Module 2 — The Pin Factory

Division of Labour, Specialisation, and Trade

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From Smith to Simulation

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Part I — The History

The Most Famous Factory in Economics

The Wealth of Nations opens not with grand theory but with a visit to a **pin factory**:

> *"One man draws out the wire, another straights it, a third cuts it, a fourth points it, a fifth grinds it at the top for receiving the head. . . "*
>
> — Adam Smith, *WN*, Book I, Ch. 1

Smith counted 18 distinct operations in making a single pin.

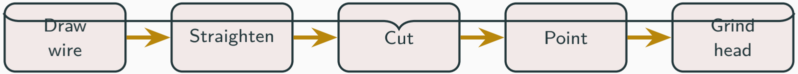
The Numbers

Alone	$\sim$ 20 pins/day
Team of 10	$\sim$ 48,000 pins/day
Per worker	$\sim$ 4,800 pins/day

A **240-fold increase** from specialisation alone.

The Pin Factory Pipeline

One pin every few seconds



. . . 18 operations divided among 10 workers . . .

The **pipeline** means each worker repeats one task all day. The factory's throughput is determined by its bottleneck — the slowest station.

Why Does Specialisation Work?

Smith identified three reasons:

1. **Skill improvement.** A worker who performs one task all day becomes extraordinarily good at it — faster, more precise, more consistent.
2. **Time saving.** No time wasted switching between tasks, moving between workstations, or picking up different tools.
3. **Innovation.** Workers focused on a single task are more likely to invent machines or methods that improve it.

Key Quote

Smith noted that many early industrial machines were invented by *workers themselves*, not by scientists.

The Extent of the Market

"The division of labour is limited by the extent of the market."

— Adam Smith, *WN*, Book I, Ch. 3

Small Village

- Too few customers to justify 10 specialist pin-makers.
- Workers remain generalists.
- Low productivity persists.

Large City / Seaport

- Enough demand for specialised factories.
- Each worker masters one operation.
- Productivity soars.

Specialisation requires scale. Trade expands the market and thereby deepens the division of labour.

From Pin Factories to Nations

Smith extended the logic of specialisation from factories to countries:

- Just as workers should specialise in what they do best, **nations** should trade rather than produce everything domestically.
- This idea was refined forty years later by **David Ricardo** (1772–1823).

"Under a system of perfectly free commerce, each country naturally devotes its capital and labour to such employments as are most beneficial to each."

— David Ricardo, *Principles of Political Economy* (1817), Ch. 7

Comparative Advantage: The Big Idea

Ricardo proved something remarkable:

Absolute vs. Comparative Advantage

- **Absolute advantage:** who produces a good with fewer resources.
- **Comparative advantage:** who produces a good at the lowest opportunity cost.

Even if one country is better at producing *everything*, both countries still gain from trade.

What matters is not who is best overall but **who gives up less** to produce each good.

This is one of the most counterintuitive — and most important — results in all of economics.

Edinburgh Connection

- The pin factory Smith described was likely based on factories near **Edinburgh and Kirkcaldy**.
- In the 1760s Scotland's manufacturing was booming: linen, iron, metalwork.
- Edinburgh's merchants were embedded in international trade networks.
- The Old Town's closes and wynds were full of workshops where the division of labour was already visible in miniature.

Smith's Genius

He saw in these ordinary workshops a **universal principle**: specialisation creates wealth.

Part II — The Computation

Setting Up

```
import numpy as np
import matplotlib.pyplot as plt
```

- `numpy` — numerical arrays and operations
- `matplotlib` — plotting

Today we will:

1. Simulate Smith's pin factory
2. Plot how productivity rises with specialisation
3. Compute Ricardo's comparative advantage
4. Visualise the gains from trade

Simulating the Pin Factory (I)

Parameters:

```
n_steps = 18  # distinct operations to make a pin
working_day = 600  # minutes (10 hours)

# GENERALIST: slow at everything, switching costs
time_per_step_generalist = 3.0  # minutes per step
switching_cost = 1.0            # minutes lost per switch

# SPECIALIST: fast through practice, no switching
time_per_step_specialist = 0.5  # 6x faster
switching_cost_specialist = 0.0
```

