

The Wealth of Nations: Aggregate Incomes

Alexander Quispe

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Introduction

Why are some countries much richer than others? Do differences in physical capital explain these gaps? Differences in education? Or is it differences in technology and how production is organized?

Introduction

We are going to study questions related to **economic inequalities across countries and economic growth** (sometimes called “long-run macroeconomics”). In particular, we explain **how to measure differences in standards of living across countries and why such disparities exist.**

Introduction

Why is the average American so much richer than the average Indian?

- We live in a world of **great disparities**.
- Standards of living, educational opportunities, health services, and infrastructure **differ** tremendously across countries.
- **Poverty is endemic in many parts of the world**, particularly in sub-Saharan Africa, South Asia, and parts of South America, while most people in the United States, Canada, Western Europe, and a few other fairly rich countries live in relative comfort, even abundance. These differences are so great that if you travel around the globe, you will be struck by the stark contrast between living conditions in some parts of the world and those back home.
- These disparities are also the reason many people from all over the world emigrate to richer countries, where standards of living are higher.

Introduction

Figure: Disparities in Education



Figure: Macroeconomics (Acemoglu, Laibson, List 2022), Page 148

Outline

1. Inequality Around the World
2. Productivity and the Aggregate Production Function
3. The Role and Determinants of Technology

Key ideas

- **There are very large differences across countries in GDP per capita.**
- We can compare income differences across countries using GDP per capita at current exchange rates or adjusted for differences in purchasing power parity.
- The aggregate production function links a country's GDP to its capital stock, its total efficiency units of labor, and its technology.
- Cross-country differences in GDP per capita result partly from differences in physical capital per worker and the human capital of workers, but differences in technology and the efficiency of production are even more important.

1. Inequality Around the World

Before we can understand the variation of income around the world, we must first **define our measurements**. *How do we quantify the differences in standards of living and economic conditions across countries?*

- Income per capita or GDP per capita is one robust measure (GDP per capita is GDP divided by total population).

1. Inequality Around the World

MEASURING DIFFERENCES IN GDP PER CAPITA

- Last lecture, we learned how to measure aggregate income or GDP. We can do so by approaching it from the production side, from the expenditure side, or from the **production expenditure income** side.
- The national income accounting identity shows that all three give exactly the same answer: **gross domestic product**, or GDP for short. Dividing GDP by the total population in the country gives us **GDP per capita**.
- GDP per capita (per person) is also referred to as **income per capita**, but to keep things simple, we use the term GDP per capita throughout.

1. Inequality Around the World

- More formally, we have:

$$GDP \text{ per capita} = \frac{GDP}{Total \text{ population}}$$

- For example, the United States in 2018 had (nominal) GDP equal to about \$20.54 trillion. With a total population of approximately 327 million, nominal GDP per capita was approximately \$62,813.

$$(GDP \text{ per capita})_{USA, 2018} = \frac{GDP}{Total \text{ population}} = \frac{\$20.54 \text{ trillion}}{327 \text{ million}} = \$62,813$$

- How does this compare to the **compare income per capita of other countries?**

1. Inequality Around the World

- Let us look to a neighboring country: **Mexico**.
- Income in Mexico is, of course, calculated in **pesos** instead of **U.S. dollars**. Thus, with a similar computation, we find GDP per capita in Mexico in the same year, 2018, to be approximately 189,010 pesos. This **number is not directly comparable** to the \$62,813 for the United States because it is expressed in Mexico pesos dollars GDP per capita in Mexico in the same year, 2018, 189,010 pesos not directly comparable to the \$62,813 for the United States different units.
- Fortunately, the exchange rate allows us to convert pesos to dollars. For example, on January 1, 2019, \$1 was worth 19.54 pesos, or 1 peso was worth $\frac{\$1}{19.54} = \0.051 .
- Using this ratio, we can convert the average income in Mexico into dollars as follows.

1. Inequality Around the World

$$\begin{aligned}\text{Mexican GDP per capita in \$} &= \text{Mexican GDP per capita in pesos} \times \frac{\$}{\text{peso exchange rate}} \\ &= 189,010 \times \$0.051 \\ &= \$9,640\end{aligned}$$

- So the average Mexican had an income of approximately \$9,640. This number is useful for thinking about how much an individual with the average Mexican income, all of which was earned in Mexico, would be able to consume in the United States.

1. Inequality Around the World

- Using this exchange-rate-based measure, we can compute GDP per capita in every country for which we have data on GDP and population.
- For example, in 2018, GDP per capita in Sweden was \$55,608, and in Germany it was \$47,603. While GDP per capita in Sweden and Germany is similar to that in the United States (\$62,813), large disparities emerge when we compare the United States to several other countries.
- For example, we have already seen that the U.S. GDP per capita is about 6 times that of Mexico. It is also 31 times greater than GDP per capita in India, 59 times greater than GDP per capita in Senegal, and approximately 74 times greater than GDP per capita in Ethiopia.

1. Inequality Around the World

- While **exchange-rate-based measures** allow us to compare how much money the **average citizen of different countries** makes, they **don't tell us how much that money can buy**. Put differently, they fail to account for the fact that **prices vary across countries**.
- For example, some goods, like phone calls, are cheaper in the United States than in Mexico (partly because there is a telecommunications monopoly in Mexico, keeping prices high). In contrast, other goods, like guacamole and haircuts, are cheaper in Mexico, often because labor and other inputs are cheaper.
- To properly take account of these price differences, we favor **comparing GDP per capita across countries using *purchasing power parity***.

