4. PRODUCTION & COST

ECON1005 Principles of Economics I (Microeconomics)

1. FIRMS

- A firm is any business entity that turns inputs into outputs.
  - The major objective of the firm is assumed to be **profit maximization.**
  - Profit is the firm's total revenue minus total cost:

$$\text{Profit } (\pi) = \text{Total Revenue } (TR) - \text{Total Cost } (TC)$$

- *What decisions firms have to make?*
  - ***How to produce (which input combination to be used in production)?***
  - ***How much to produce (and what price to charge)?***
  - The two decisions are closely link to production costs

To be discussed in next topic



1. FIRMS

Quantity (q)	Total Revenue (TR)	Total Cost (TC)	Profit
100	:	:	:
200	:	:	:
:	:	:	:
600	:	:	:
:	:	:	:

max



1. Cost-output relationship

Depends on input choices

The main objective of this topic: to understand the firm's input choice and develop the analytical tools describing the ***cost and output relationships*** that can be integrated into the analysis of output and pricing decisions.

2. PRODUCTION FUNCTION: HOW INPUTS ARE TURNED INTO OUTPUT?

- **Production function**: describes the relationship between the amount of inputs a firm uses and the amount of output it produces, given the current *technology*.
  - Input (or factors of production): labor, capital, raw materials…
  - Output: the firm's product (goods or services)

Labor: Riders/couriers

Capital: Motorbikes, bicycles, smartphones, …

- Consider a simple *two-input case* (e.g. food delivery), the production function is:

Output: Deliveries per day

$$q = f(L, K)$$

where L is the quantity of *labor* input (in labor-hours) and K is the quantity of *capital* input (in capital-hours).



2. PRODUCTION FUNCTION: HOW INPUTS ARE TURNED INTO OUTPUT?

- However, a firm's input choice depends on the firm's decision time frame:
  - **Long run**: a time period long enough that *all* inputs are flexible, i.e. *all* **variable inputs**.
  - **Short run**: a time period during which *at least* one input is fixed, i.e. *some* **fixed inputs**.
  - Economists usually assume labor to be a variable input and capital to be a fixed input *in the short run*, as hiring and firing labors could be done in a short period of time.
  - *How long does it take for a firm to move from the short run to the long run?*

What can we do if we want to produce 1 million more face masks in 1 month vs. in 1 year?





2.1 SHORT-RUN PRODUCTION

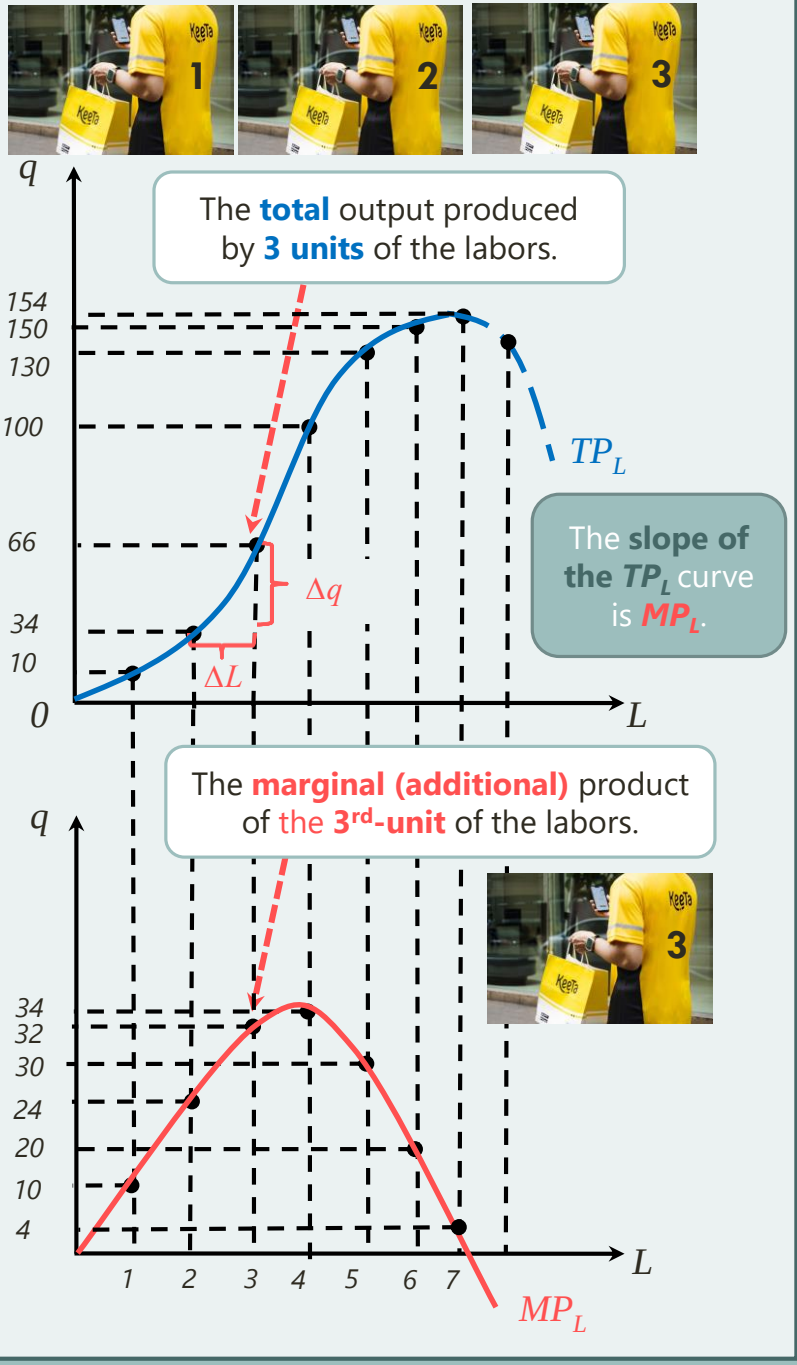
- In the short run, assuming that capital is fixed, the firm's production function becomes:

$$q = f(L)$$

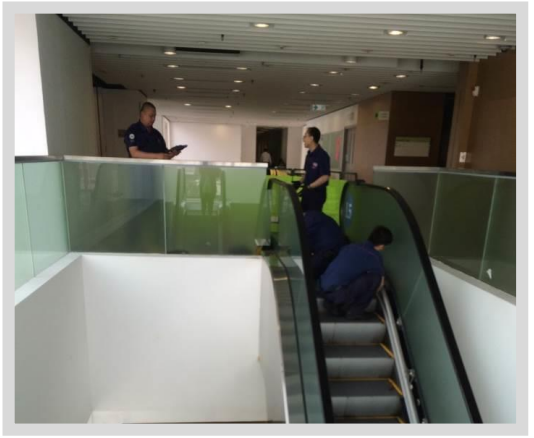
- Graphically, the **total product curve** shows the short-run production function – the relationship between total output and the single variable input, *labor*.

- **Marginal product** is the additional output that can be produced by employing one more unit of labor, *keeping the amount of capital constant*.

$$MP_L = \frac{\Delta q}{\Delta L}$$



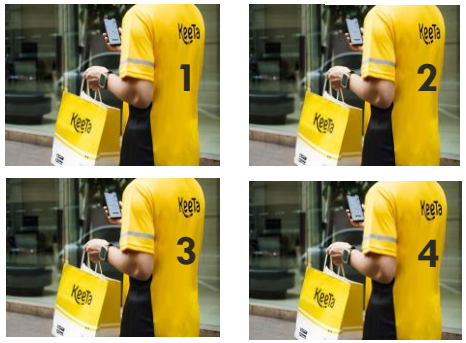
2.1 SHORT-RUN PRODUCTION



- Features of a typical production function in the short run:
  - Marginal product is positive (more input → more output) in general
  - **Law of diminishing marginal returns**: as more of any variable input is added, *holding other inputs constant*, its marginal product (additional output) will eventually decline (*why?*)
    - **Specialization** (Why MP_L increases at the beginning?)
    - **Fixed inputs** (Why MP_L eventually decreases?)

Capital (*K*)	Labor (*L*)	Total Output (*q*)	Marginal Product (MP_L)
2	0	0	
2	1	10	10
2	2	34	24
2	3	66	32
2	4	100	34
2	5	130	30
2	6	150	20