Key modelling choices:

- Specialists are **6**× faster per step (skill improvement)
- Switching between tasks wastes 1 minute each time

Simulating the Pin Factory (II)

```
# GENERALIST: time to make one pin
time_per_pin = n_steps * 3.0 + (n_steps - 1) * 1.0
pins_per_day_generalist = working_day / time_per_pin
# => 71 min/pin => 8.5 pins/day

# SPECIALIST TEAM: 10 workers in a pipeline
n_workers = 10
steps_per_worker = n_steps / n_workers  # ~1.8 steps
bottleneck_time = np.ceil(steps_per_worker) * 0.5
pins_per_day_total = working_day / bottleneck_time
# => 600 pins/day total, 60 per worker
```

Generalist

71 min/pin $\Rightarrow$ **8.5** pins/day

Specialist Team

1 min/pin $\Rightarrow$ **60** pins/worker/day

Even our simple model produces a 7$\times$ gain. Smith observed 240$\times$ in practice — the real world has even stronger learning effects.

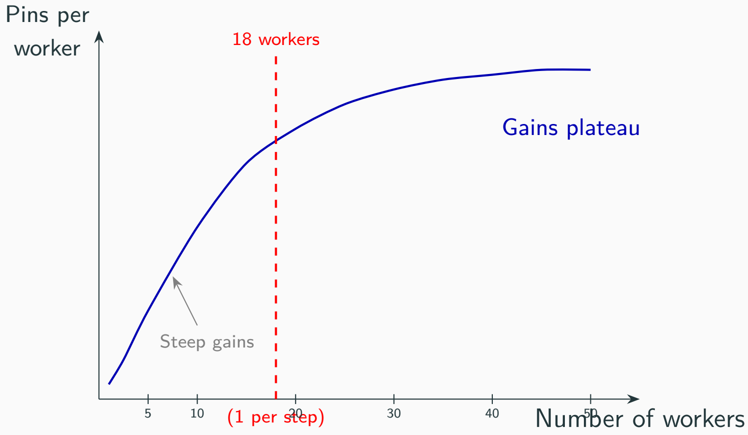
Productivity vs. Number of Specialists

```
def pins_per_worker(n_workers, n_steps=18,
    t_specialist=0.5, t_generalist=3.0,
    switch_cost=1.0, day=600):
    if n_workers == 1:
        time_per_pin = (n_steps * t_generalist
                        + (n_steps - 1) * switch_cost)
        return day / time_per_pin
    steps_each = max(1, n_steps / min(n_workers, n_steps))
    effective_time = t_specialist * steps_each**0.3
    bottleneck = np.ceil(steps_each) * effective_time
    total_pins = day / bottleneck
    return total_pins / n_workers
```

The model captures:

- **Pipeline throughput** limited by the bottleneck worker
- **Learning curve**: fewer steps per worker $\Rightarrow$ faster per step (time $\propto$ steps$^{0.3}$)

Productivity Rises with Specialisation



Output per worker rises steeply as workers specialise in fewer steps. Beyond 18 workers (one per step), gains plateau — the division of labour is limited by the number of distinct tasks.

Ricardo's Two-Country Model

Consider **Scotland** and **Portugal** producing **cloth** and **wine**:

	Hours per cloth	Hours per wine
Scotland	100	120
Portugal	90	80

- Portugal is better at producing *both* goods (**absolute advantage** in everything).
- A naive analysis: Portugal has nothing to gain from trading with Scotland.
- Ricardo proved this wrong.

