Module 10 — Edinburgh's Legacy

Market Failures, Externalities, and the Future of Economics

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From Smith to Simulation
The University of Edinburgh · School of Economics

Part I — The History

Full Circle

- We began this course on the Royal Mile, in the Edinburgh of David Hume and Adam Smith.
- We end it there too — but with **new eyes**.
- In the 1750s, Hume and Smith applied the methods of natural philosophy — observation, systematic reasoning, scepticism — to the study of human society.
- Their gift: the conviction that society is a natural system, governed by regularities discoverable through evidence.

The Method

Observe the world carefully, build models that formalise your intuition, test those models against data, and — when the evidence demands it — change your mind.

That is the Scottish Enlightenment's legacy to economics.

The Arc of the Course (Weeks 1–5)

Module 1: Smith Decentralised markets coordinate via the *invisible hand*. We computed equilibrium by root-finding.

Module 2: Ricardo & Malthus Limits to growth — scarcity shapes distribution. We simulated Malthusian dynamics and diminishing returns.

Module 3: Keynes Markets do *not* always clear — demand failures cause unemployment. We built the multiplier model.

Module 4: Marx Who benefits? Surplus value, capital accumulation, the falling labour share. We modelled CES production.

Module 5: Marginalists Subjective utility replaces labour theory of value. We derived demand from optimisation.

The Arc of the Course (Weeks 6–10)

Module 6: Solow Capital accumulation and technological progress drive long-run growth. We simulated convergence to steady state.

Module 7: Game Theory Strategic interaction — payoffs depend on others' choices. We computed Nash equilibria.

Module 8: Lucas Rational expectations and the Lucas critique. Policy works differently when agents anticipate it.

Module 9: Piketty $r > g$: when returns on capital exceed growth, wealth concentrates across generations.

Module 10: Today When does the invisible hand fail? Market failures, externalities, and the future.

The First Welfare Theorem

Adam Smith's central claim, formalised:

First Welfare Theorem

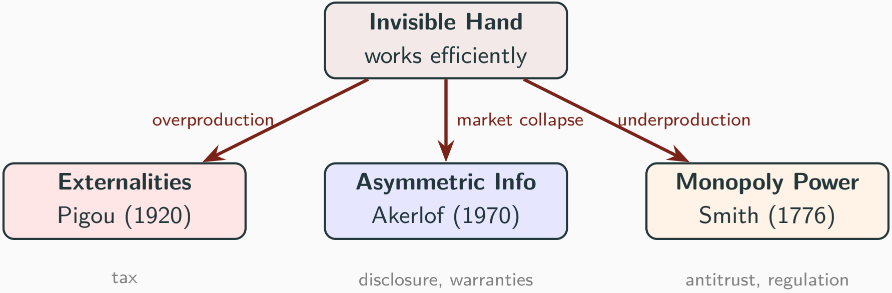
Under **perfect competition**, with **no externalities** and **complete information**, the competitive equilibrium is **Pareto efficient** — no one can be made better off without making someone worse off.

But those conditions are demanding. Today we run three computational experiments that each violate one condition:

1. **Externalities** — pollution (violates "no externalities")
2. **Asymmetric information** — Akerlof's lemons
3. **Market power** — monopoly (violates "perfect competition")

In each case, we compute the gap between what the market delivers and what society needs.

Market Failures as Challenges to Smith



Externalities: Pigou's Correction

- A **negative externality** is a cost imposed on third parties who are not part of the market transaction.
- Example: a factory on the Water of Leith produces cloth but pollutes the river, harming fishermen and residents downstream.
- The factory ignores these costs $\Rightarrow$ it produces too much.
- **Arthur Pigou** (1877–1959): a tax equal to the marginal external cost can restore efficiency.

Key Distinction

PMC Private marginal cost (what the firm pays)

EMC External marginal cost (the pollution damage)

SMC Social marginal cost $= PMC + EMC$

Information Asymmetry: Akerlof's Lemons

- George Akerlof, "The Market for 'Lemons'" *QJE* (1970). Nobel Prize 2001.
- **Setup:** sellers know the quality of their used cars; buyers cannot observe it.
- Buyers offer a price reflecting *average* quality.
- Sellers of *good* cars find this price too low $\Rightarrow$ they withdraw.
- Average quality drops $\Rightarrow$ price drops further $\Rightarrow$ more good cars leave.
- **Adverse selection spiral**: only "lemons" remain.

