Introduction to Environmental Economics

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Environmental and Natural Resource Economics - **December 7, 2024**

Presentation Outline

Who am I?

- Dana Golden. Fourth year PhD student at SBU
- Research focuses on electricity markets and energy transition
- Worked as an economist for USDA and FERC and data scientist for Treasury
- Ask me about: transmission, nuclear energy, industrial organization, how to find a job

What is Environmental Economics?

- Study of how economy interacts with environment and how to manage natural resources in a way that meets human needs while preserving the environment

What is Environmental Economics?

- Study of how economy interacts with environment and how to manage natural resources in a way that meets human needs while preserving the environment
- Focuses of environmental economics
  - Externalities
  - Resource allocation
  - Impacts of imperfect information
  - Non-market valuation
  - Cost-benefit analysis
  - Economics of commodity markets

Why Environmental Economics is its own Class

- Need for an understanding of externalities and cost-benefit analysis
- Focuses particularly on the interaction between the environment and economy
- Takes seriously notions of non-renewable resources and long-term impacts of market actions
- Environmental concerns have become more important globally and also from an employment perspective

Why Environmental Economics Matters

- Resources are not infinite
- Economics has interesting value to add on issue of climate change
- Many actors have economic motives and will not listen to non-economic arguments on environmental issues
- Traditional economics has odd discounting ideas
- We only get one earth

Overview of Topics

- Externalities and market failure
- Non-market valuation
- Imperfect Information and Insurance Markets
- Cost-benefit analysis
  - Discounting, LCOE, techno-economic analysis
  - Damage functions, evaluation of policy, distributional effects
- Economics of commodity markets
  - Commodity market supply and demand
  - Commodity market derivatives
  - Electricity markets
  - Energy market policy
- Analysis of environmental data
  - Where to find data
  - Geographic information systems

Skills You will be Exposed to

- Non-market valuation
  - Techniques for valuation of non-market goods
  - Discrete choice modelling in R
- Geographic Information Systems
- Analysis of commodities markets
  - Commodities market derivatives
  - Commodities market portfolios
  - Analysis of electricity markets
- Cost benefit analysis
  - Basic framework, applications of risk
  - NPV, LCOE, analysis of projects
  - Sensitivity analysis

Overview of Evaluation Criteria

- 5 Homeworks: 50% of grade
- Midterm: Everything up to Commodity markets 25% of grade
- Final: Commodity markets and electricity markets 25% of grade
- Project: Replaces final and midterm, must communicate desire before midterm

Utility Functions: A Review

- **Definition:** A utility function $U(x_1, x_2, \ldots, x_n)$ represents a consumer's preferences over a bundle of goods $(x_1, x_2, \ldots, x_n)$.
- **Assumptions:**
  - **Completeness:** Consumers can rank all bundles of goods.
  - **Transitivity:** If $A \succ B$ and $B \succ C$, then $A \succ C$.
  - **Non-Satiation:** More is preferred to less.
- **Common Forms:**
  - **Linear:** $U(x_1, x_2) = a_1x_1 + a_2x_2$
  - **Cobb-Douglas:** $U(x_1, x_2) = x_1^a x_2^b$
  - **Quasilinear:** $U(x_1, x_2) = f(x_1) + x_2$

Properties of Utility Functions

- **Marginal Utility:**

$$MU_{x_i} = \frac{\partial U}{\partial x_i}$$

Measures the additional satisfaction from consuming one more unit of x_i.

- **Diminishing Marginal Utility:** For most goods:

$$\frac{\partial^2 U}{\partial x_i^2} < 0$$

- **Indifference Curves:**
  - Represent combinations of goods that yield the same utility.
  - Slope is given by the Marginal Rate of Substitution (MRS):

$$MRS = -\frac{MU_{x_1}}{MU_{x_2}}$$

- **Key Concept:** Utility is ordinal, not cardinal. Only the ranking of bundles matters.

Production Functions

- **Definition:** A production function $Q = f(L, K)$ represents the maximum output Q produced from inputs L (labor) and K (capital).
- **Common Forms:**
  - **Linear:** $Q = aL + bK$
  - **Cobb-Douglas:** $Q = AL^{\alpha}K^{\beta}$
  - **Leontief (Fixed Proportions):** $Q = \min(aL, bK)$
- **Key Properties:**
  - **Marginal Product:** $MP_L = \frac{\partial Q}{\partial L}, \quad MP_K = \frac{\partial Q}{\partial K}$
  - **Diminishing Marginal Returns:** $\frac{\partial^2 Q}{\partial L^2} < 0$ and $\frac{\partial^2 Q}{\partial K^2} < 0$ for most realistic cases.