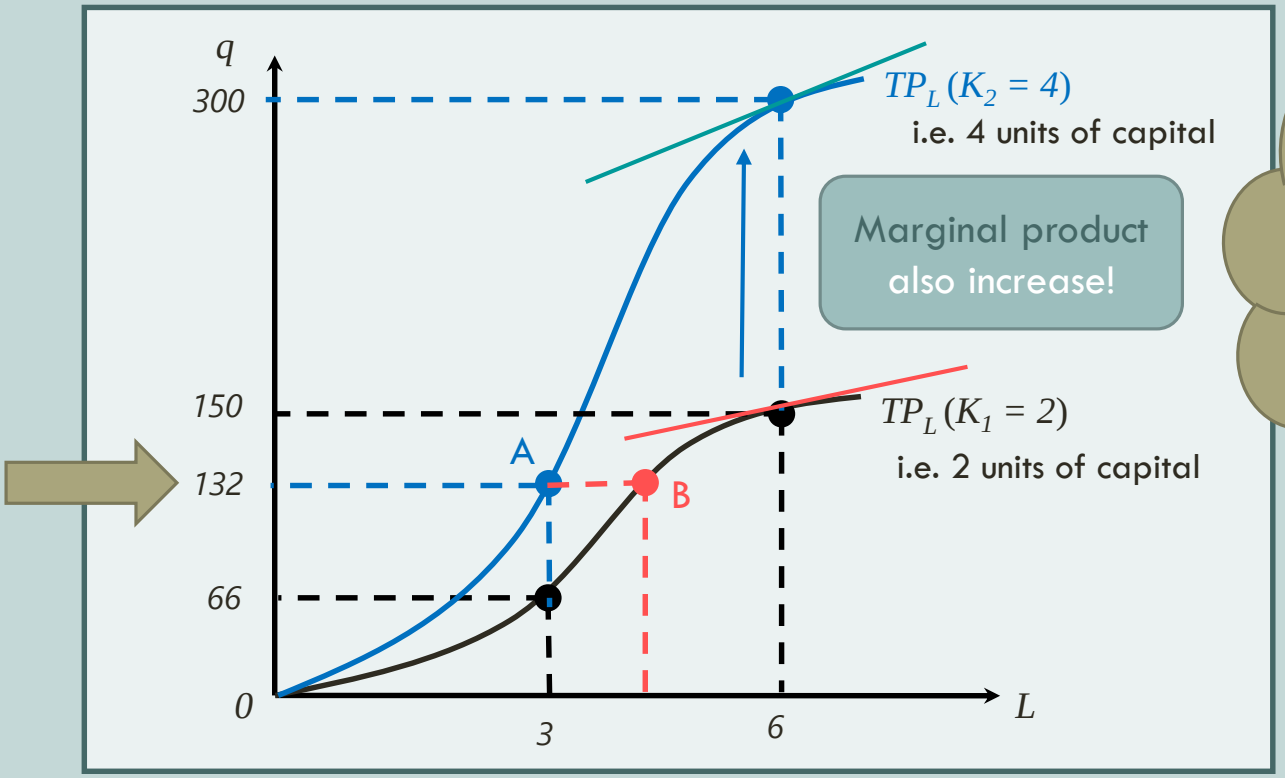




- For the two-input case, the amount of labor (variable input) employed only depends on output level.

2.2 LONG-RUN PRODUCTION

- In the long run, *both labor and capital are variable*.
  - What would happen to the total product curve when there is an increase in capital?
  - How about technological progress?



If the firm wants to produce **132 units of output**, what are its choices in the long run (when capital is no longer fixed)? Which one should it choose?

It depends on **production cost**!

3. SHORT-RUN COSTS: WHAT COSTS DO FIRMS CONSIDER IN THE SHORT RUN?

- In the simple *two-input case*, the **total cost** of production is the sum of the labor cost and capital cost:

$$TC = wL + rK$$

where *w* is the price of labor (wage rate) and *r* is the price of capital (rental rate).

- In the short run, we assume **capital is fixed** at $\overline{K}$ (i.e. fixed input) and that the firm is free to vary only the amount of labor employed (i.e. variable input) to produce any particular output level.

An example of the short-run production function:

Capital (*K*) (fixed in *SR*)	Labor (*L*)	Total Output (*q*)
2	0	0
2	1	10
2	2	34
2	3	66
2	4	100
2	5	130
2	6	150



3. SHORT-RUN COSTS: WHAT COSTS DO FIRMS CONSIDER IN THE SHORT RUN?

- Since capital is fixed at $\bar{K}$, the short-run total cost is:

$$TC = wL + r\bar{K}$$

Total variable cost (TVC) | Total fixed cost (TFC)

  - The term $r\bar{K}$ is referred to as **fixed cost**, because it will *remain constant as output changes*.
  - The term wL is referred to as **variable cost** as it *changes with output level* (In order to produce more, the firm can achieve only by employing more labor)

- In the short run, the total cost can be naturally divided into two parts:

$$TC = TVC + TFC$$

where ***TFC*** is the **total fixed cost** (the cost of all fixed inputs in the short run) and ***TVC*** is the **total variable cost** (the cost of all variable inputs).

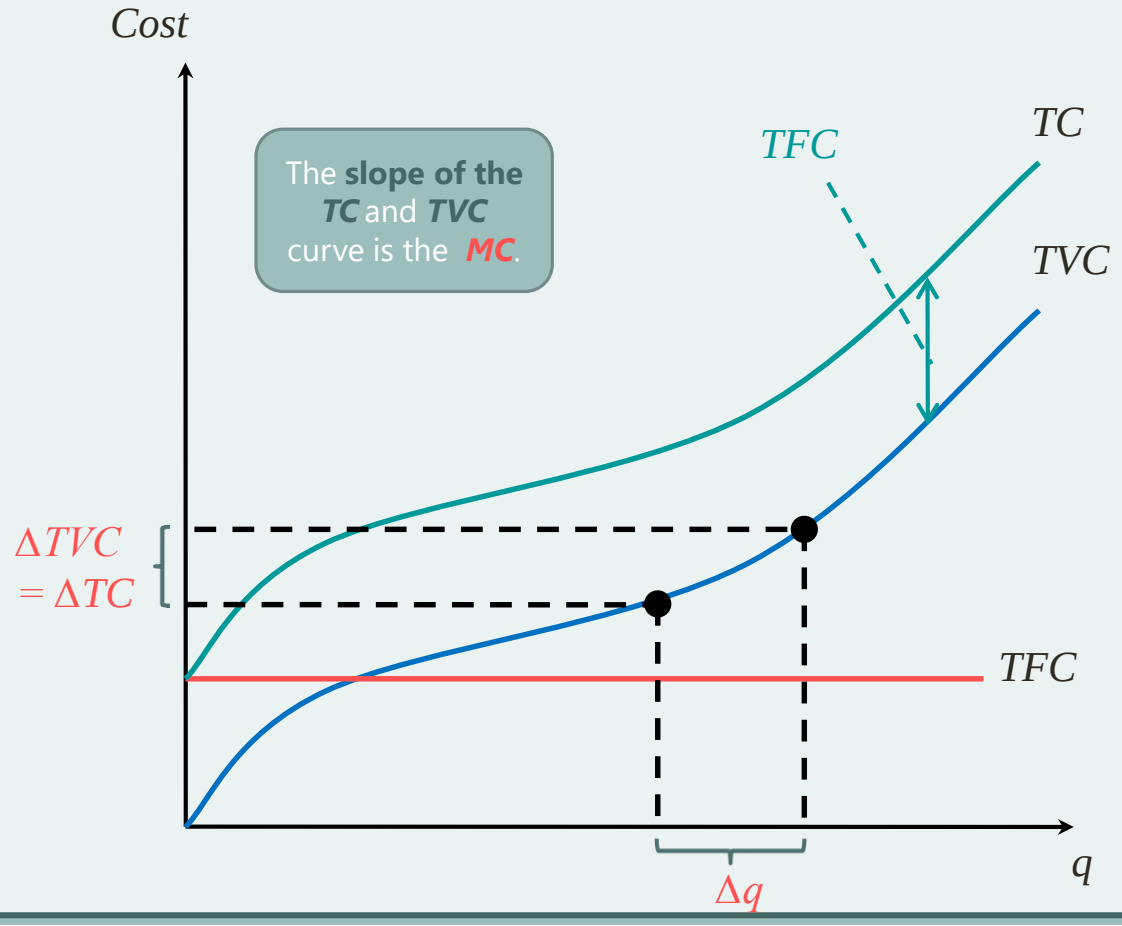
3. SHORT-RUN COSTS: WHAT COSTS DO FIRMS CONSIDER IN THE SHORT RUN?

- In our example, given the wage rate of labor, w = \$200 per day and rental rate of capital r = \$75 per day, the firm's short-run total costs:

q	*K*	*L*	*TFC*	*TVC*	*TC*
0	2	0			
10	2	1			
34	2	2			
66	2	3			
100	2	4			
130	2	5			
150	2	6			

3. SHORT-RUN COSTS: WHAT COSTS DO FIRMS CONSIDER IN THE SHORT RUN?

- To visualize the typical relationship between output and short-run costs, a set of **short-run cost curves** is used:



So, what is the explanation behind the shape of the TVC (and TC)?