Computing Opportunity Costs

```python
scotland_cloth, scotland_wine = 100, 120
portugal_cloth, portugal_wine = 90,  80

# Opportunity cost of 1 cloth (in wine forgone)
opp_cloth_scot = scotland_cloth / scotland_wine  # 0.833
opp_cloth_port = portugal_cloth / portugal_wine  # 1.125

# Opportunity cost of 1 wine (in cloth forgone)
opp_wine_scot = scotland_wine / scotland_cloth  # 1.200
opp_wine_port = portugal_wine / portugal_cloth  # 0.889
```

Scotland

1 cloth costs **0.833** wine

1 wine costs 1.200 cloth

Portugal

1 cloth costs 1.125 wine

1 wine costs **0.889** cloth

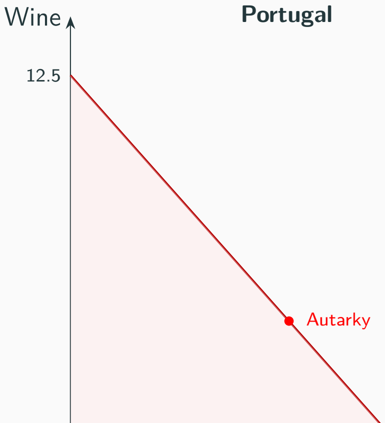
Who Has Comparative Advantage?

- Scotland gives up *less wine* to make cloth $\Rightarrow$ CA in **cloth**.
- Portugal gives up *less cloth* to make wine $\Rightarrow$ CA in **wine**.
- Each country specialises in the good where its opportunity cost is lower.

The Production Possibility Frontier

Each country has $L = 1{,}000$ labour hours. The PPF shows all feasible combinations of cloth and wine:

$$Q_{\text{wine}} = \frac{L - c_{\text{cloth}} \cdot Q_{\text{cloth}}}{c_{\text{wine}}}$$



PPF in Python

```python
total_hours = 1000

def ppf(Q_cloth, cost_cloth, cost_wine, hours=1000):
    """Maximum wine given cloth production."""
    hours_left = hours - cost_cloth * Q_cloth
    return np.maximum(hours_left / cost_wine, 0)

scot_max_cloth = total_hours / 100   # 10.0
scot_max_wine  = total_hours / 120   # 8.33
port_max_cloth = total_hours / 90    # 11.11
port_max_wine  = total_hours / 80    # 12.5

cloth_s = np.linspace(0, scot_max_cloth, 100)
cloth_p = np.linspace(0, port_max_cloth, 100)

plt.plot(cloth_s, ppf(cloth_s, 100, 120), label='Scotland')
plt.plot(cloth_p, ppf(cloth_p, 90, 80),  label='Portugal')
plt.xlabel('Cloth'); plt.ylabel('Wine')
plt.legend(); plt.show()
```

Autarky: No Trade

Suppose each country splits its 1,000 hours equally:

```
half = 500  # hours on each good

scot_cloth_a = 500 / 100  # 5.0
scot_wine_a  = 500 / 120  # 4.17
port_cloth_a = 500 / 90   # 5.56
port_wine_a  = 500 / 80   # 6.25

world_cloth_a = 5.0 + 5.56   # 10.56
world_wine_a  = 4.17 + 6.25  # 10.42
```

	Cloth	Wine
Scotland	5.00	4.17
Portugal	5.56	6.25
World	**10.56**	**10.42**

Specialisation + Trade

Each country produces *only* its comparative-advantage good:

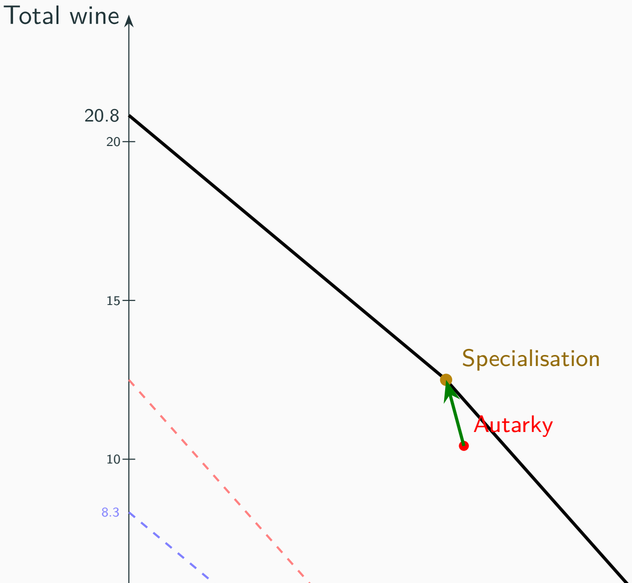
```
# Scotland: all labour on cloth
scot_cloth_t = 1000 / 100  # 10.0 cloth, 0 wine
# Portugal: all labour on wine
port_wine_t  = 1000 / 80   # 12.5 wine, 0 cloth

world_cloth_t = 10.0   # vs 10.56 autarky
world_wine_t  = 12.5   # vs 10.42 autarky
```