1. Inequality Around the World

- Last lecture, we saw how to adjust economic variables like GDP to correct for changes in prices over time (which led to the notion of real GDP). We should make a similar adjustment when comparing GDP between countries. But the exchange rate between dollars and pesos doesn't fully do this, because is just a consequence of converting Mexican income into dollars using the current exchange rate, which fluctuates for a variety of reasons unrelated to differences in the cost of living.
- **Purchasing power parity provides a better way to convert GDP in domestic currencies into common units.** The idea here is very similar to the adjustment we developed for converting nominal GDP into real GDP in the previous lesson.

1. Inequality Around the World

- Specifically, the purchasing power parity (PPP) **constructs the cost of a representative basket of commodities in each country and adjusts GDP so that a dollar in each country can purchase this representative basket.**
- The resulting measure is a country's GDP in PPP-adjusted U.S. dollars. For example, this representative basket cost \$1 in the United States and 9.23 pesos in Mexico in 2019. On this basis, the PPP conversion factor between U.S. dollars and pesos is \$1 for 9.23 pesos.

1. Inequality Around the World

- Using this procedure, GDP per capita in Mexico in PPP can be compared by multiplying GDP per capita in Mexico in pesos by the peso-dollar PPP conversion factor we just derived:

$$\begin{aligned} \text{Mexican GDP per capita in PPP \$} &= \text{Mexican GDP per capita in pesos} \times \frac{\$}{\text{peso PPP}} \\ &= 189,010 \times \frac{\$1}{9.23} \\ &= 189,010 \times \$0.11 \\ &= \$20,478 \end{aligned}$$

1. Inequality Around the World

- Comparing this result for Mexico with the \$8,911 obtained using the peso/dollar exchange rate, we see that there is often a **significant difference** between exchange-rate-based measures and PPP-based measures of GDP per capita, with the gap between the U.S. economy and poorer economies generally being smaller when we use PPP-based measures. This pattern reflects the lower cost of living in countries with lower GDP per capita.
- In other words, exchange-rate-based comparisons of GDP ignore the fact that many commodities are cheaper in poorer countries.

1. Inequality Around the World

CROSS-COUNTRY DIFFERENCES IN GDP PER CAPITA

- Very large disparities still exist across countries when we use PPP-based measures.
- Next Figure shows a graph of PPP-adjusted GDP per capita across countries in 2018 (expressed in terms of 2011 constant dollars, where the notion of constant dollars was defined last lecture). Note that there are four countries with less than \$1,000 per capita, including Burundi and Niger, and another seventeen with PPP-adjusted GDP per capita of between \$1,000 and \$2,000, including Ethiopia, Haiti, and Rwanda. These numbers contrast sharply with those of the United States (\$55,719), France (\$39,556), and Germany (\$45,936) in the same year.

1. Inequality Around the World

There are wide disparities in GDP per capita across countries. Fifty countries had GDP per capita less than \$5,000 in 2018 (in PPP-adjusted 2011 constant dollars), while only twelve countries had GDP per capita above \$50,000.

Figure: GDP per Capita Around the World in 2018 (PPP-Adjusted 2011 Constant Dollars)

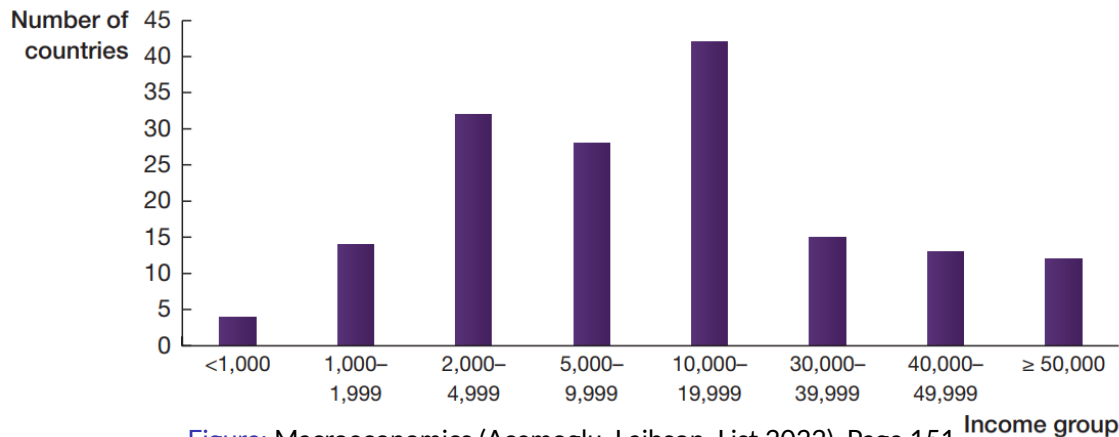


Figure: Macroeconomics (Acemoglu, Laibson, List 2022), Page 151

1. Inequality Around the World

The large disparities in PPP-adjusted GDP per capita across countries are easily visible in this map, which also shows that the poorest countries are concentrated in Africa, parts of Asia, Central America, and the Caribbean.