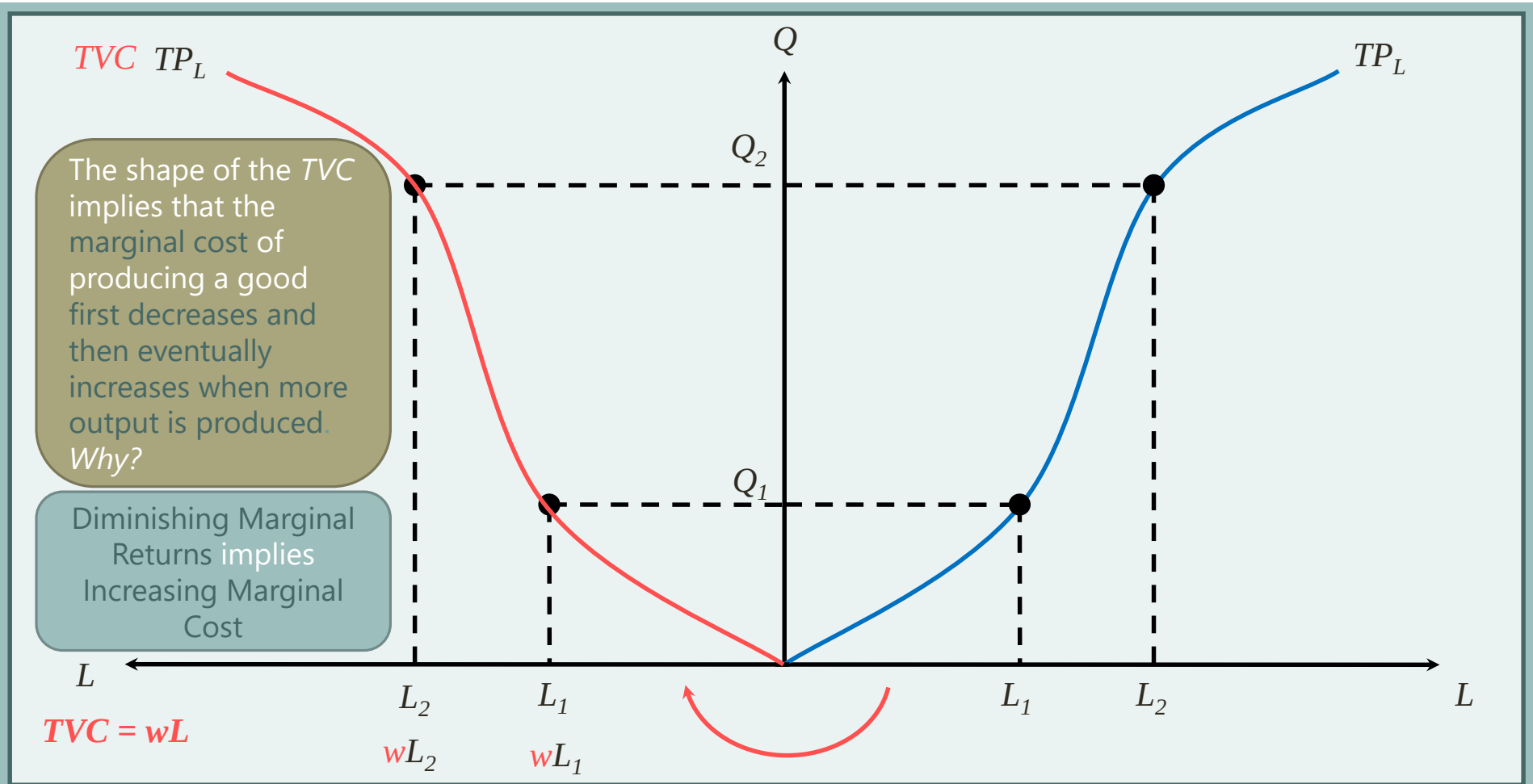
Marginal cost (*MC*): the *additional* cost incurred by producing one more unit of output.

$$MC = \frac{\Delta TVC}{\Delta q} = \frac{\Delta TC}{\Delta q}$$

The shape of the *TVC* implies that the marginal cost of producing a good first decreases and then eventually increases when more output is produced. *Why?*

3. SHORT-RUN COSTS: WHAT COSTS DO FIRMS CONSIDER IN THE SHORT RUN?

- The **total variable cost curve** can be derived directly from the **total product curve** in the short run:



3. SHORT-RUN COSTS: WHAT COSTS DO FIRMS CONSIDER IN THE SHORT RUN?

- It is often useful to express production costs *per unit* of output (i.e. average cost) because they are often compared with market price (*per unit*).

$$TC = TVC + TFC$$

$$\frac{TC}{q} = \frac{TVC}{q} + \frac{TFC}{q}$$

Average total cost:
$$ATC = \frac{TC}{q}$$

Average variable cost:
$$AVC = \frac{TVC}{q}$$

Average fixed cost:
$$AFC = \frac{TFC}{q}$$

$$ATC = AVC + AFC$$

- **Marginal cost *(MC)***

$$MC = \frac{\Delta TVC}{\Delta q} = \frac{\Delta TC}{\Delta q}$$



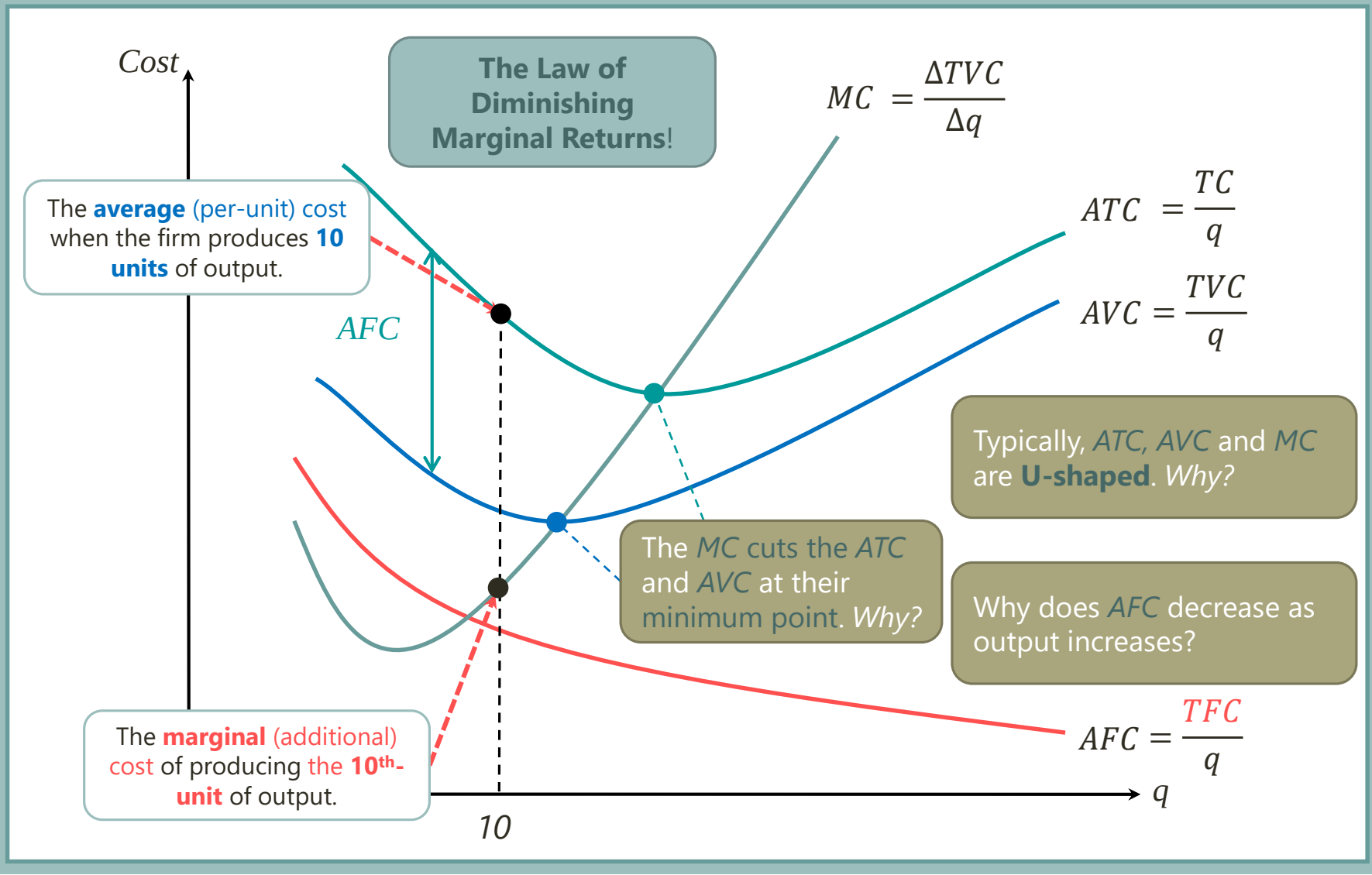
In the orange market game, the unit cost of producing that particular orange (say the 2nd unit) is called the **marginal cost**.

3. SHORT-RUN COSTS: WHAT COSTS DO FIRMS CONSIDER IN THE SHORT RUN?

- In our example, the firm's short-run average and marginal costs can be found:

q	*TFC*	*TVC*	*TC*	*MC*	*AFC*	*AVC*	*ATC*
0	150	0	150				
10	150	200	350				
34	150	400	550				
66	150	600	750				
100	150	800	950				
130	150	1000	1150				
150	150	1200	1350				

The typical **short-run average cost curves** and **the marginal cost curve**:



APPLICATION: AIR RAGE

- The United Airlines Incident, 2017: In April 2017, a passenger on a United Airlines flight in Chicago refused to give up his seat when the flight was overbooked. Police dragged him off the plane, hurting him in the process.
- Many airlines often sell more tickets than there are seats. This is called **overbooking**.
- *Why do they do this?*
  - Some passengers don't show up for their flight, so airlines try to fill every seat. Running a flight costs a lot, whether or not every seat is full. These are **fixed costs** (like fuel, and crew). If a seat goes empty, airlines' average cost will be high and they lose!
- Most of the time, if too many people show up, airlines persuade paying passengers to take a later flight by offering money, usually before boarding and someone accepts.
  - On this flight, no one took their offer (up to $1,000), so they chose people to remove from the plane instead. This made a bad situation into **a major PR disaster**.



The Economist April 15th 2017

United Airlines

Air rage

Top tip: don't refuse to cede your plane seat to an off-duty airline employee

UNITED AIRLINES urges travellers to "Fly the Friendly Skies". The company makes no promises about its customer ser-

did not work. Such bargains are best struck before boarding the plane. United, however, let passengers take their seats as it offered up to $1,000 to catch a later flight. When not enough travellers were tempted, rather than raising the price further, the crew selected four travellers for disembarkation. The man in question, a doctor aged 69 called David Dao, said he had patients to see the next day and refused to go.