Supply and Cost Functions

- **Cost Function:** Total cost $C(Q)$ is the sum of fixed costs (FC) and variable costs $(VC(Q))$:

$$C(Q) = FC + VC(Q)$$

- **Marginal Cost:** Cost of producing one additional unit:

$$MC(Q) = \frac{\partial C}{\partial Q}$$

- **Supply Function:** Represents the quantity supplied at each price, derived from profit maximization:

$$P = MC(Q) \quad \text{(in competitive markets).}$$

- **Elasticity of Supply:**

$$E_s = \frac{\partial Q}{\partial P} \cdot \frac{P}{Q}$$

Production Function Visualized

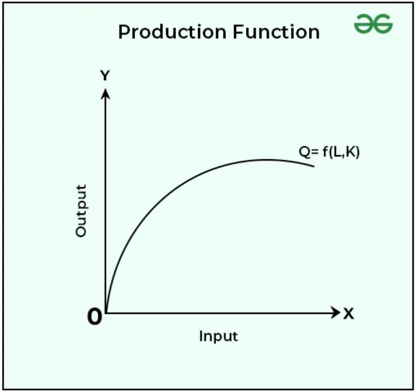

Figure 1: Dimishing returns are diminishing.

Profit Maximization

- **Objective:** Maximize profit π, defined as:

$$\pi = TR - TC = P \cdot Q - C(Q)$$

where TR is total revenue and TC is total cost.

- **First-Order Condition (FOC):**

$$\frac{\partial \pi}{\partial Q} = \frac{\partial TR}{\partial Q} - \frac{\partial TC}{\partial Q} = 0$$

$$MR = MC$$

- **Second-Order Condition (SOC):**

$$\frac{\partial^2 \pi}{\partial Q^2} < 0$$

- **Result:** The firm produces at Q^* where $MR = MC$ and profit is maximized.

Demand Functions

- **Definition:** A demand function $Q_d(P)$ represents the quantity of a good that consumers are willing and able to purchase at a given price P.
- **Law of Demand:**

$$\text{As } P \downarrow, Q_d \uparrow \quad \text{(holding other factors constant).}$$

- **Linear Demand Function:**

$$Q_d = a - bP, \quad \text{where } a > 0, b > 0.$$

- **Elasticity of Demand:** Measures the responsiveness of quantity demanded to changes in price:

$$E_d = \frac{\partial Q_d}{\partial P} \cdot \frac{P}{Q_d}.$$

- **Shift Factors:**
  - Income (Y): Normal vs. inferior goods.
  - Prices of related goods: Substitutes and complements.

Market Equilibrium:

- **Definition:** A market is in equilibrium when the quantity demanded (Q_d) equals the quantity supplied (Q_s) at a given price (P^*).

$$Q_d(P^*) = Q_s(P^*).$$

- **Finding Equilibrium:**
  - Solve $Q_d(P) = Q_s(P)$ to find P^*.
  - Substitute P^* into either function to find Q^*.
- **Example:**

$$Q_d = 50 - 2P,$$
$$Q_s = 10 + 3P.$$
$$\text{Set } Q_d = Q_s: \quad 50 - 2P = 10 + 3P.$$
$$\text{Solve:} \quad P^* = 8, \quad Q^* = 34.$$

- **Key Concept:** Any deviation from P^* results in excess demand or supply, causing price to adjust toward equilibrium.

Market Equilibrium Visualized

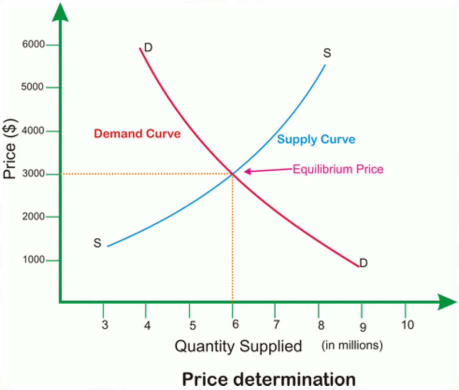

Figure 2: Supply and demand must balance unless...

