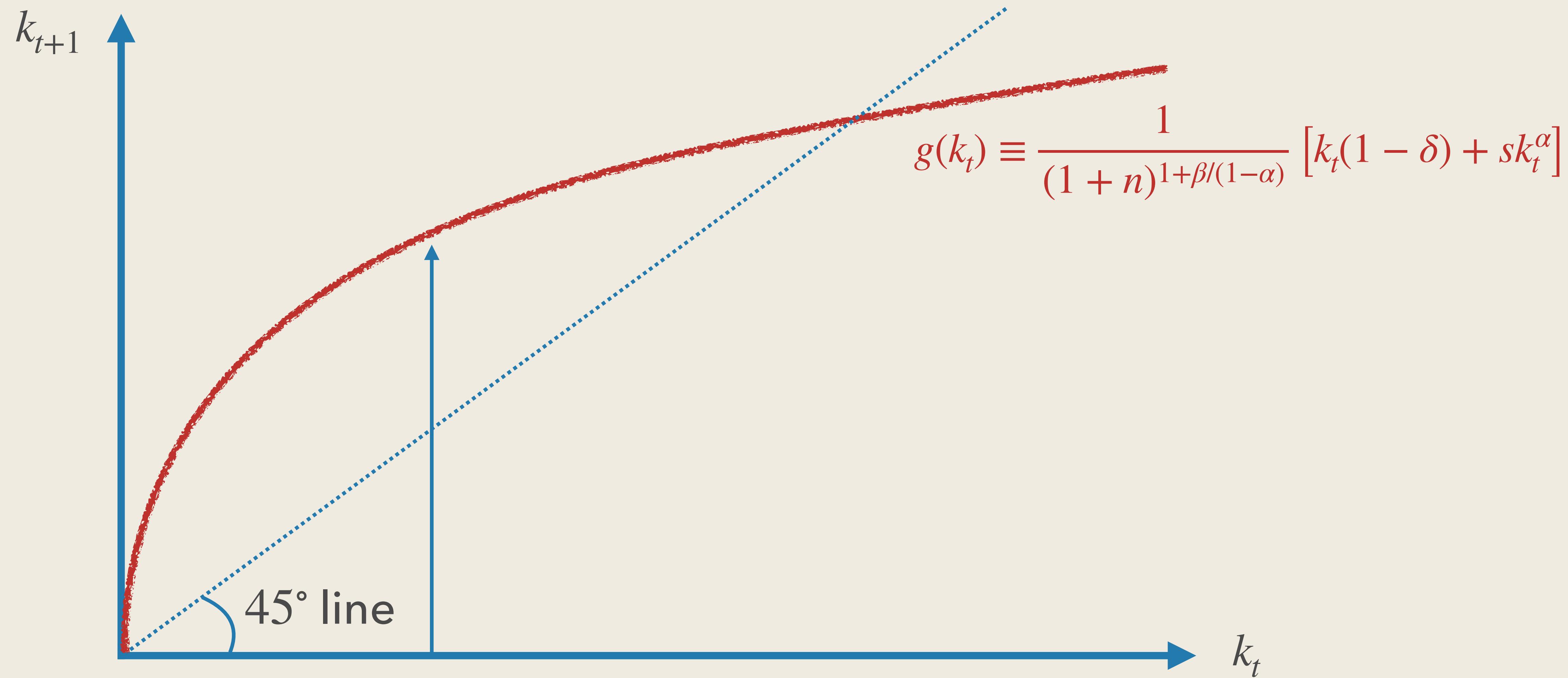
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