As the scene looped on the world's news channels and Twitter feeds (one user, @Reflog_18, suggested the cabin layout for United below), Mr Munoz was derided for his apparent antipathy towards passengers. Before the man's identity was known, his airline became the top-trending topic on Weibo, a Chinese microblog, as rumours swirled (erroneously) that the passenger had been singled out because he was Chinese. Amid calls for a boycott, United's share price fell by nearly 4% on April 11th before recovering. That day Mr Munoz issued a fresh apology that was different in tone, saying of the forcibly removed customer that "no one should ever be mistreated this way". He promised a review of company practices, including its partnerships with law enforcement.

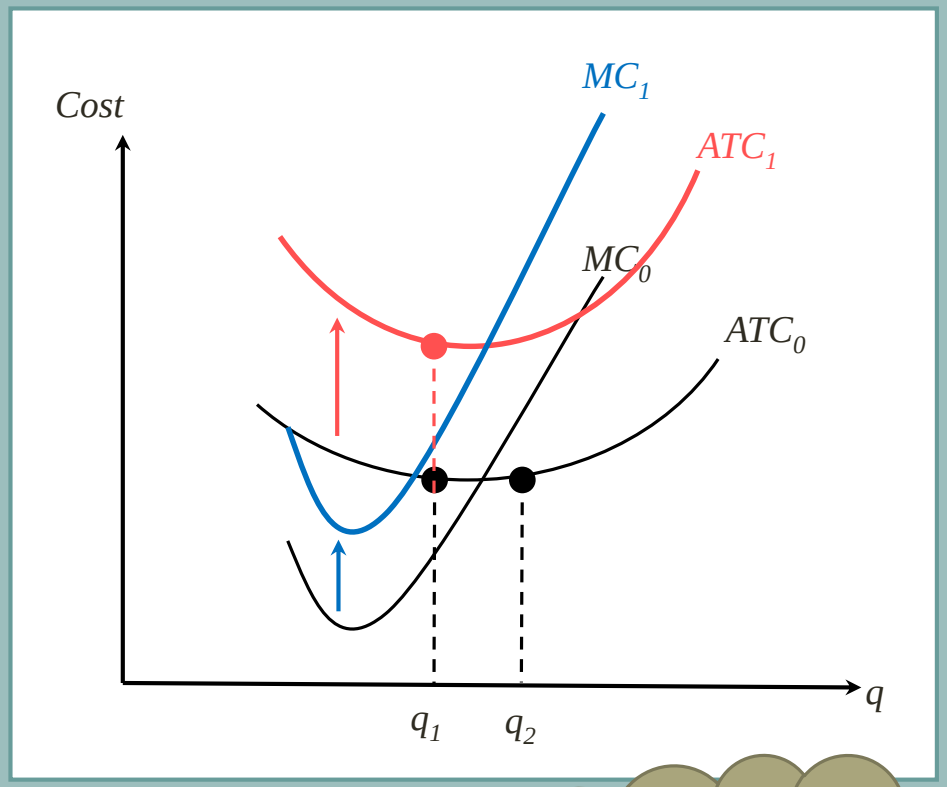
Investors are watching to see how quickly the social-media frenzy will subside. Many praise the way that Mr Munoz has run the company since his appointment in 2015. He has focused on costs and delivered pre-tax profit of $3.8bn in 2016,



(Source: Air rage, *The Economist*, April 15th, 2017.)

4. SHIFTS IN SHORT-RUN COST CURVES

- The cost curves show the relationship between cost and output, other things remain constant.
- If there are changes in *input prices* or *technology*, cost curves generally will shift to new position.
- If the price of an input changes, it is important to distinguish whether the input is a *fixed input* or *variable input*.
- An *increase* in **the price of a variable input** (e.g. wage rate of labor):
  - *TVC* and *TC* shifts *up*
  - *AVC, MC* and *ATC* shifts *up*



If cost changes because the firm changes its output level, it is shown by a movement along the cost curve.

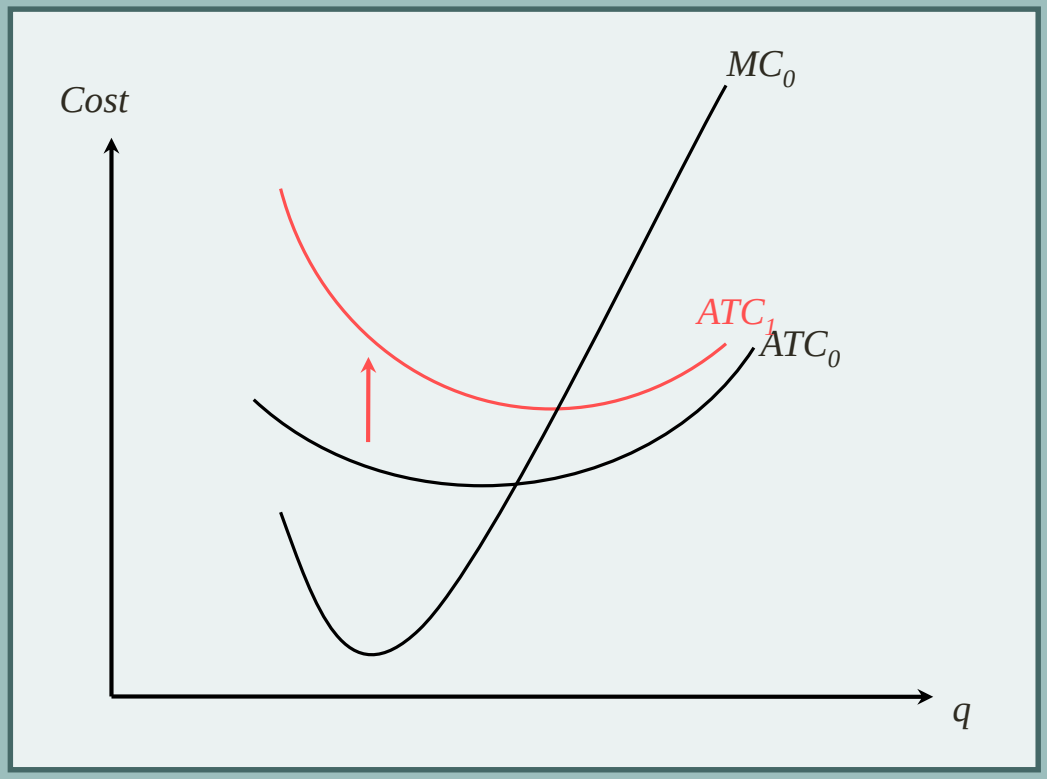
Because of other factors, the cost changes *even at the same output level.*

An *increase* in **the price of a fixed input** (e.g. rental rate of capital):

- *TFC* and *TC* shift *up*
- *AFC* and *ATC* shift *up*

Technological progress: producing the same amount of output with fewer inputs.

- *All cost curves* shift *down*



APPLICATION: FROM TREES TO TEST TUBES

- Cocoa is the main input to produce chocolate. Recently, cocoa prices have gone up a lot.
  - In December, cocoa prices hit a record high of over $12,000 per tonne – more than three times higher than just three years ago. Now, the price is around $8,000 per tonne.
  - Disease, climate change, and poor farming in countries that grow about 70% of the world's cocoa (Côte d'Ivoire and Ghana).
- ***How would the increase of cocoa prices affect the cost of chocolate makers?***



Business | From trees to test tubes

Big Chocolate has a growing taste for lab-grown cocoa

Can science solve the problem of a shortage of beans?

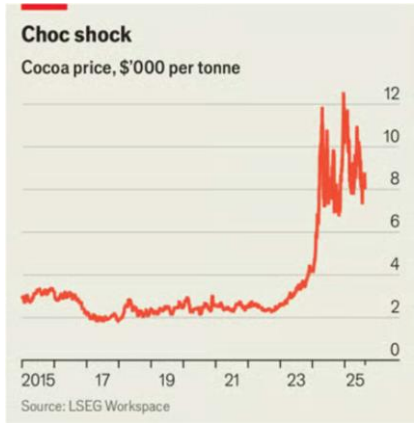
Photograph: AP

Aug 21st 2025 | 3 min read

The first half of the scientific name for the fiendishly fickle cocoa tree means "food of the gods". By the time *Theobrama cacao* was christened by Carl Linnaeus, a Swedish naturalist, in 1753, wealthy Europeans, like the Mayans before them, were already worshipping its seeds. Three centuries on, demand for cocoa, the basic ingredient for chocolate, is still climbing heavenwards. Supply cannot keep pace.

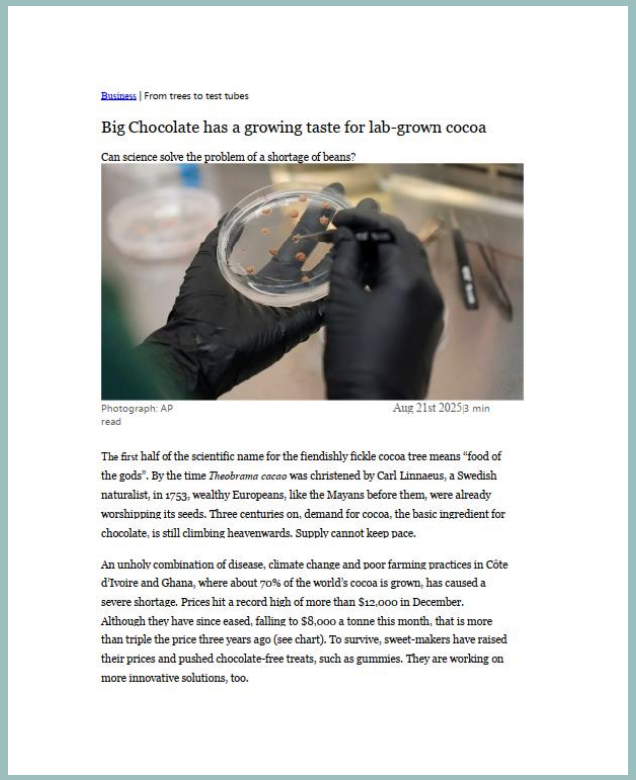
An unholy combination of disease, climate change and poor farming practices in Côte d'Ivoire and Ghana, where about 70% of the world's cocoa is grown, has caused a severe shortage. Prices hit a record high of more than $12,000 in December. Although they have since eased, falling to $8,000 a tonne this month, that is more than triple the price three years ago (see chart). To survive, sweet-makers have raised their prices and pushed chocolate-free treats, such as gummies. They are working on more innovative solutions, too.