Real-world consequences

Vehicle history reports, health insurance mandates, warranties, and certifications all exist to combat this market failure.

Monopoly: Smith's Original Warning

"The price of monopoly is upon every occasion the highest which can be got. The natural price, or the price of free competition, . . . is the lowest which can be taken."

— Adam Smith, *The Wealth of Nations*, Book I, Ch. 7

- A monopolist restricts output and raises price above marginal cost.
- Consumer surplus falls; part is captured as monopoly profit, part is deadweight loss — pure waste.
- Smith understood this in 1776. Two and a half centuries later, the same logic drives antitrust enforcement against tech giants.

The Frontier Today

Climate Economics

Nordhaus's DICE model integrates climate science with growth theory. Draws on Solow (growth), Piketty (distribution), marginalists (optimisation).

AI and Automation

The "machinery question" of Ricardo and Marx returns. CES production (Module 4) is precisely the tool economists use.

Agent-Based Models

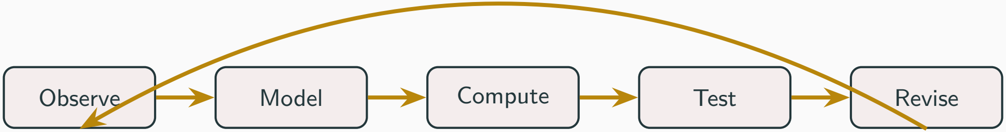
Simulate millions of heterogeneous agents interacting. Smith's invisible hand made literal: outcomes *emerge* from decentralised interaction.

Machine Learning in Economics

Causal inference and high-dimensional data transform empirical economics. The Scottish emphasis on evidence has never been more relevant.

Edinburgh's Continuing Legacy

- The University of Edinburgh remains at the frontier: inequality, development, behavioural economics, computational methods.
- The city that gave the world Hume's scepticism and Smith's invisible hand continues to shape how we understand economic life.
- And the method remains the same:



Hume's scepticism made operational: don't trust your assumptions — test them.

Part II — The Computation

Setting Up

```
import numpy as np
import matplotlib.pyplot as plt
from scipy.optimize import minimize, fsolve
```

- `numpy` — numerical arrays and operations
- `matplotlib` — plotting
- `fsolve` — root-finding (equilibrium as $ED = 0$)
- `minimize` — optimisation (monopolist's problem)

Today we put the invisible hand on trial with three computational experiments.

Model 1: The Polluting Factory

A factory on the Water of Leith produces cloth. Production generates pollution that harms downstream residents.

$$
\begin{aligned}
PMC(Q) &= 2 + 0.1\,Q && \text{(Private marginal cost)} \\
EMC(Q) &= 0.05\,Q && \text{(External marginal cost)} \\
SMC(Q) &= 2 + 0.15\,Q && \text{(Social marginal cost)} \\
P(Q) &= 20 - 0.2\,Q && \text{(Demand)}
\end{aligned}
$$

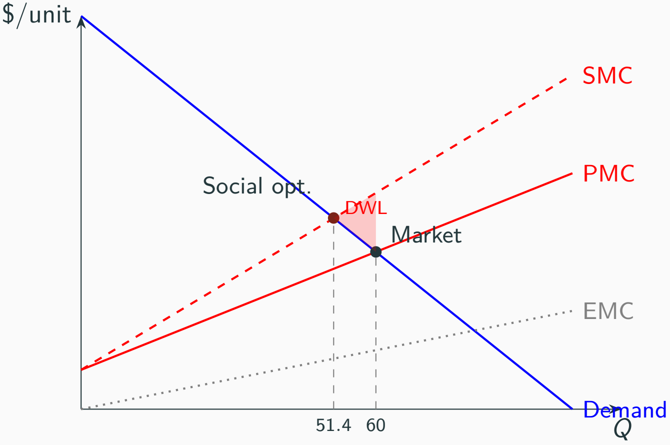
- **Free market:** set $P = PMC$ (factory ignores pollution).
- **Social optimum:** set $P = SMC$ (society accounts for pollution).
- The gap is the market failure.

Computing the Externality Equilibria

```python
def demand(Q):     return 20 - 0.2 * Q
def PMC(Q):        return 2 + 0.1 * Q
def EMC(Q):        return 0.05 * Q
def SMC(Q):        return PMC(Q) + EMC(Q)

# Free-market: demand = PMC
# 20 - 0.2Q = 2 + 0.1Q => Q = 60
Q_market = fsolve(lambda Q: demand(Q) - PMC(Q), 30)[0]

# Social optimum: demand = SMC
# 20 - 0.2Q = 2 + 0.15Q => Q = 51.43
Q_social = fsolve(lambda Q: demand(Q) - SMC(Q), 30)[0]

# Pigouvian tax = EMC at social optimum
pigouvian_tax = EMC(Q_social)   # 2.57 per unit
```

The free market overproduces by $60 - 51.4 \approx 8.6$ units.