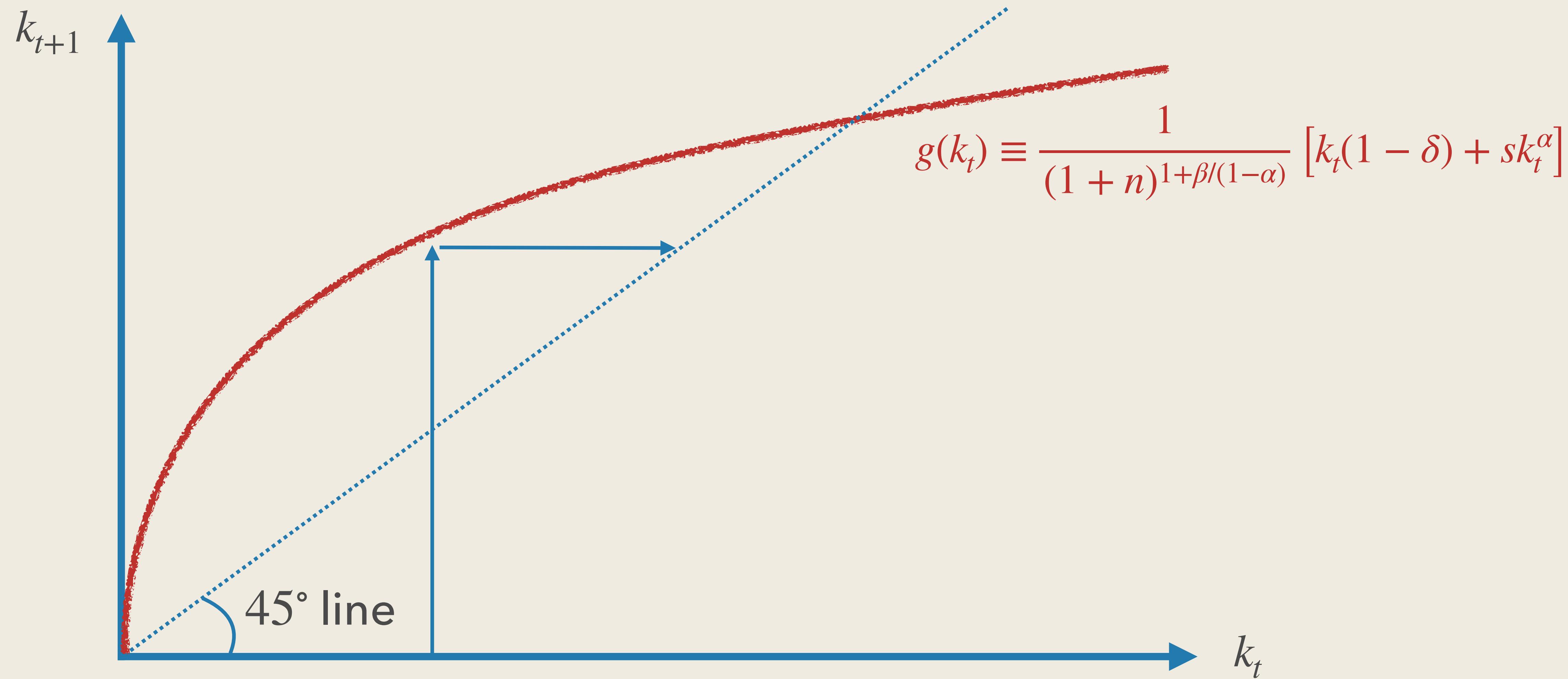
Evolution of Capital Stock