Figure: Map of PPP-Adjusted GDP per Capita Around the World

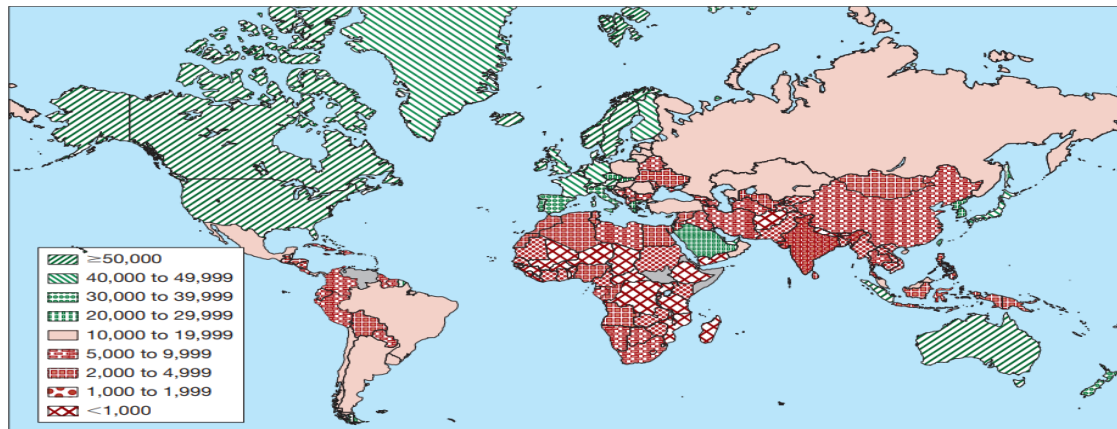


Figure: Macroeconomics (Acemoglu, Laibson, List 2022), Page 152

1. Inequality Around the World

- Previous Figure shows a map of the world with different ranges of PPP-adjusted GDP per capita shaded in different colors. Reds, oranges, and yellows correspond to lower GDP per capita, and greens correspond to relatively high GDP per capita.
- The overall picture identifies where the rich and the poor countries are. There are some striking patterns to the differences in incomes.
- For example, the African continent appears to be uniformly poorer than other continents, except for a few spots. Much of South Asia and Latin America is also quite poor. In contrast, North America and Western Europe are relatively prosperous.
- This map makes it clear that there are indeed major economic disparities throughout the world. Our purpose is to understand the causes behind them.

1. Inequality Around the World

GDP PER WORKER

- We have so far talked about GDP per capita aggregate income (GDP) divided by total population. But total population includes children, the elderly, and those who are not employed.
- This raises the possibility that part of the variation in GDP per capita across countries might be due to differences in what fraction of the population works.
- Therefore, a natural alternative that avoids this problem is to focus on GDP per worker, defined as GDP divided by number of “workers,” meaning those in employment:

$$\text{GDP per worker} = \frac{\text{GDP}}{\text{Number of people in employment}}$$

- This measure gives us a better picture of how much each worker produces on average by excluding those who do not work.

1. Inequality Around the World

Figure: GDP per Worker Across Countries in 2017 (PPP-Adjusted 2011 Constant Dollars)

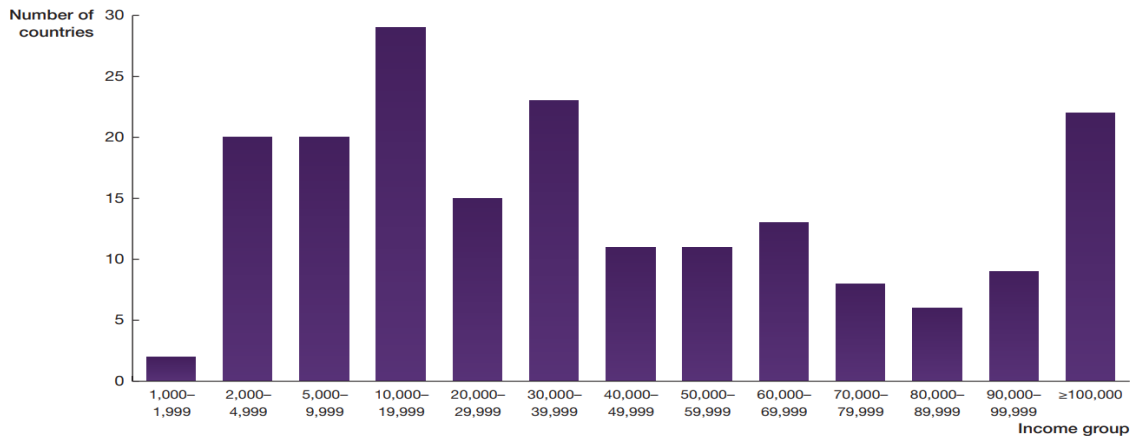


Figure: Macroeconomics (Acemoglu, Laibson, List 2022), Page 153

1. Inequality Around the World

- In the previous Figure, we can see a direct comparison between GDP per capita and GDP per worker.
- Naturally, GDP per worker is higher for every country than GDP per capita because the denominator is always smaller for GDP per worker.
- For example, PPP-adjusted GDP per capita in 2018 (in 2011 constant dollars) for Mexico is \$18,133 (equal to \$19,844 in current dollars), whereas PPP-adjusted GDP per worker for Mexico in 2018 (again in 2011 constant dollars) is \$40,453. For India, the two corresponding numbers are \$6,888 and \$19,588. As a reflection of this, the group of countries with the highest GDP per worker now corresponds to \$100,000+ instead of \$50,000+ as Figure showing GDP per capita Across Countries.