Review of Univariate Derivatives

- **Definition:** The derivative of a function $f(x)$ with respect to x measures the rate of change of f as x changes.
- **Notation:** Common notations include $f'(x)$, $\frac{df}{dx}$, and $\frac{d}{dx}f(x)$.
- **Economic Interpretation:** In economics, derivatives represent concepts like marginal cost (the change in cost with respect to quantity) or marginal revenue.
- **Rules of Differentiation:**
  - **Power Rule:** $\frac{d}{dx}x^n = nx^{n-1}$
  - **Product Rule:** $\frac{d}{dx}[u(x)v(x)] = u'(x)v(x) + u(x)v'(x)$
  - **Quotient Rule:** $\frac{d}{dx}\left(\frac{u(x)}{v(x)}\right) = \frac{u'(x)v(x)-u(x)v'(x)}{[v(x)]^2}$
  - **Chain Rule:** If $y = f(g(x))$, then $\frac{dy}{dx} = f'(g(x)) \cdot g'(x)$
- **Example:** For $f(x) = 3x^2 + 2x$, the derivative is:

$$f'(x) = 6x + 2$$

Review of Multivariate Derivatives

- **Definition:** Multivariate derivatives extend the concept of derivatives to functions with more than one variable, measuring the rate of change with respect to each variable.
- **Partial Derivative Notation:** For a function $f(x, y)$, the partial derivative with respect to x is $\frac{\partial f}{\partial x}$, and with respect to y is $\frac{\partial f}{\partial y}$.
- **Economic Interpretation:** In economics, partial derivatives show how a change in one variable, holding others constant, affects outcomes, such as the effect of one input on production.
- **Calculating Partial Derivatives:**
  - For $f(x, y) = x^2 + 3xy + y^2$:

$$\frac{\partial f}{\partial x} = 2x + 3y, \quad \frac{\partial f}{\partial y} = 3x + 2y$$

Total Derivative

- **Total Derivative:** If $z = f(x, y)$ and both x and y change, the total derivative is:

$$\frac{dz}{dt} = \frac{\partial f}{\partial x}\frac{dx}{dt} + \frac{\partial f}{\partial y}\frac{dy}{dt}$$

Review of Multivariate Optimization with Calculus

- **Objective:** Multivariate optimization finds the maximum or minimum of a function with respect to multiple variables, often under constraints.
- **Unconstrained Optimization:** For a function $f(x, y)$, a critical point occurs where:

$$\frac{\partial f}{\partial x} = 0 \quad \text{and} \quad \frac{\partial f}{\partial y} = 0$$

  Determine if it's a maximum, minimum, or saddle point using the second derivative test.

Lagrangian Optimization

- **Constrained Optimization (Lagrange Multipliers):**
  - **Goal:** Maximize $f(x, y)$ subject to a constraint $g(x, y) = c$.
  - **Lagrangian Function:** Define $\mathcal{L}(x, y, \lambda) = f(x, y) + \lambda(c - g(x, y))$.
  - **Conditions:** Solve:

$$\frac{\partial \mathcal{L}}{\partial x} = 0, \quad \frac{\partial \mathcal{L}}{\partial y} = 0, \quad \frac{\partial \mathcal{L}}{\partial \lambda} = 0$$

- **Example:** Maximize $f(x, y) = xy$ subject to $x + y = 10$.

Application

Multivariate optimization is used in economics for utility maximization, cost minimization, and profit maximization, providing insights into optimal decision-making.

Example: Solving a Lagrangian Optimization Problem

- **Problem Statement:** Maximize the utility function $U(x, y) = x^{0.5}y^{0.5}$ subject to a budget constraint $2x + 3y = 12$.
- **Step 1: Set Up the Lagrangian Function**

$$\mathcal{L}(x, y, \lambda) = x^{0.5}y^{0.5} + \lambda(12 - 2x - 3y)$$

Lagrangian Optimization

- **Step 2: Take Partial Derivatives and Set to Zero**
  - Partial derivative with respect to x:

$$\frac{\partial \mathcal{L}}{\partial x} = 0.5x^{-0.5}y^{0.5} - 2\lambda = 0$$

  - Partial derivative with respect to y:

$$\frac{\partial \mathcal{L}}{\partial y} = 0.5x^{0.5}y^{-0.5} - 3\lambda = 0$$

  - Partial derivative with respect to λ (constraint):

$$\frac{\partial \mathcal{L}}{\partial \lambda} = 12 - 2x - 3y = 0$$

Lagrangian Optimization

- **Step 3: Solve the System of Equations**
  - From $\frac{\partial \mathcal{L}}{\partial x} = 0$ and $\frac{\partial \mathcal{L}}{\partial y} = 0$, we get:

$$\frac{0.5y^{0.5}/x^{0.5}}{2} = \frac{0.5x^{0.5}/y^{0.5}}{3} \Rightarrow \frac{y}{x} = \frac{3}{2} \Rightarrow y = \frac{3}{2}x$$

  - Substitute $y = \frac{3}{2}x$ into the constraint $2x + 3y = 12$:

$$2x + 3\left(\frac{3}{2}x\right) = 12 \Rightarrow 6.5x = 12 \Rightarrow x = 2$$

$$y = \frac{3}{2} \cdot 2 = 3$$

- **Solution:** The optimal values are $x = 2$ and $y = 3$.
- **Interpretation:** Given the budget constraint, maximizing utility results in consuming 2 units of x and 3 units of y.