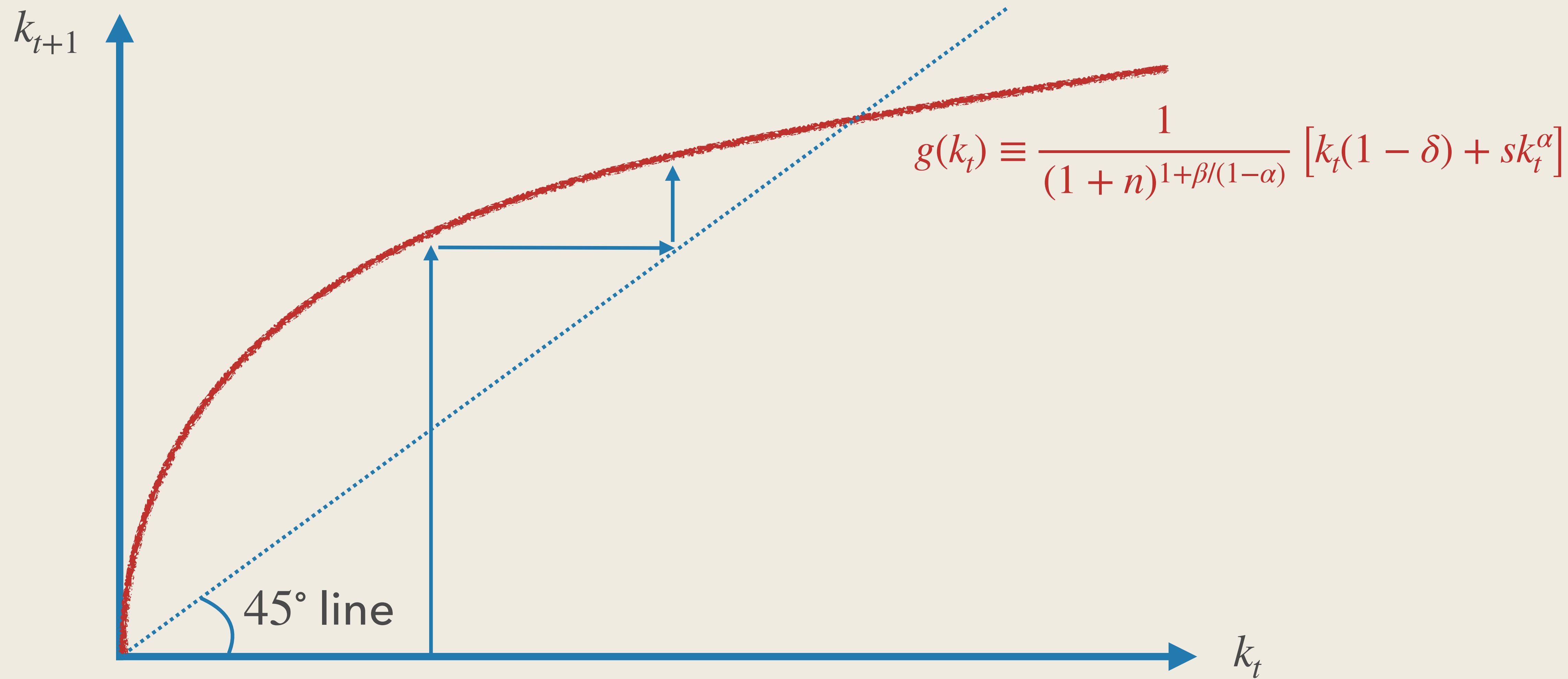
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