Externality: Social vs Private Optimum



Every unit between Q_{social} and Q_{market} costs society more (SMC) than it benefits consumers (demand). The shaded triangle is the deadweight loss from the externality.

The Pigouvian Tax

Corrective Policy

A **Pigouvian tax** $\tau^* = EMC(Q^*_{\text{social}}) \approx 2.57$ per unit shifts the private cost curve up so that $PMC(Q) + \tau^* = SMC(Q)$ at the optimum.

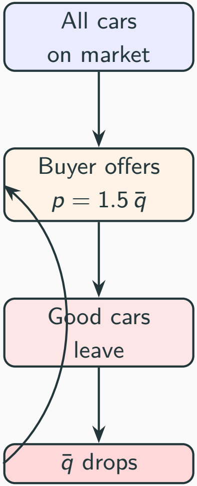
- Named after **Arthur Pigou** (1877–1959), a student of Alfred Marshall at Cambridge.
- The tax "internalises the externality" — the polluter now faces the *full* social cost.
- Deadweight loss:

$$DWL = \frac{1}{2}(Q_{\text{mkt}} - Q_{\text{soc}})\big(SMC(Q_{\text{mkt}}) - P(Q_{\text{mkt}})\big) \approx 12.86$$

- This is the gain from imposing the carbon tax.

Model 2: Akerlof's Market for Lemons

- $n = 10{,}000$ used cars, quality $q \sim U[0, 1]$.
- Seller values car at q; buyer values it at $1.5\,q$ (gains from trade exist for every car).
- But the buyer cannot observe q.
- Buyer offers price $= 1.5 \times \bar{q}$ (expected quality of cars on the market).
- Sellers with $q >$ price withdraw.



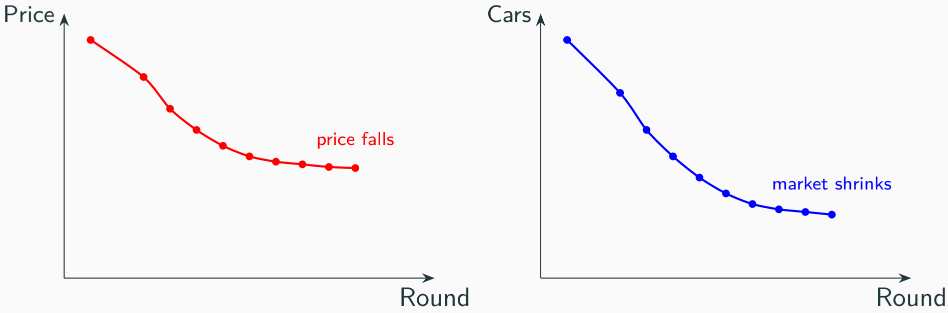
Simulating Adverse Selection

```python
def lemons_market(n_cars=10000, buyer_premium=1.5, seed=42):
    rng = np.random.default_rng(seed)
    qualities = rng.uniform(0, 1, n_cars)
    on_market = np.ones(n_cars, dtype=bool)

    for round_num in range(1, 51):
        if on_market.sum() == 0:
            break
        avg_q = qualities[on_market].mean()
        price = buyer_premium * avg_q
        new_on = on_market & (qualities <= price)
        if np.array_equal(new_on, on_market):
            break
        on_market = new_on
    return qualities, on_market
```

With **full information**: all 10 000 cars trade.

With **asymmetric information**: only lemons remain — the market has partially collapsed.

The Adverse Selection Spiral



Low price $\rightarrow$ good cars leave $\rightarrow$ quality drops $\rightarrow$ lower price $\rightarrow$ ...

The invisible hand cannot work when one side of the market is blind.

Model 3: Monopoly vs Competition

Market with inverse demand $P(Q) = 20 - 0.2\,Q$ and constant marginal cost $MC = 4$.