1. Inequality Around the World

PRODUCTIVITY

- **The main reason GDP per capita or GDP per worker varies across countries is because productivity varies across countries.**
- Productivity here refers to the value of goods and services that a worker generates for each hour of work.
- From our discussion of the national income accounting identity in last lecture, you will recall that the value of goods and services produced in a country, GDP, is equal to the total income in that country. Thus productivity also measures GDP per hour of work.
- **GDP per worker and productivity are very closely related and thus vary across countries for the same reasons.**
- It is useful to focus on productivity differences across countries because it emphasizes that to understand the huge differences in GDP per capita across countries, we have to look at the production side. In particular, we need to study the factors that make labor much more productive in some countries than in others.

1. Inequality Around the World

INCOMES AND THE STANDARD OF LIVING

- A natural question is whether GDP per capita or GDP per worker is the quantity we should focus on. The answer depends on what we are trying to measure. GDP per worker is informative when we would like to understand why some economies are more productive than others because it focuses directly on differences in GDP relative to the number of workers in employment.
- Another reason we care about disparities in income across countries is that we want to measure differences in the standards of living across countries. For this purpose, GDP per capita is a natural first step because the conditions of the whole population, including children and the elderly, are conveyed by this measure.
- However, there is much that is left out of GDP per capita, as you have already seen in the previous lecture.

1. Inequality Around the World

- However, **there is much that is left out of GDP per capita**, as you have already seen in the previous lecture. Even though, GDP per capita is a fairly good predictor of average life satisfaction in a country, we **cannot capture the diverse dimensions of well-being and the standards of living of an entire population** by looking at a single number.
- **GDP per capita may not provide a complete picture of how comfortably most people in a country actually live.** GDP per capita is greater in the United States than in Sweden, but the significantly higher level of U.S. inequality implies that the average American may be worse off than the average Swede.
- Finally, as already mentioned in the previous chapter, **people do not care only about income and consumption but also about factors such as pollution, the quality of healthcare, and public safety.** Variations in these factors across countries are not captured by GDP per capita numbers.

1. Inequality Around the World

- In the previous lecture, we saw the **relationship between GDP per capita and average life satisfaction**.
- In addition, one of the things we care about when discussing a particular country is whether many people are living in extreme poverty.
- Researchers at the World Bank have come up with the notion of **absolute poverty**, corresponding to **living on less than \$1.08 per day in 1993** - a measure commonly referred to as the ***one dollar a day per person poverty line***. This measure has now been updated to \$1.90 per person per day (in 2011 U.S. dollars), though it is still sometimes referred to as one dollar a day.

1. Inequality Around the World

Figure: The Relationship Between Poverty and GDP per Capita in 2014 (PPP-Adjusted 2011 Constant Dollars)

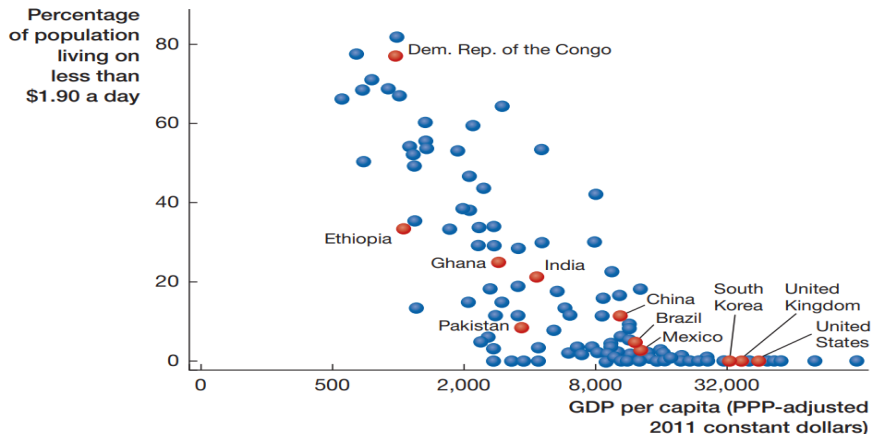


Figure: Macroeconomics (Acemoglu, Laibson, List 2022), Page 155

1. Inequality Around the World

- The previous Figure shows a scatter plot with the fraction of a nation's population living in poverty (according to this definition) on the y-axis and its PPP-adjusted GDP per capita on the x-axis. The exhibit shows a strong association, indicating that GDP per capita gives us a fairly good idea of which countries have populations suffering from extreme poverty.
- Absolute poverty, measured here by the fraction of the population living on less than \$1.90 per day, is higher among countries with lower GDP per capita. In the exhibit, when you focus on countries with GDP per capita above \$10,000, this relationship disappears because relatively few people in these relatively prosperous countries actually live on less than \$1.90 per day.