(Source: From trees to test tubes, *The Economist*, 21 August, 2025.)



APPLICATION: FROM TREES TO TEST TUBES

- Because cocoa from trees is so expensive and unpredictable, big chocolate companies, like Lindt, Barry Callebaut, and Meiji, are investing in new technology, called **lab-grown cocoa**, made from plant cells in a laboratory.
- Making cocoa this way could become cheaper and easier than relying only on cocoa trees.
  - Lab-grown cocoa uses fewer resources and it can be produced more reliably in factories, without worrying about weather and plant diseases.
- ***How would the adoption of this new technology affect the cost of chocolate makers?***



Business | From trees to test tubes

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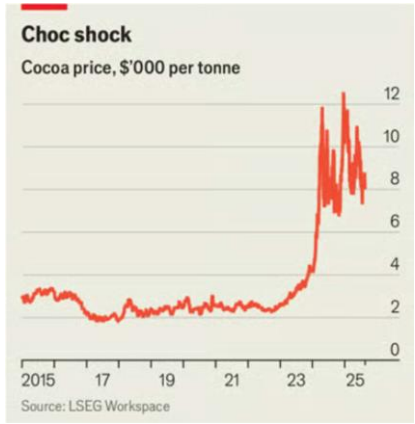
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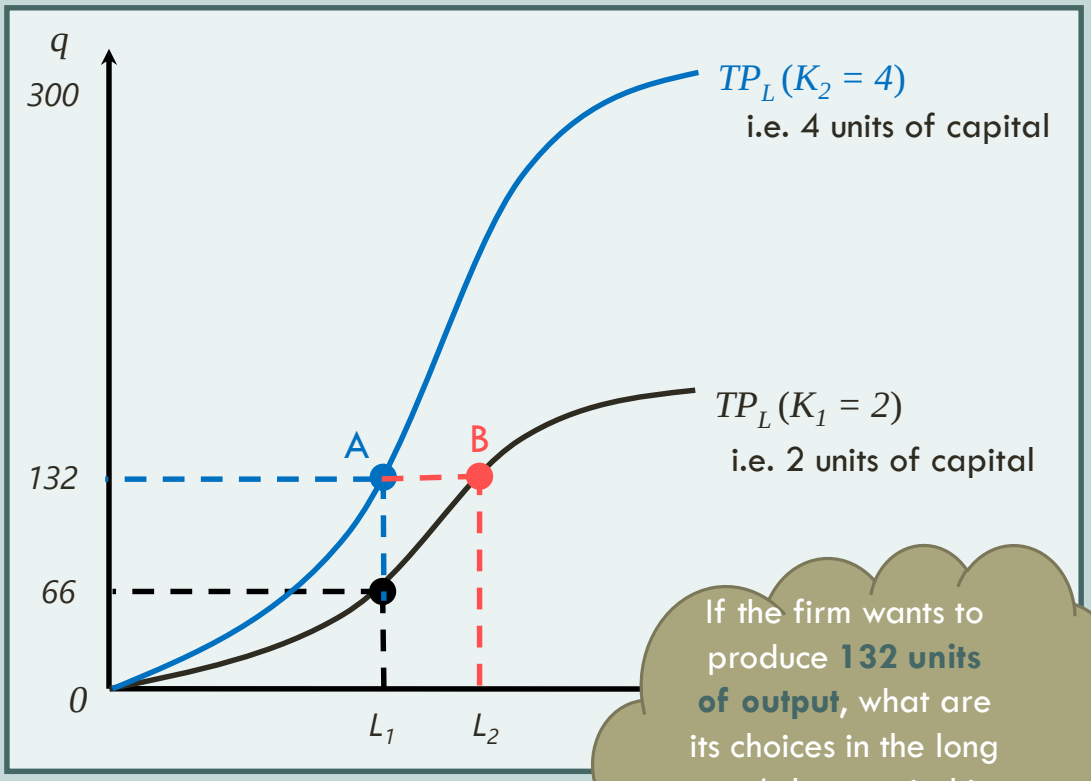
APPLICATION: MIST A SPOT

- Fully 3 million tonnes of pesticides are sprayed annually onto crops worldwide every year, of which only a small fraction are needed. Global pesticide sales reached $79 billion in 2022.
  - **Overuse of pesticides** have significant damaging environmental and health effects.
- **Precision Spraying** with AI (including camera-based sensors on spray booms, real-time analysis of spray effectiveness, and so on), developed by AgZen – a firm spun out of the MIT, are promised by AgZen, offers a potential solution.
  - ***Results?***
    - 30-50% saving on chemical costs.
    - Reduces fungicide and insecticide use by ~90%
- Reduces chemical runoff and gricultural waste and improve crop health (sustainability), also lower production costs for farmers (economic)!



(Source: Mist a Spot, *The Economist*, May 8th 2024)

5. FROM THE SHORT RUN TO LONG RUN: LONG-RUN COSTS



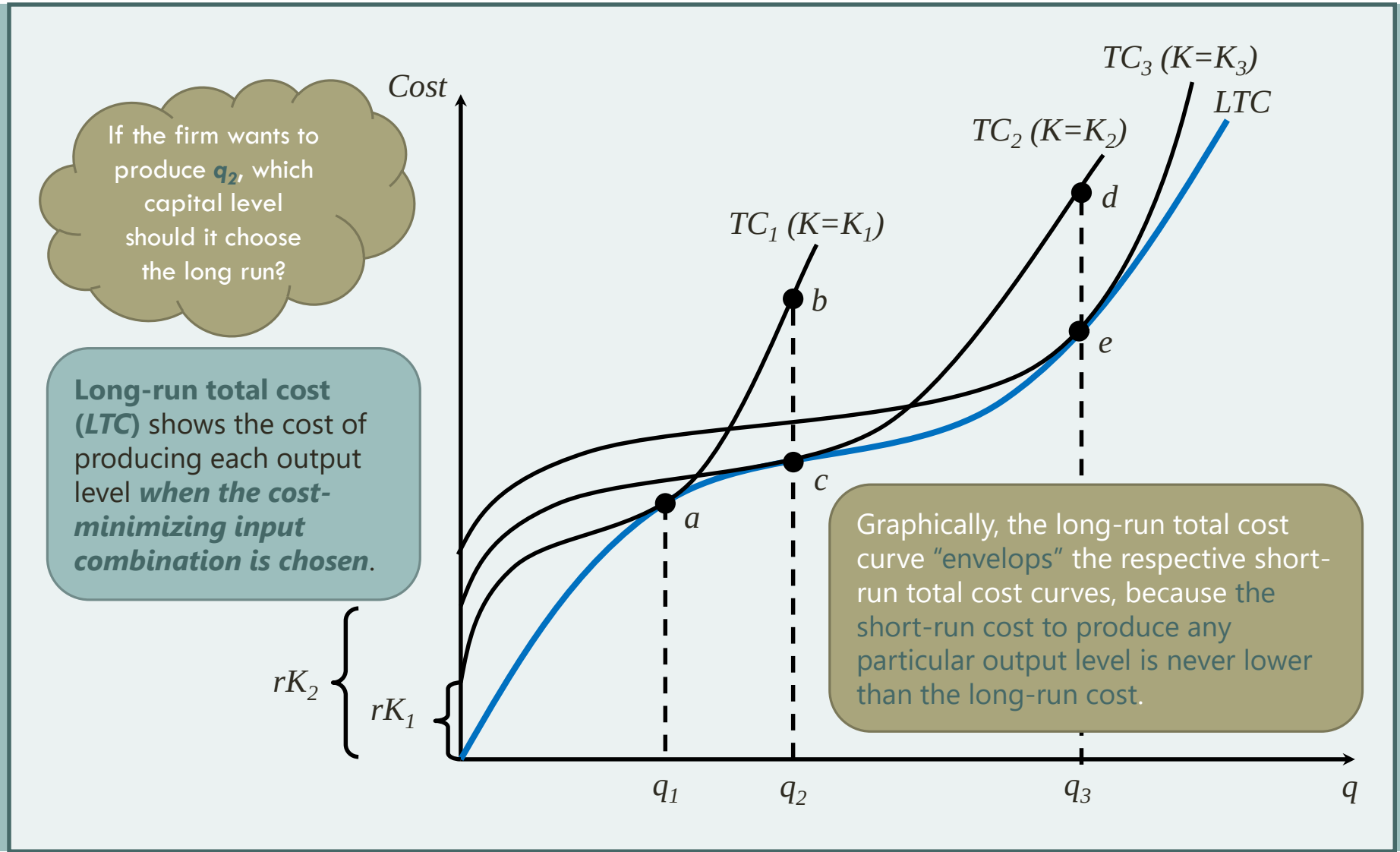




If the firm wants to produce **132 units of output**, what are its choices in the long run (when capital is no longer fixed)? Which one should it choose?