Perfect Competition

Many firms, price-takers: $P = MC$

$$20 - 0.2\,Q = 4 \implies Q_c = 80,\ P_c = 4$$

Monopoly

Single firm maximises $\pi = (P - MC)\,Q$

$MR = 20 - 0.4\,Q$; set $MR = MC$:

$$20 - 0.4\,Q = 4 \implies Q_m = 40,\ P_m = 12$$

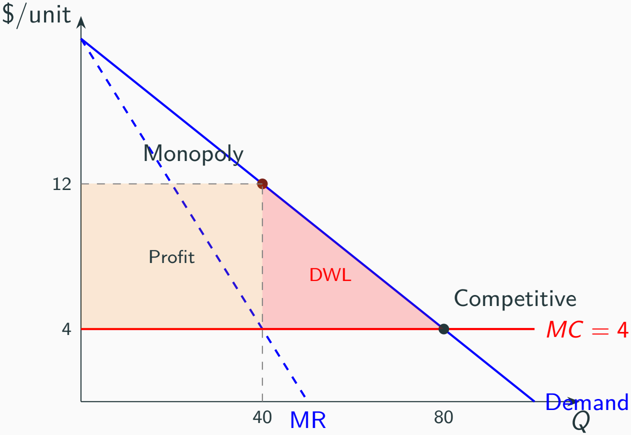
- Monopoly profit: $(12 - 4) \times 40 = 320$
- Deadweight loss: $\frac{1}{2}(80 - 40)(12 - 4) = 160$

Computing Monopoly vs Competition

```
MC = 4

def inverse_demand(Q): return 20 - 0.2 * Q
def marginal_revenue(Q): return 20 - 0.4 * Q

# Competitive: P = MC
Q_comp = fsolve(lambda Q: inverse_demand(Q) - MC, 50)[0]

# Monopoly: MR = MC
Q_mono = fsolve(lambda Q: marginal_revenue(Q) - MC, 30)[0]
P_mono = inverse_demand(Q_mono)

# Deadweight loss
DWL = 0.5 * (Q_comp - Q_mono) * (P_mono - MC)  # 160
profit = (P_mono - MC) * Q_mono                 # 320
```

The monopolist restricts output by 40 units and raises price by 8.
Society loses 160 in value that no one captures — pure waste.

Monopoly: Deadweight Loss



The orange rectangle is monopoly profit (transferred from consumers).

The red triangle is deadweight loss — value destroyed, captured by no one.

Synthesis: When Does the Invisible Hand Work?

Condition violated	Failure	Result	Policy
No externalities	Pollution	Overproduction	Pigouvian tax
Full information	Adverse selection	Market collapse	Disclosure
Perfect competition	Monopoly	Under-production	Antitrust

The Mature View

Neither “markets always work” nor “markets never work” survives contact with computation. The question is always: *which conditions hold here, and what happens when they don’t?*

Part III — Exercises & Discussion

Exercise 1: Carbon Tax Calibration

A coal-fired power plant with:

$$
\begin{aligned}
P(Q) &= 50 - 0.5\,Q && \text{(Inverse demand)}\\
PMC(Q) &= 10 + 0.2\,Q && \text{(Private marginal cost)}\\
EMD(Q) &= 0.3\,Q && \text{(External marginal damage)}
\end{aligned}
$$

(a) Find the free-market equilibrium ($P = PMC$) and the social optimum ($P = PMC + EMD$). Compute both quantities and prices.

(b) Compute the optimal Pigouvian tax $\tau^* = EMD(Q_{\text{soc}})$. Verify it restores the social optimum.

(c) Compute the deadweight loss from the unregulated market.

(d) Plot demand, PMC, SMC, and PMC + tax on one graph. Shade the deadweight loss.

Exercise 2: Public Goods and the Free-Rider Problem

Setup: $N = 10$ residents each choose contribution $g_i \geq 0$ to a shared park. Total provision $G = \sum g_i$.

$$u_i = (w - g_i) + \beta\sqrt{G}, \qquad w = 100,\ \beta = 20$$

(a) **Nash equilibrium:** each player maximises u_i taking others' contributions as given. Show $g_i^* = \frac{\beta^2}{4N^2}$. Compute G^{NE}.

(b) **Social optimum:** a planner maximises $\sum u_i$ choosing a common g. Derive g^{SO} and G^{SO}.

(c) Compute the ratio G^{NE}/G^{SO}. By what factor does the voluntary mechanism underprovide?

(d) Plot total provision and utility under both regimes as N varies from 2 to 50. Does the free-rider problem get better or worse?