	Cloth	Wine
Autarky	10.56	10.42
Specialisation	10.00	12.50
Change	−0.56	+2.08

Full specialisation produces much more wine at a small cost in cloth. The net gain is positive: the world is richer overall.

Gains from Trade: The World PPF



Terms of Trade

Specialisation creates a surplus. But who gets it? That depends on the terms of trade.

For trade to benefit **both** countries, the price of cloth (in wine) must lie between the two opportunity costs:

$$\underbrace{0.833}_{\text{Scotland's OC}} < \text{price of cloth} < \underbrace{1.125}_{\text{Portugal's OC}}$$

Example: 1 cloth $= 1$ wine

Scotland produces 10 cloth, keeps 5, trades 5 for 5 wine.
Portugal produces 12.5 wine, keeps 7.5, trades 5 for 5 cloth.

Both end up with more than under autarky.

Computing the Terms of Trade

```
terms_of_trade = 1.0  # 1 cloth = 1 wine

# Scotland: produces 10 cloth, keeps 5, trades 5
scot_keeps_cloth = 5
scot_gets_wine = 5 * terms_of_trade  # = 5.0
# Autarky: 5.0 cloth, 4.17 wine
# Trade:   5.0 cloth, 5.0 wine  => +0.83 wine!

# Portugal: produces 12.5 wine, sends 5, keeps 7.5
port_gets_cloth = 5
port_keeps_wine = 12.5 - 5.0  # = 7.5
# Autarky: 5.56 cloth, 6.25 wine
# Trade:   5.0 cloth, 7.5 wine  => +1.25 wine!
```

Ricardo's comparative advantage in action: both countries consume more than they could produce alone.

Part III — Exercises & Discussion

Exercise 1: The Extent of the Market

Smith wrote: *"the division of labour is limited by the extent of the market."*

A town consumes $D = 0.5 \times$ population pins per day.

- Generalist: 10 pins/day (cost $=$ wage / 10 per pin).
- Specialist team of 10: 4,800 pins/day (cost $= 10 \times$ wage / 4,800 per pin).

(a) What is the minimum population that justifies a specialist pin factory?

(b) Plot cost per pin under each mode as a function of daily demand. At what demand does specialisation become cheaper?

(c) Smith observed specialisation is most extreme in large cities and near seaports. Explain why in 2–3 sentences.

Exercise 2: Three-Country Comparative Advantage

Extend Ricardo's model to three countries:

	Hours per cloth	Hours per wine
Scotland	100	120
Portugal	90	80
France	110	90

Each country has 1,000 hours.

(a) Compute opportunity cost of cloth for all three countries. Who has strongest CA in cloth? In wine?

(b) Under autarky (50/50 split), what is world output?

(c) Under full specialisation (one country must split production), find the allocation that maximises world output.
Hint: rank countries by opportunity cost of cloth.

(d) Compute the gains from trade.

Exercise 3: Learning by Doing

Smith's first reason for specialisation: practice improves skill. Model with a **learning curve**:

$$t(n) = t_0 \cdot n^{-\beta}$$

where $t(n)$ = time for the n-th repetition, t_0 = first attempt, $\beta > 0$ = learning rate.

(a) A generalist performs each of 18 tasks 30 times/day. A specialist performs 1 task 540 times/day. Using $t_0 = 5$ min and $\beta = 0.3$, compute the average time per task for each.