- In the long run, all inputs are variable, because even machines and buildings can be built, purchased, expanded, or sold hiring and firing labors over a longer period of time.
  - The **scale of production**, which determines production capacity, relates to the amount of capital (which is fixed factors in the short run) that a firm has.
- *How would the firm choose the optimal input combination?*
  - Among all the possible input combinations, the firm chooses the one with the lowest costs

- By considering all possible choices in capital input, we can find the relationship between the output and the firm's long-run costs.

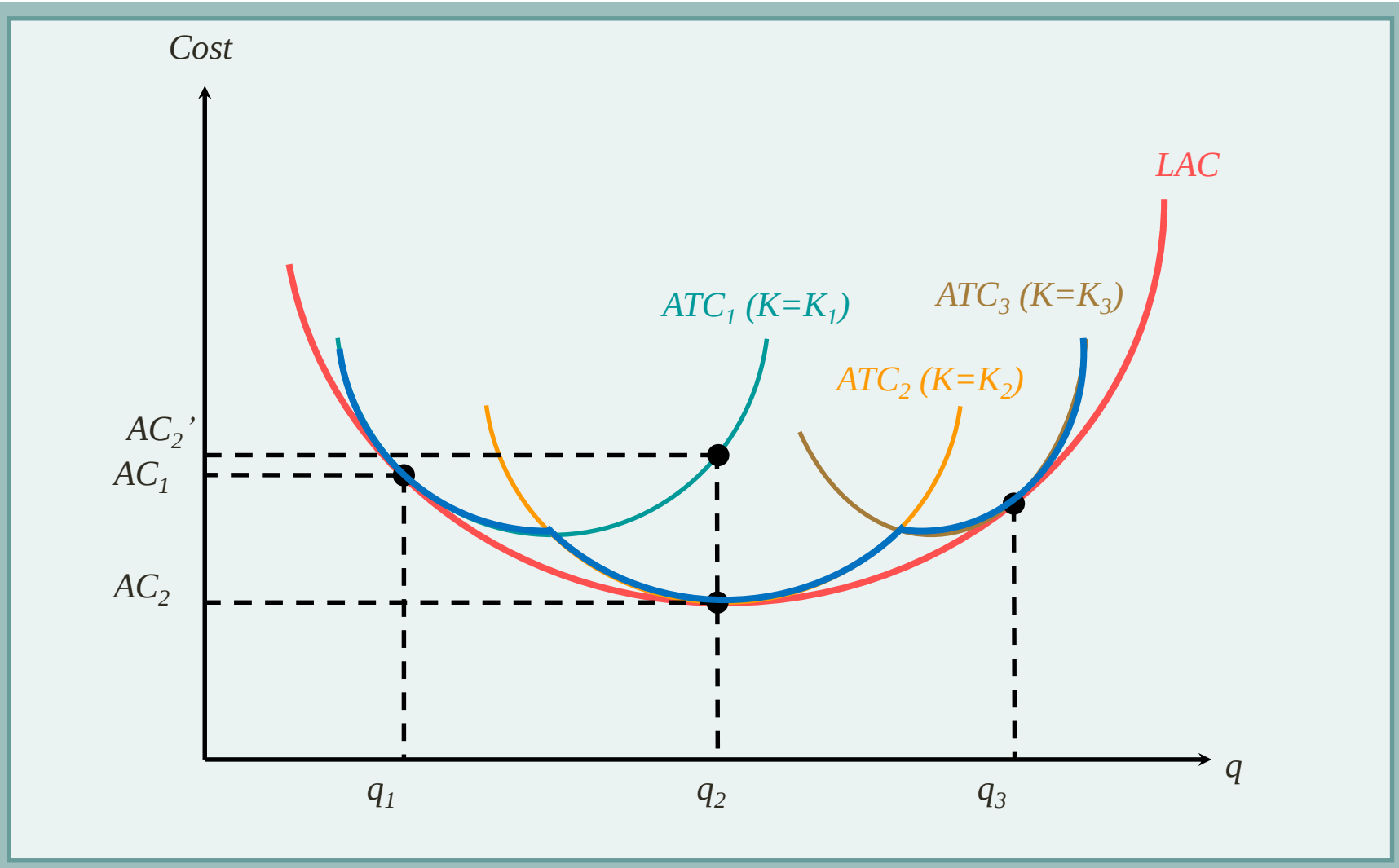


- **Long-run average cost (*LAC*)**: production costs *per unit* of output *in the long run*.

$$LAC = \frac{LTC}{q}$$

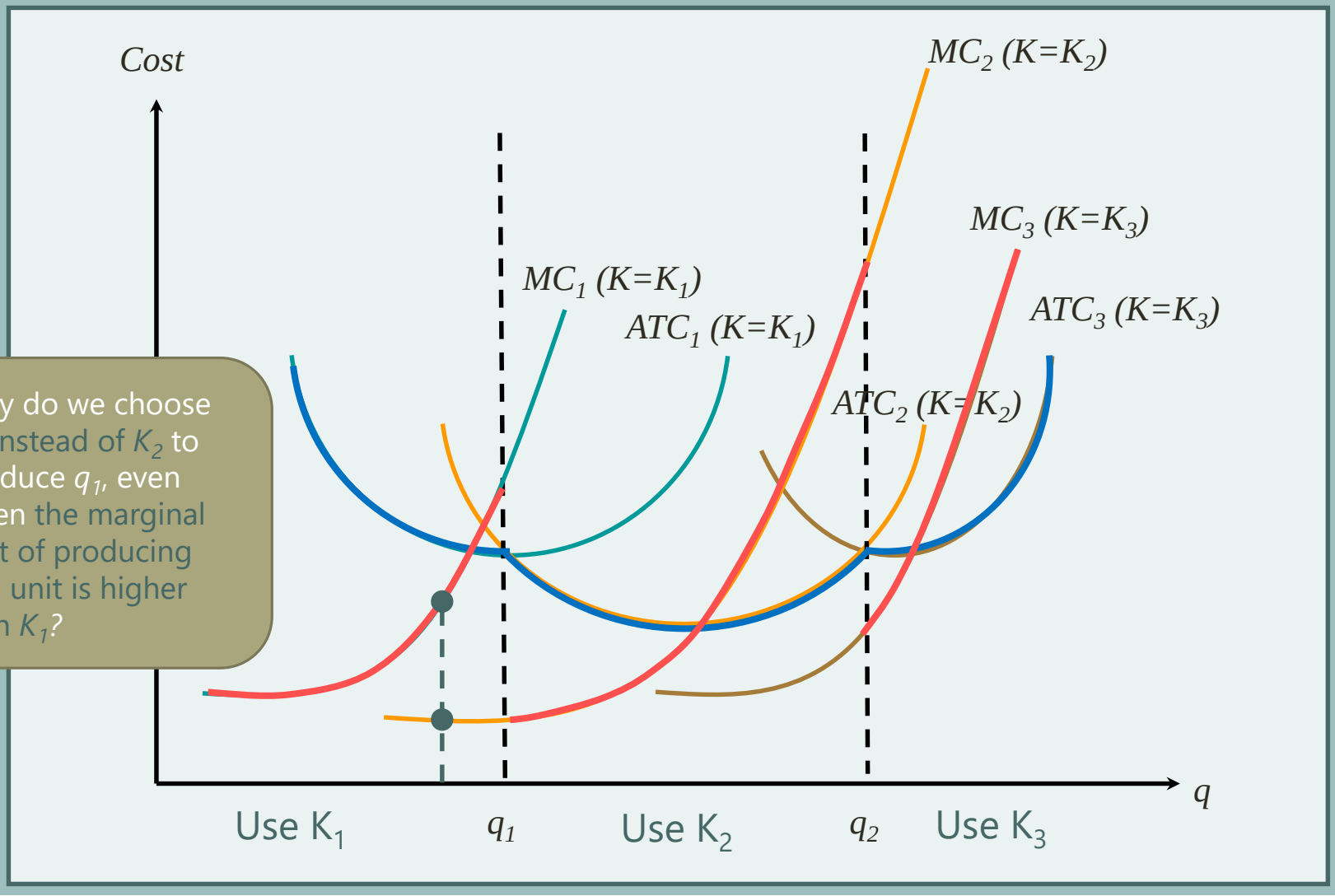
- Similarly, *LAC* curve "envelops" all the *ATC* curves.

Choosing an input combination minimizing *LTC* is equivalent to "minimizing *LAC*".