1. Inequality Around the World

Figure: Relationship Between Life Expectancy at Birth and GDP per Capita in 2017 (PPP-Adjusted 2011 Constant Dollars)

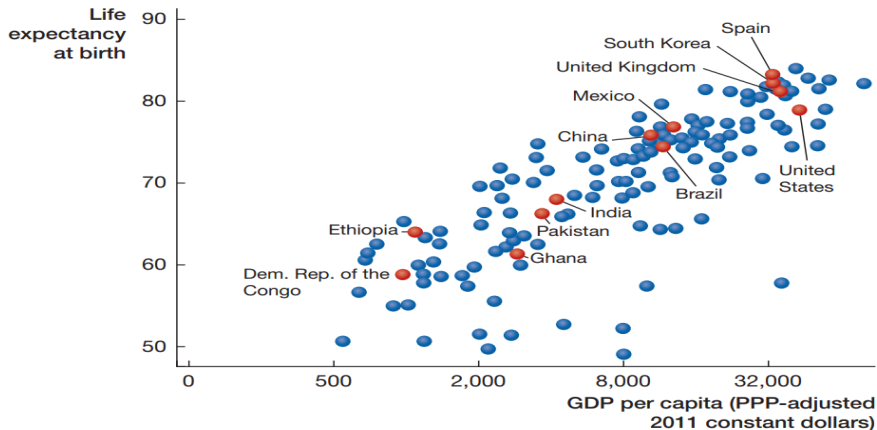


Figure: Macroeconomics (Acemoglu, Laibson, List 2022), Page 156

1. Inequality Around the World

- Another reason we care about GDP per capita is that poverty often brings poor health.
- **One way to measure the health of a nation is by looking at the average life expectancy at birth.**
- The previous Figure shows a scatter plot with life expectancy on the y-axis and PPP-adjusted GDP per capita on the x-axis, and again there is a strong association, indicating that this non-income-based measure of the standard of living also correlates strongly with GDP per capita.

1. Inequality Around the World

- We should also account for several other factors when measuring the standard of living across countries.
- One alternative measure is the **United Nations' Human Development Index**, which combines **GDP per capita, life expectancy, and measures of education** to more holistically measure the **standard of living**.
- The Figure below presents a scatter plot with the Human Development Index on the y-axis and PPP-adjusted GDP per capita on the x-axis. It shows that there is once again a **strong association between GDP per capita and this measure**.

1. Inequality Around the World

Figure: Relationship HDI Between the Human Development Index and GDP per Capita in 2017 (PPP-Adjusted 2011 Constant Dollars)

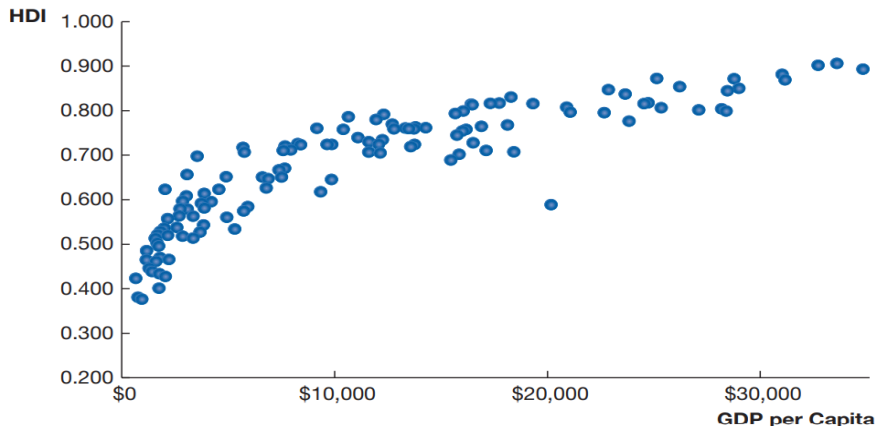


Figure: Macroeconomics (Acemoglu, Laibson, List 2022), Page 156

1. Inequality Around the World

- Overall, the relationship between GDP per capita and several measures of the standard of living, including poverty, life expectancy, and the Human Development Index, suggests a simple strategy: **first focus on GDP per capita and then look in greater detail at issues related to health, education, poverty, and inequality within and across countries.** This is the strategy we adopt here.

2. Productivity and the Aggregate Production Function

- As noted above, to understand differences in GDP per capita or GDP per worker across countries, we need to **understand differences in productivity**.
- To do so, we first outline the **main sources of variation in productivity across countries**.
- Then we turn to a more systematic analysis of these factors using the **aggregate production function**.

2. Productivity and the Aggregate Production Function

PRODUCTIVITY DIFFERENCES

- There are three main reasons productivity differs across countries:
 1. *Human capital*: Workers differ in terms of human capital, which is their **stock of skills to produce output or economic value**. For example, a worker with a university degree can do the same tasks as two workers with high school degrees, then she has **twice the human capital** as the workers with high school degrees. But this also implies that she is **twice as productive**.
 2. *Physical capital*: Physical capital is the **stock of all machines (equipment) and buildings used for production** (typically expressed in dollars, which enables us to sum the value of all machines and buildings). For example, in agriculture, aggregate production will depend on agricultural machinery. Workers will be more productive when the economy has a bigger physical capital stock, enabling each worker to work with more (or better) equipment and structures.
 3. *Technology*: Technology refers to a **set of devices and practices that determine how efficiently an economy uses its labor and capital**. In particular, an economy with better technology uses its labor and capital more efficiently and thus achieves higher productivity.