Exercise 3: Reflection — One Economist, One Model

A combined writing and coding exercise:

(a) **Choose one economist** from the course (Smith, Ricardo, Malthus, Marx, the Marginalists, Keynes, Solow, Nash, Lucas, Piketty, or Akerlof). Write 150–250 words explaining their key idea and why it mattered.

(b) **Implement a computational model** of that idea. It need not be complex — but it must produce a quantitative result or a plot.

(c) **Discuss:** what does your model *capture* about the idea, and what does it *miss*? (100–150 words)

(d) **Connect** your economist's idea to one issue in the world today. How does it help us think? How might it mislead?

Quiz

Conceptual Questions (Q1–Q5)

Q1. The First Welfare Theorem requires:
(b) No externalities, no market power, and complete information.

Q2. A negative externality causes the free market to:
(b) Overproduce the good.

Q3. In Akerlof's lemons model, adverse selection occurs because:
(b) Sellers with high-quality goods withdraw when price reflects average quality.

Q4. The Scottish Enlightenment's key contribution to economics:
(b) Emphasis on empirical observation, scepticism, and systematic reasoning.

Q5. Which is *not* required for the invisible hand?
(d) All consumers must have equal income.

Computational Questions (Q6–Q10)

Q6. Social optimum quantity in the pollution model ($P = SMC$):
(b) $Q \approx 51.4$.

Q7. A Pigouvian tax corrects an externality by:
(b) Setting tax $= EMC$ at the socially optimal quantity.

Q8. Monopoly DWL with $Q_m = 40$, $P_m = 12$, $Q_c = 80$, $MC = 4$:
(a) $\frac{1}{2}(80 - 40)(12 - 4) = 160$.

Q9. As N increases in the public goods game, the ratio G^{NE}/G^{SO}:
(c) Decreases as $1/N^2$ — free-riding gets worse.

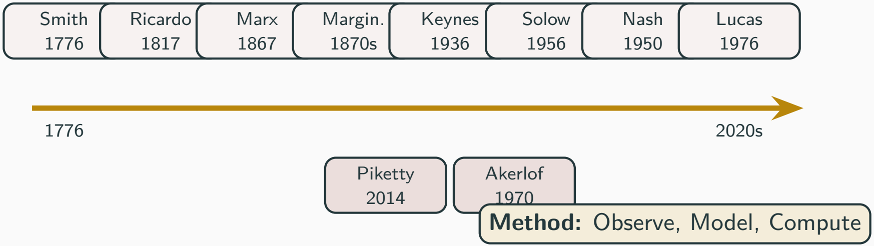
Q10. The recurring computational method throughout the course:
(b) Root-finding and optimisation (`fsolve`, `minimize`).

Key Takeaways

What We Learned This Week

1. Smith's invisible hand works **under specific conditions**: perfect competition, no externalities, complete information.
2. **Externalities** cause overproduction; a Pigouvian tax equal to the marginal external cost restores efficiency.
3. **Asymmetric information** can cause markets to unravel through adverse selection (Akerlof's lemons).
4. **Monopoly power** leads to underproduction and deadweight loss — a concern Smith himself raised in 1776.
5. We can **compute** each market failure precisely: the gap between market outcome and social optimum, and the policy that closes it.
6. The mature view: the question is not "markets vs. government" but *which conditions hold and what follows when they don't*.

Course Synthesis



Every module: an idea, a model, a computation.

The tools change; the commitment to evidence-based reasoning endures.

Closing Reflection

"The real voyage of discovery consists not in seeking new landscapes, but in having new eyes."

— Marcel Proust, *In Search of Lost Time*

- The models are simple. Real economies are not.
- But the point of a model is not to replicate reality — it is to **isolate a mechanism**, to make an idea precise enough to test.
- Computation gives us not answers, but sharper questions.
- Economics is unfinished. The great questions remain open.
- But the method is clear: **Observe. Model. Compute. Test. Revise.**
- It is the method of Hume and Smith, updated for an age of data and code.

Further Reading

- Akerlof, G. "The Market for 'Lemons'" *QJE* (1970).
  The paper that launched information economics.
- Pigou, A. C. *The Economics of Welfare* (1920).
  The original treatment of externalities and corrective taxation.
- Nordhaus, W. *The Climate Casino* (2013).
  Climate economics for a general audience.
- Broadie, A. *The Scottish Enlightenment*.
  The intellectual world that made economics possible.
- Heilbroner, R. *The Worldly Philosophers*.
  A magnificent tour through the lives and ideas of the great economists.

End of course.

From Smith to Simulation — The University of Edinburgh.