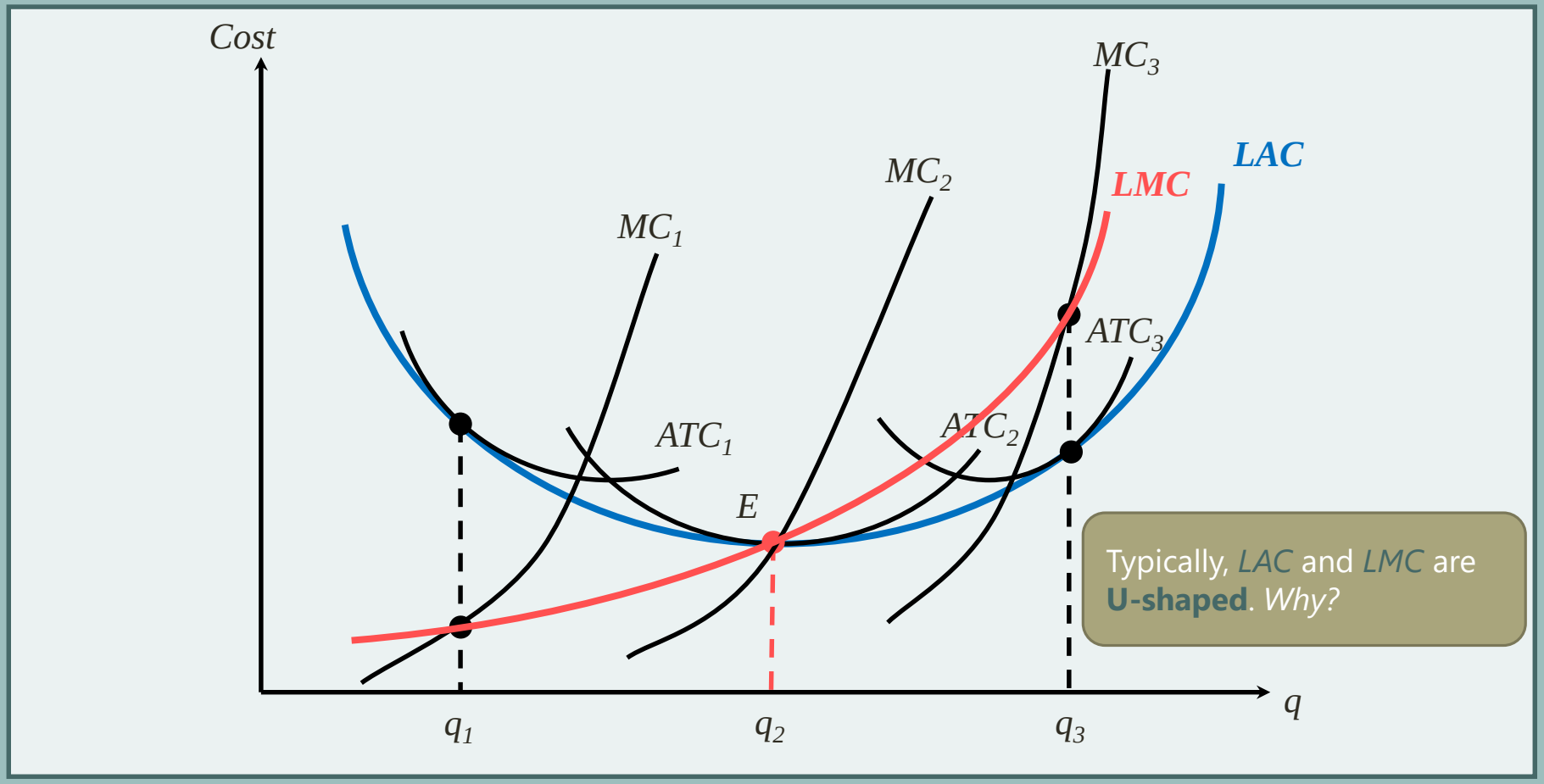


- **Long-run marginal cost (*LMC*)**: the additional cost incurred by producing one more unit of output *in the long run*.

$$LAC = \frac{\Delta LTC}{\Delta q}$$



The relationship between short-run cost curves and long-run cost curves can be shown:



6. RETURNS TO SCALE

- **Returns to scale**: to measure how output responds to increases in *all* inputs together.

- When all inputs are increased by a certain percentage, a firm's production exhibits:

  - **constant returns to scale** if output increases by the *same percentage*
    - E.g. doubling all its inputs, a firm doubles its outputs.

  - **increasing returns to scale** if it results in *more-than-proportionate* increase in output
    - E.g. doubling all its inputs, a firm's outputs will increase by more than doubled.

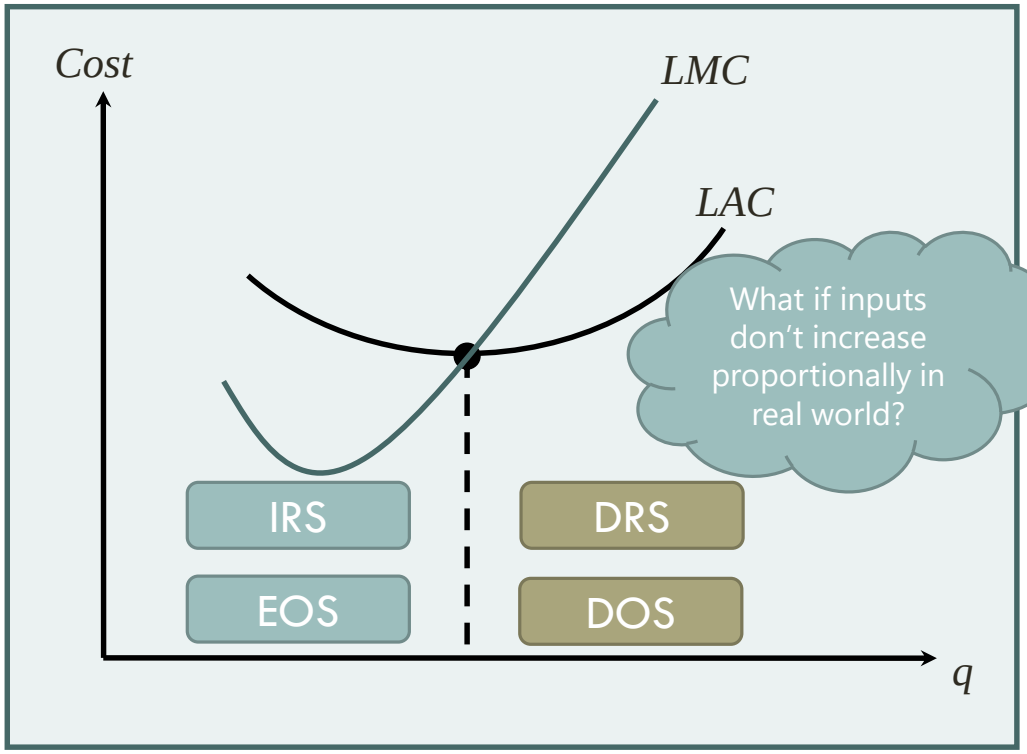
  - **decreasing returns to scale** if it results in *less-than-proportionate* increase in output
    - E.g. doubling all its inputs, a firm's outputs will increase, but less than doubled

6. RETURNS TO SCALE

- *How does it relate to costs?*

Production Function	Employing L, K: q is produced	To produce q, it requires: L , K	LTC (C) $= wL + rK$	$LAC = LTC/q$
Returns to Scale	**Doubling both inputs results in:**	**To produce $2q$, it requires:**	***LTC***	***LAC:***
Constant				
Increasing				
Decreasing				

6. RETURNS TO SCALE



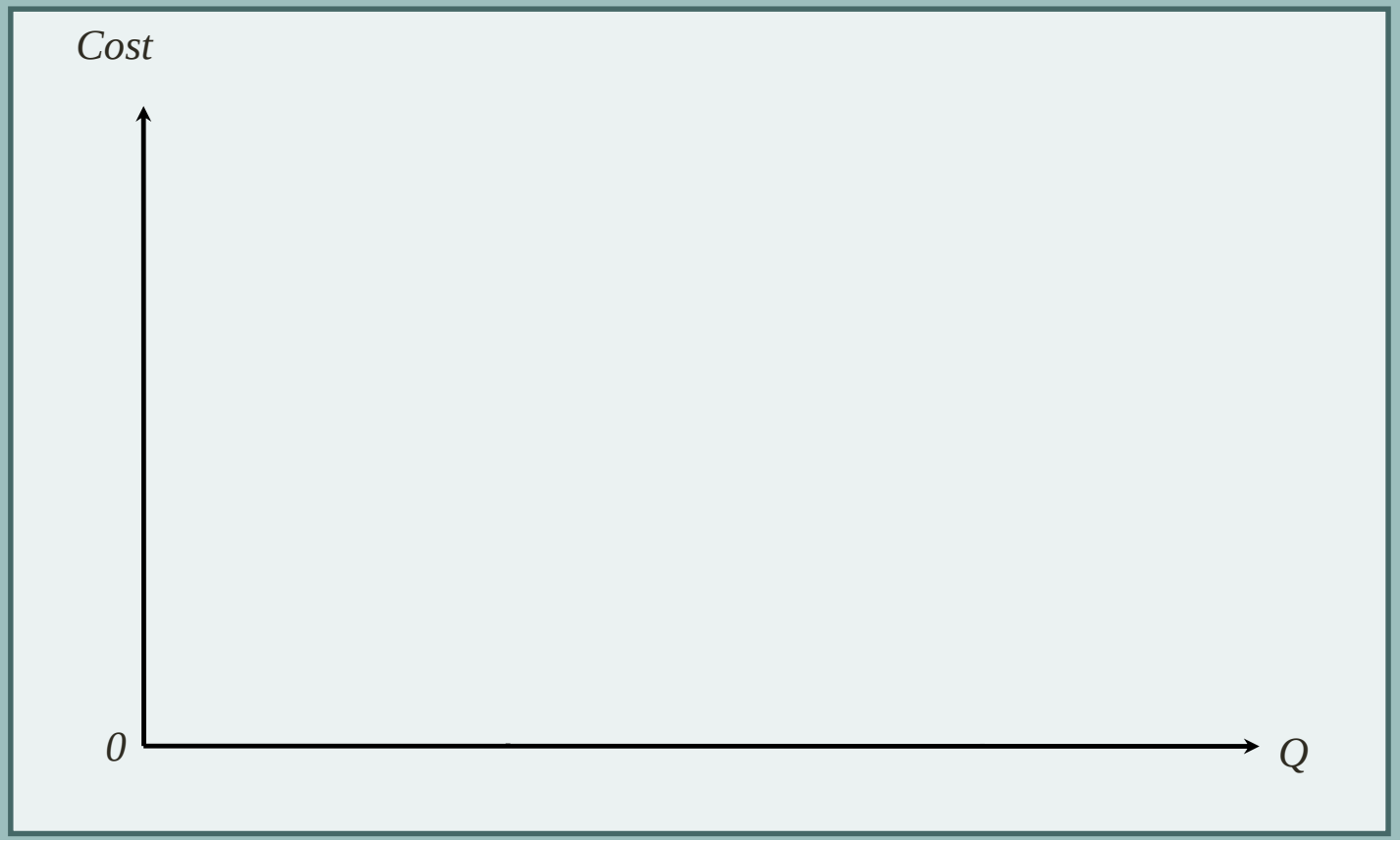
- **Economies of scale:** the average cost falls as output increases
- **Diseconomies of scale:** the average cost rises as output increases