2. Productivity and the Aggregate Production Function

THE AGGREGATE PRODUCTION FUNCTION

- Human capital, physical capital, and technology each play a part in determining how productive workers in an economy are. **The aggregate production function is our tool for understanding how these three ingredients come together to generate GDP in an economy.**
- For the analysis here, once we have made the simplification of aggregating everything into GDP, we can just think of GDP as if it were a single commodity. Even though this simplification ignores the *composition* of GDP, it allows us to more clearly look at what determines the *level* of GDP, which is our main purpose in this chapter.

2. Productivity and the Aggregate Production Function

- The advantage of looking at GDP in this way is that once we start thinking of the world in terms of a single commodity, we can study the aggregate production function of the economy, which describes the relationship between GDP and its various inputs.
- For example, if we wanted to understand how much corn a farm produces, we would first specify the relationship between total corn production and its key inputs, for example, the number of workers on the farm and the equipment that the farm uses.

2. Productivity and the Aggregate Production Function

- A key concept in our study of the aggregate production function is **factors of production**. Recall from the previous lecture that factors of production are the **inputs to the production process—goods or services purchased in the market for producing other goods**, in this case for producing GDP.
- To understand a nation's output, we will look at a production function that describes how the factors of production are combined to produce GDP. But differently from the case in which we study a single firm, our focus is not specific commodities, such as T-shirts or iPhones, but **all of GDP**, and we therefore refer to this function as the **aggregate production function**.

2. Productivity and the Aggregate Production Function

LABOR

- The first and most important factor of production is labor. A nation can increase output by employing more workers.
- Remember that some workers will have greater human capital than others and will be able to produce more output or economic value (and this is why, as we have seen, human capital is a major determinant of productivity).
- Such differences in workers' human capital make looking at the total number of workers in an economy a poor indicator of how much the economy can produce. Instead, we need to know the **total efficiency units of labor**.

2. Productivity and the Aggregate Production Function

- **Total efficiency units of labor** is defined as the product of the total number of workers and the average human capital (efficiency) of workers.
- We can compute the total efficiency units of labor, denoted by H , as the product of the total number of workers in the economy, L , and the average efficiency or human capital of workers, h :

$$H = L \times h$$

- This equation implies that the total efficiency units of labor in the economy can be increased either if more workers take part in the production process (for example, because employment increases) or if each worker becomes more productive.
- Acquiring more skills through formal schooling is one way for a worker to increase his or her productivity.

2. Productivity and the Aggregate Production Function

PHYSICAL CAPITAL AND LAND

- The second major factor of production is **physical capital**, typically denoted by k (corresponding to the first letter of “Kapital,” the German spelling of capital).
- When an economy has **more physical capital**, or equivalently, a greater physical capital stock, its **workers can work with more and better equipment and structures, and thus the economy will produce more GDP**.
- A third factor of production is **land**. For example, if we think of an economy in the eighteenth century, land and other natural resources would be the key factors of production.
- To simplify the discussion, we focus only on physical capital and labor (specifically, total efficiency units of labor). When we do so, the value of land and natural resources can be included in the physical capital stock (the same way that the value of buildings is).

2. Productivity and the Aggregate Production Function

TECHNOLOGY

- Another major determinant of GDP is technology, which, as you will recall, determines **how efficiently the economy uses its inputs—labor, capital, and land.**
- In the aggregate production function, technology **summarizes the relationship between the factors of production and GDP.**
- A **better technology** means that the economy can generate **more output from the same set of inputs**, and thus **increases its productivity** for given total efficiency units of labor and capital.

2. Productivity and the Aggregate Production Function

REPRESENTING THE AGGREGATE PRODUCTION FUNCTION

- Let us represent the aggregate production function as

$$Y = A \times F(K, H)$$

where:

- Y stands for GDP.
- K is the physical capital stock of the nation.
- H is the efficiency units of labor that the economy uses in production.
- The function F signifies that there is a relationship between physical capital, labor, and GDP (the expression for F in the above equation is read as “ F is a function of K and H ”). In particular, GDP is generated through a combination of physical capital and the efficiency units of labor.
- A is an index of technology. As A increases, the economy produces more GDP with the same level of physical capital stock and total efficiency units of labor. We discuss the role of technology in greater detail below.

2. Productivity and the Aggregate Production Function

- The aggregate production function is useful for understanding not only how GDP is determined but also why productivity varies across countries.
- The aggregate production function:

$$Y = A \times F(K, H)$$

- Using the following form, which is often estimated as an empirical approximation to data:

2. Productivity and the Aggregate Production Function

$$Y = A \times F(K, H) = A \times K^{1/3} \times H^{2/3}$$

- This form is referred to as a **Cobb-Douglas function** and has several attractive features. For instance, the coefficients to which K and H are raised add up to 1 $\left(\frac{1}{3} + \frac{2}{3} = 1\right)$.
- This ensures that the production function exhibits *constant returns to scale*: that is, increasing K and H 1 percent would lead to a 1 percent increase in Y .
- Moreover, this functional form is consistent with the empirical fact that, roughly speaking, about two-thirds of national income goes to labor and one-third to physical capital.

2. Productivity and the Aggregate Production Function

- Let us now divide both sides of the above equation by the total number of workers in the economy, L :

$$Y \times \frac{1}{L} = A \times K^{1/3} \times H^{2/3} \times \frac{1}{L}$$

- this can be rewritten as

$$y = \frac{Y}{L} = A \times K^{1/3} \times H^{2/3} \times \frac{1}{L^{1/3} \times L^{2/3}}$$

where y is income per worker, or GDP divided by the number of workers in the economy.