(b) Plot $t(n)$ for $n = 1$ to 1,000. When does the learning curve flatten?

(c) Compute total pins per day for a 10-worker specialist team with learning effects vs. a generalist with learning effects. How does the learning curve amplify specialisation gains?

Quiz

Quiz — Conceptual Questions (I)

Q1. Which is **not** one of Smith's three reasons for specialisation?

(a) Workers become more skilled through repetition
(b) Workers save time by not switching between tasks
(c) Workers are paid lower wages when they specialise
(d) Specialised workers are more likely to invent improvements

Q2. Smith's pin factory showed that 10 workers with division of labour could produce roughly:

(a) 10 times more than 10 generalists
(b) 50 times more than 10 generalists
(c) 240 times more per worker than a generalist
(d) The same amount, but at lower cost

Quiz — Conceptual Questions (II)

Q3. "The division of labour is limited by the extent of the market" means:

(a) Markets should be regulated to prevent over-specialisation
(b) Specialisation only pays off with enough customers
(c) Large markets lead to monopolies
(d) Division of labour only works in manufacturing

Q4. Comparative advantage means:

(a) A country can produce a good more cheaply in absolute terms
(b) A country gives up less of another good to produce one unit
(c) A country has more natural resources
(d) A country has lower wages

Q5. Portugal has absolute advantage in both goods. Scotland has CA in cloth. Ricardo says:

(a) Portugal should produce both; Scotland imports everything
(b) Scotland specialises in cloth, Portugal in wine; they trade

Quiz — Computational Questions (I)

Q6. Scotland: 100 hrs/cloth, 120 hrs/wine. Opportunity cost of 1 cloth is:

(a) $100/120 = 0.833$ wine
(b) $120/100 = 1.2$ wine
(c) 100 wine
(d) 20 wine

Q7. A country with 1,000 hours, 50 hrs/cloth, 100 hrs/wine can produce at most:

(a) 20 cloth or 10 wine
(b) 10 cloth or 20 wine
(c) 50 cloth or 100 wine
(d) 20 cloth or 20 wine

Q8. The PPF is a straight line when:

(a) There are increasing returns to scale
(b) The opportunity cost is constant

Quiz — Computational Questions (II)

Q9. For trade to benefit both countries, the terms of trade must lie:

(a) Above both countries' opportunity costs
(b) Below both countries' opportunity costs
(c) Between the two countries' opportunity costs
(d) Equal to the average of their opportunity costs

Q10. Full specialisation with trade increases world output because:

(a) Each country produces what it is relatively best at, minimising total resource use
(b) Trade increases the total number of workers
(c) Specialisation eliminates diminishing returns
(d) Both countries adopt the same technology

Answers: Q1(c), Q2(c), Q3(b), Q4(b), Q5(b), Q6(a), Q7(a), Q8(b), Q9(c), Q10(a)

Key Takeaways

What We Learned This Week

1. Smith's **pin factory** (1776) showed that dividing labour into specialised tasks can increase productivity by orders of magnitude.
2. Specialisation works through **skill improvement**, **time saving**, and **innovation** — but is limited by the extent of the market.
3. Ricardo's **comparative advantage** (1817): even if one country is better at everything, both gain from trade based on *opportunity cost*.
4. The **PPF** visualises production trade-offs; specialisation and trade move the world *beyond* individual frontiers.
5. We can **simulate** these ideas: pin factory pipelines, opportunity cost calculations, and gains from trade — all in a few lines of Python.

Further Reading

- Smith, A. *The Wealth of Nations* (1776), Book I, Chs. 1–3.
  Free at `https://www.econlib.org/library/Smith/smWN.html`
- Ricardo, D. *Principles of Political Economy and Taxation* (1817), Ch. 7.
- Heilbroner, R. *The Worldly Philosophers*, Ch. 3.
- Krugman, P. "Ricardo's Difficult Idea" (1996) — a short essay on why people find comparative advantage so hard to accept.

Next week: Malthus, Ricardo, and the Limits to Growth —
population dynamics, diminishing returns, and the Malthusian trap.