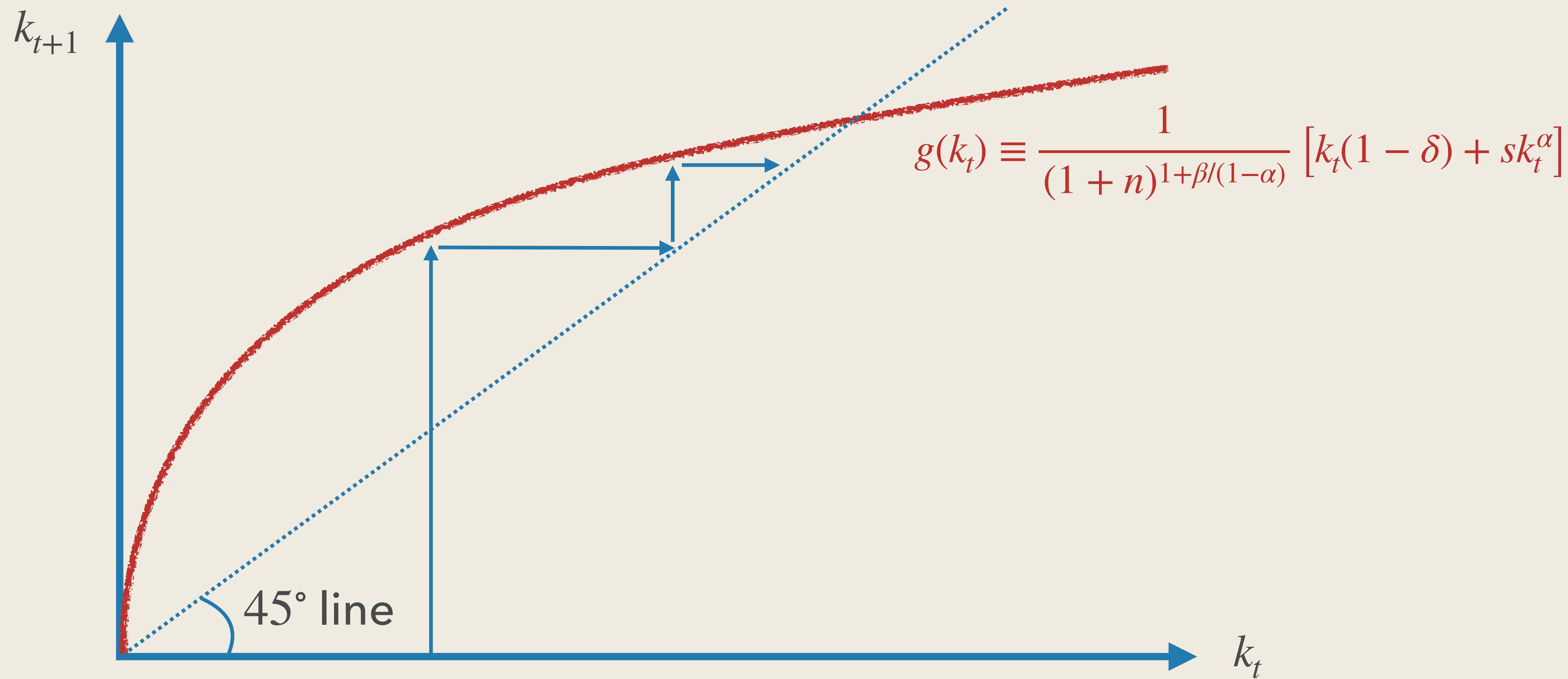
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