The last term simply rewrites $\frac{1}{L}$ differently to derive the next equation.

2. Productivity and the Aggregate Production Function

- Now rearranging the previous equation, we obtain:

$$y = A \times \frac{K^{1/3}}{L^{1/3}} \times \frac{H^{2/3}}{L^{2/3}}$$
$$y = A \times \left(\frac{K}{L}\right)^{1/3} \times \left(\frac{H}{L}\right)^{2/3}$$

- Finally, recalling that $h = \frac{H}{L}$, this can be rewritten as

$$y = A \times \left(\frac{K}{L}\right)^{1/3} \times h^{2/3}$$

- Stated differently:

$$\text{GDP per worker} = \text{Technology} \times (\text{Capital per worker})^{1/3} \times (\text{Human capital per worker})^{2/3}$$

2. Productivity and the Aggregate Production Function

- This derivation also shows why there is a **tight relationship between cross-country differences in GDP per worker and cross-country differences in productivity**.
- For simplicity, assuming that each worker works the same number of hours in every country, the left-hand side of this equation is also GDP per hour worked and thus the productivity of a country.
- The equation therefore demonstrates that **productivity is determined by the three ingredients** we have emphasized in the text: **technology, physical capital, and human capital**.

2. Productivity and the Aggregate Production Function

- As we have already emphasized, this aggregate production function is similar to the production function of an individual firm for producing a specific type of commodity.
- In particular: The aggregate production function is also subject to the **Law of Diminishing Marginal Product**. The Law of Diminishing Marginal Product states that the marginal contribution of a factor of production to GDP diminishes when we increase the quantity used of that factor of production (holding all other factors of production constant).
- We can illustrate the aggregate production function graphically.

2. Productivity and the Aggregate Production Function

Figure: The Aggregate Production Function with Physical Capital Stock on the x-Axis (with the Total Efficiency Units of Labor and Technology Held Constant)

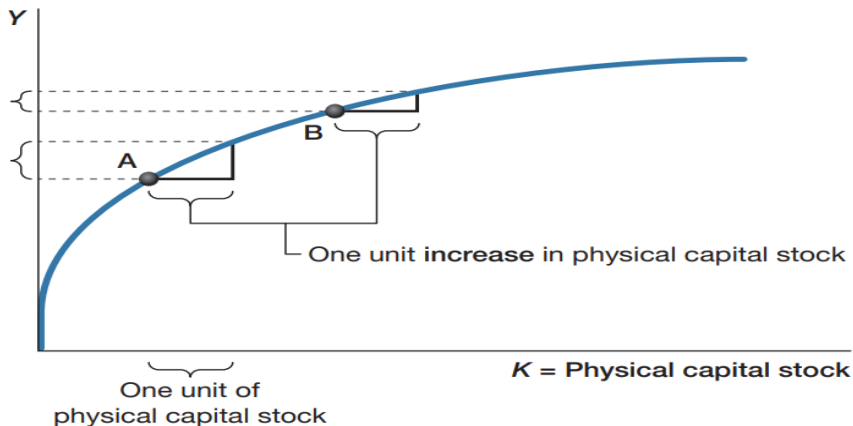


Figure: Macroeconomics (Acemoglu, Laibson, List 2022), Page 159

2. Productivity and the Aggregate Production Function

- Holding the total efficiency units of labor and technology constant, the aggregate production function shows the relationship between the physical capital stock and GDP in the economy. As the physical capital stock increases, so does GDP. But the relationship becomes less and less steep as the physical capital stock of the economy increases because of the Law of Diminishing Marginal Product. For the same one-unit increase in the physical capital stock, the increase in GDP is greater at point A (with lower physical capital stock) than at point B (with greater physical capital stock).

2. Productivity and the Aggregate Production Function

Figure: The Aggregate Production Function with the Efficiency Units of Labor on the x-Axis (with Physical Capital Stock and Technology Held Constant)

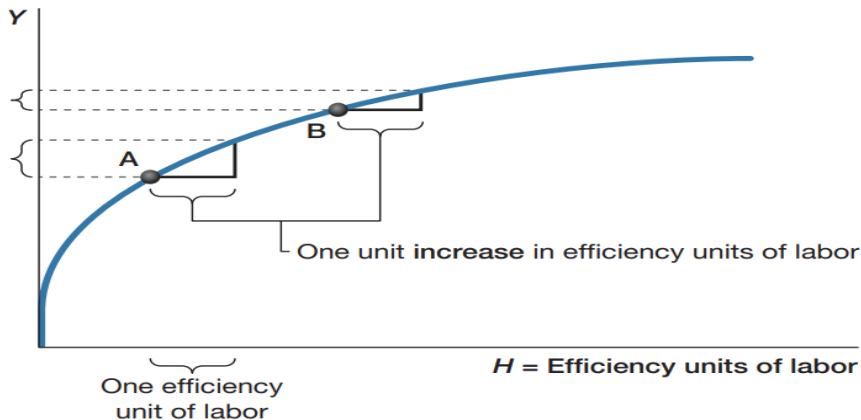


Figure: Macroeconomics (Acemoglu, Laibson, List 2022), Page 160

2. Productivity and the Aggregate Production Function

- Holding the physical capital stock and technology constant, the aggregate production function shows the relationship between the total efficiency units of labor and GDP. Once again, as the total efficiency units of labor increase, so does GDP, but consistent with the Law of Diminishing Marginal Product, the relationship becomes less and less steep as the total efficiency units of labor increase.