- In real world, when firms increase their output level, their production typically shows:
  - Increasing Returns to Scale when output and firm size are small
  - Constant Returns to Scale when medium output and firm size
  - Decreasing Returns to Scale when very large output and firm size

- Why?
- **Specialization**
- Spreading costs of **indivisible inputs**
  - Indivisible inputs are usually resources or equipment that can only be added in large, whole units – not in small pieces or fractions – as output increases.
- **Managerial difficulties**

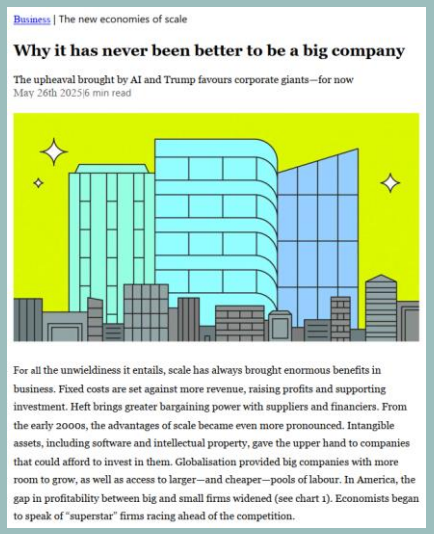
6. RETURNS TO SCALE

- Although our figure shows a U-shaped long-run average cost (LAC) curve, in reality, economists have found that long-run average costs usually fall at low levels of output. After reaching a certain level of output, average costs tend to remain flat for a range of output, rather than increasing right away. This flat part of the curve reflects **constant returns to scale**.



APPLICATION: THE NEW ECONOMIES OF SCALE

- **AI (Artificial Intelligence)**, especially for large, custom AI models and deep integrations, is a new way big companies get the cost advantages from **economies of scale**.
  - JPMorgan Chase, a giant bank, now uses AI tools for most of its 320,000 employees! UnitedHealth has over 1,000 different AI applications.
  - **Big companies can invest much more in AI** than small businesses. For example, in 2024, large US companies (with more than $5 billion in revenue) spent about $27 million per year on generative AI projects. Smaller companies spent around $9 million.
  - **AI works better with more data**, and big firms have huge amounts of data to train smarter AI systems. This gives them better insights, automations, and helps cut costs.
  - **Implementing AI is expensive and complex.** It's easier for big businesses to afford the money and staff needed to set up and customize AI tools.
- All these advantages mean big firms can spread their **high AI costs** over more sales, lowering their average costs as they grow.



Business | The new economies of scale

Why it has never been better to be a big company

The upheaval brought by AI and Trump favours corporate giants—for now

May 26th 2025|6 min read

For all the unwieldiness it entails, scale has always brought enormous benefits in business. Fixed costs are set against more revenue, raising profits and supporting investment. Heft brings greater bargaining power with suppliers and financiers. From the early 2000s, the advantages of scale became even more pronounced. Intangible assets, including software and intellectual property, gave the upper hand to companies that could afford to invest in them. Globalisation provided big companies with more room to grow, as well as access to larger—and cheaper—pools of labour. In America, the gap in profitability between big and small firms widened (see chart 1). Economists began to speak of "superstar" firms racing ahead of the competition.

(Source: The new economies of scale, *The Economist*, 26 May, 2025.)

6. RETURNS TO SCALE

- The biggest obstacle to achieve economies of scale is that the market demand for the product may not be large enough.
- In many real-world cases, a firm produces two or more goods (usually related).
  - **Economies of scope**: It is less expensive to produce two goods (usually related) jointly than separately.





APPLICATION: HOW TO ACHIEVE **ECONOMIES OF SCOPE?**

- One common way is to produce very similar (essentially the same) products and sell it to the public. Here are some examples:
  - Software packages: The company usually designs the professional version (the full version) first, and disable certain features for the mass market version! Why?
  - IBM's "LaserWriter E", a low-end laser printer, turned out to be exactly the same piece of equipment as their high-end product – except there was an additional chip in the cheaper version to slow it down!
  - Intel, the chip manufacturer, using a similar strategy by selling two similar clips.

Consider Bandai, a Japanese toy manufacturer. Can you see the differences between the following models?







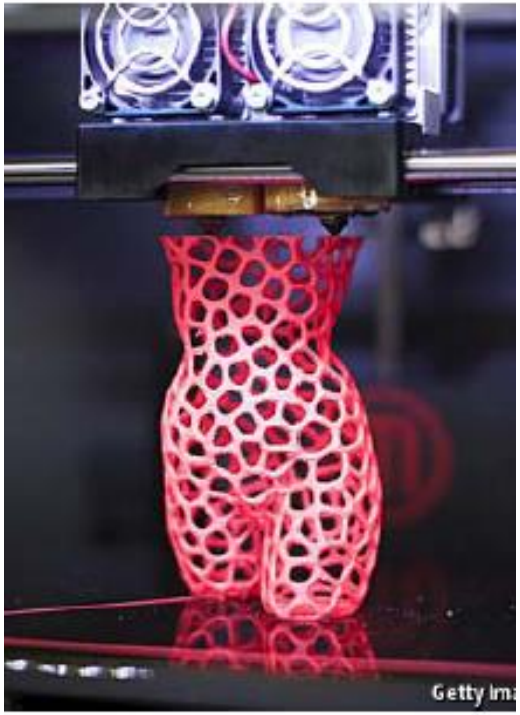








- An example of **economies of scope**:
  - Bandai produces several different specific plastic models by pouring molten plastic in the same molds for most of the parts (*the indivisible input*!)



Source: How 3D printing will transform mass production, *Financial Times*, Oct 7th, 2019



APPLICATION: HOW 3D PRINTING WILL TRANSFORM MASS PRODUCTION

- The rise of **3D printing**, or **addictive manufacturing**, is set to disrupt the old way of manufacturing. Traditionally, big companies enjoyed economies of scale. However, 3D printing will change that:

- Little or No ***Economies of Scale***:
  - The cost of making one unit or many units is about the same. This is why addictive manufacturing is ideal for small productions runs.

- Affordable **Mass Customization** :
  - 3D printing makes it practical and affordable to create complex, individualized designs for customers.
    - Companies like, Daihatsu (Japan) lets buyers personalize car parts using 3D printers — something only super-luxury brands, such as Rolls-Royce and Ferraris, could offer before.

APPLICATION: HOW 3D PRINTING WILL TRANSFORM MASS PRODUCTION



- ***Cutting Material and Waste***:
  - 3D printing builds objects layer by layer, so you only use as much material as you need, making products lighter and saving material costs
  - In Formula 1 racing, cutting even one kilogram from a car's weight can be worth more than $120,000!
  - It is also environmental friendly.

Weighty matters

	Value of weight saving, $/kg
F1 motorsport	More than 120,000
Spacecraft	25,000
Aircraft	1,200-13,000
Automotive	20-600
Trucks, excavators, etc	1.3-12.7
Factory equipment	0-6

Source: Marcus Pont, Domin Fluid Power, 2017

omist.com

- ***Faster and Flexible Production***:
  - In California, Palari Homes and Mighty Buildings can build a house in less than 24 hours using factory-printed 3D parts. In Malawi, 14Trees can print a house in just 12 hours, for less than US$10,000.
  - Some companies, by automating 80% of the 3D printing process, need only 5% of the usual labor.

(Source: How 3D printing will transform mass production, *Financial Times,* Oct 7th, 2019; Making things anew, *The Economist*, July 1st, 2017; A printed smile, *The Economist*, April 30th, 2016; Solid print, *The Economist*, April 21th, 2012; How 3D printers work, *The Economist*, Sept 7th 2013.)

APPLICATION: HOW 3D PRINTING WILL TRANSFORM MASS PRODUCTION

Why Tariffs Could Be the Tipping Point for Industrial 3D Printing Adoption

By Charles Goulding on September 20th, 2025 in news, Usage
Tags: manufacturing, reshoring, supply chain innovation, tariffs



Metal and industrial 3D printed parts – finished parts (e.g., aerospace or manufacturing components [Source: AMFG]



- Recently, the U.S. and other countries have introduced new tariffs (15-20% or more) on many imported goods. This makes buying parts from overseas much costlier, especially for companies like Caterpillar, GE, and Ford.

- **3D printing offers a solution:**
  - Companies can "reshore" production, making parts locally via 3D printing, avoiding tariffs.
  - This reduces supply chain risks, lowers shipping costs, and speeds up delivery.
  - Many big firms and the military are already doing this, printing spare parts and even medical devices on-site.

Source: Why Tariffs Could Be the Tipping Point for Industrial 3D Printing Adoption, *Fabbaloo,* September 20th, 2025.