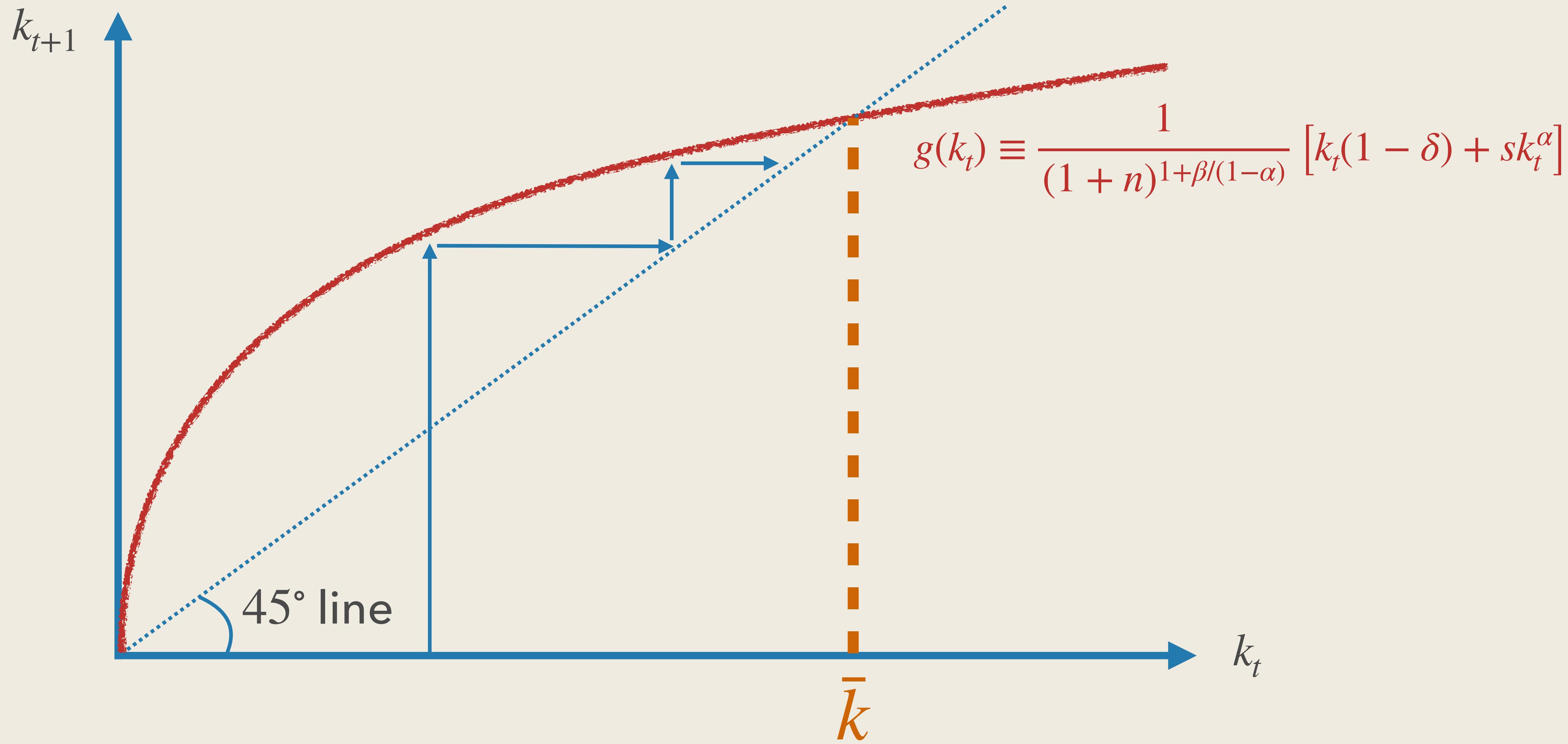
Evolution of Capital Stock