3. The Role and Determinants of Technology

- We now discuss in more detail how technology affects the aggregate production function and the factors that influence the level of technology of an economy.

3. The Role and Determinants of Technology

TECHNOLOGY

- You will recall that technology determines how efficiently an economy's inputs are utilized. Next Figure shows the implications of better technology for the aggregate production function.
- We once again hold the efficiency units of labor, H , constant, and plot the relationship between GDP and the physical capital stock, K . When technology improves (that is, when the economy uses better technology), the relationship between GDP and the physical capital stock shifts up. Therefore, for every level of the efficiency units of labor, **a better technology implies that the economy will produce more GDP.**
- Holding the total number of workers constant, greater human capital, a larger stock of physical capital, and better technology will all increase GDP. Because the total number of workers (and hours of work per worker) is constant, this also corresponds to an increase in productivity.

3. The Role and Determinants of Technology

Figure: The Aggregate Production Function with the Efficiency Units of Labor on the x-Axis (with Physical Capital Stock and Technology Held Constant)

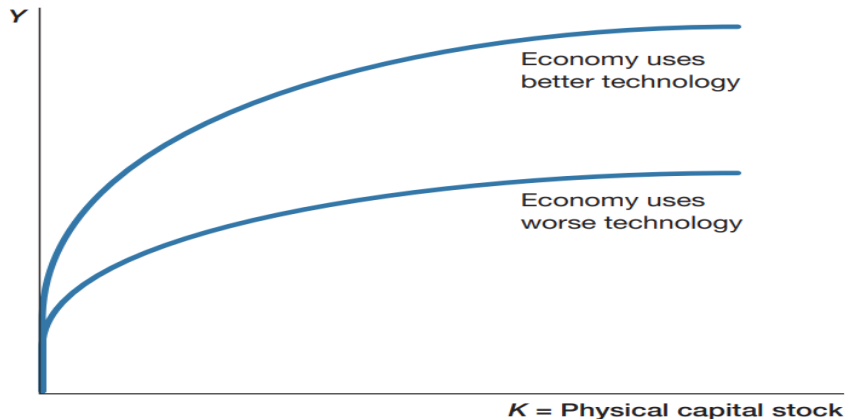


Figure: Macroeconomics (Acemoglu, Laibson, List 2022), Page 160

3. The Role and Determinants of Technology

DIMENSIONS OF TECHNOLOGY

- Technology, as we have defined it, is a rather broad concept, and in fact has two very distinct components. The first is *knowledge*, and the second is the *efficiency of production*.

3. The Role and Determinants of Technology

- A. **Knowledge:** Today, we know how to produce many new goods, such as smartphones and tablets, which were not available previously.
- For example, when you use a computer for writing an essay or doing computations for a class, you are making use of the computing power, which comes from the knowledge that society has acquired and has applied to its production process. Part of this knowledge is in the human capital of the workers: workers today can perform a range of tasks more productively than their grandparents could. But an important part of this knowledge is embodied in the physical capital stock of firms: the computers that firms are using are part of the physical capital stock of the economy.
- Thus **advances in technology** - in this specific instance, in computer technology - **directly increase the number of tasks we can perform and the speed at which we can accomplish them.**

3. The Role and Determinants of Technology

- B. Efficiency of production:** Is the ability of society to produce the maximal amount of output at a given cost or for given levels of the factors of production and knowledge. When the economy is able to increase the efficiency of production, there will be a shift in the aggregate production function. We therefore include efficiency of production as part of our definition of technology because it captures the differences in how much output an economy can generate with given amounts of inputs.

3. The Role and Determinants of Technology

- The importance of technology for GDP is the reason we include A and represent the aggregate production function as

$$A \times F(K, H)$$

- Greater values for A correspond to better technology and increased GDP for given levels of efficiency units of labor and physical capital stock, which shifts the aggregate production function up.
- But note that A is not a factor of production. Although it designates the technology available to the economy, it does not correspond to an input that the producer can purchase in the marketplace.

Summary

- **GDP per capita**, defined as aggregate income or gross domestic product (GDP) divided by total population, **varies greatly across countries**.
- GDP per capita across countries can be compared using **exchange-rate-based measures**, which rely on current exchange rates, or **purchasing power parity (PPP)-based measures**, which compare estimates of the cost of the representative basket of commodities in each country. The latter tend to be more reliable, as they more appropriately capture differences in relative prices across countries and are not subject to fluctuations resulting from changes in exchange rates. Though GDP per capita omits a wealth of other important information about a country (including information on health, schooling, inequality, and poverty), it provides a good summary of prosperity, and higher GDP per capita is typically correlated with higher life expectancy, better schooling, and lower poverty.
- **The aggregate production function links the GDP of a nation to its total efficiency units of labor, physical capital stock, technology, and efficiency of production.**
- The most important determinant of cross-country differences in GDP per worker appears to be differences in technology and the efficiency of production.