Evolution of Capital Stock



Evolution of Capital Stock



Long-run Growth

- What is the long-run growth in this economy?
- Does the fact that y is a constant mean per-capita income is also a constant?
 - No, recall per capita income is $Y_t/N_t = A_t^{\frac{\beta}{1-\alpha}}y_t$
... which grows at a rate $g_{Y/N} \approx \frac{\beta}{1-\alpha}n$ (when n small)
- The economy grows faster than the previous model (which was βn). Why?

$$Y_t/N_t = (1 - s_R)^{1-\alpha} A_t^\beta (K_t/N_t)^\alpha$$

- A_t grow at rate $g_A = n$ and contribute to GDP growth by βg_A
- K_t/N_t grow at rate $\frac{\beta}{1-\alpha}g_A$ and contribute to GDP growth by $\frac{\alpha\beta}{1-\alpha}g_A$
- Technology growth leads to capital accumulation and even faster growth

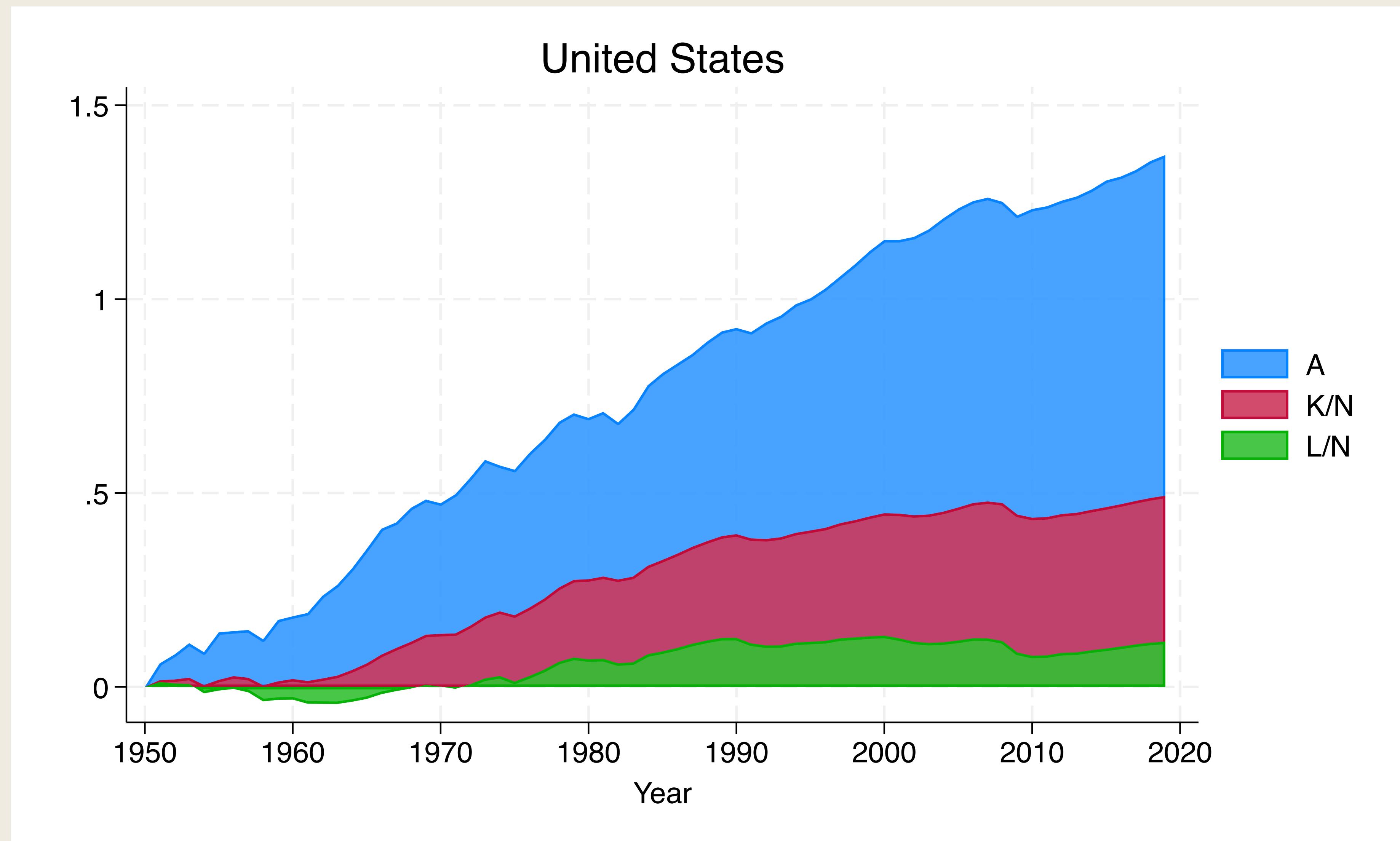
Growth Accounting Revised

- In this model,

$$g_{Y/N} = \underbrace{\beta g_A}_{\text{growth due to A}} + \underbrace{\frac{\alpha}{1-\alpha} \beta g_A}_{\text{growth due to K}}$$

- If $\alpha = 1/3$, A should be twice as important as capital in growth accounting
- Let us go back to the data and test it

Validating Solow + Romer Model



Putting a Number

$$g_{Y/N} = \frac{\beta}{1 - \alpha} n$$

- Per-capita GDP in the US has been growing at 2% every year, $g_{Y/N} = 0.02$
- The US population has been growing roughly at 1%, $n = 0.01$
- Labor share implies $\alpha = 1/3$
- Jointly, this implies $\beta \approx 1.33$