Vocabulary Terms

- Ambient Quality: The quantity of pollutants in the environment. [concentration of SO_2 in the air]
- Environmental Quality: the state of the natural environment. [visual and aesthetic quality]
- Residuals: Material leftover from production and consumption.
- Emissions: The portion of residuals that is placed in the environment.
- Recycling: The process of returning some residuals to be used again.
- Pollutant: A substance, energy form or action that results in lowering the ambient quality level
- Damages: Negative impacts resulting from pollution.

Mixing of Emissions

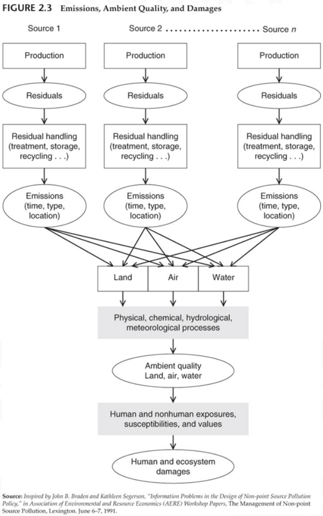

Figure 3: Emissions from multiple sources hard to abate.

Types of Sources

- Source: The location at which emission occurs. [point source or non-point source]. Local, regional or global.
- Point Source: Pollution that comes from a single identifiable source such as factory
- Non-point source: Pollution that is difficult to trace or comes from many sources

Point Source vs. Non-point Source

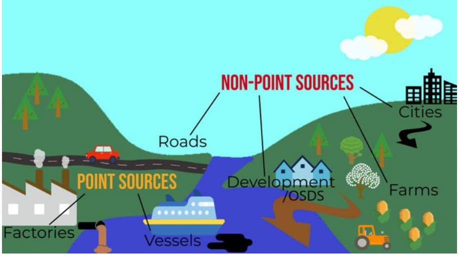

Figure 4: Point-source vs. Non-point Source Pollution

What is Life-Cycle Analysis (LCA)?

- **Definition:** LCA is a method used to assess the environmental impacts associated with all stages of a product's life, from raw material extraction to disposal.
- **Key Stages:**
  - Raw Material Extraction
  - Manufacturing and Processing
  - Transportation and Distribution
  - Usage and Maintenance
  - End-of-Life (Disposal or Recycling)
- **Goal:** Identify and quantify environmental trade-offs and impacts to make informed decisions for sustainable development.
- **Application:** Helps policymakers, businesses, and consumers evaluate the total environmental cost of a product or process.

Example: Comparing Plastic and Paper Bags

Scope of the Analysis:

- **Plastic Bag:**
  - Low manufacturing energy use
  - High pollution from raw material (oil) extraction
  - Long decomposition period in landfills
- **Paper Bag:**
  - Higher energy use in production
  - Uses renewable raw materials (trees)
  - Biodegrades more quickly

Results:

- Plastic bags have a lower environmental footprint for single use.
- Paper bags are more sustainable when reused or disposed of responsibly.

Conclusion: LCA helps weigh trade-offs in material choice to guide environmentally conscious decisions.

Life Cycle Analysis Paper and Polyurathane Cups

Utilities:		
Steam (kg)	9,000-12,000	5,000
Power (kWh)	980	120-180
Cooling water (m^3)	50	154
Water effluent		
Volume (m^3)	50-90	0.5-2.0
Suspended solids (kg)	35-60	Trace
BOD (kg)	30-50	0
Organochlorines (kg)	5-7	0
Metal salts (kg)	1-20	20
Air emissons		
Chlorine (kg)	0.5	0
Chlorine dioxide (kg)	0.2	0
Reduced sulfides (kg)	2.0	0
Par ticulates (kg)	5-15	0.1
Chlorofluorocarbons (kg)	0	0
Pentane (kg)	0	35-50
Sulfur dioxide (kg)	10	10

Source: Based on M. Hocking (1991)

Figure 5: Life Cycle Analysis Numerical Example

Lifecycle Analysis and Recycling

Table 1-4 Recyclable Potential of Paper Cups and Polyfoam Cups

Item	Paper Cup	Polyfoam Cup
Recyclable Potential		
To primary user	Possible, though washing can destroy	Easy, negligible water uptake
After use	Low, hot melt adhesive or coating difficulties	High, resin reuse in other applications
Source: Based on M. Hocking (1991)		

Table 1-5 Ultimate Disposal of Paper Cups and Polyfoam Cups

Item	Paper Cup	Polyfoam Cup
Ultimate Disposal		
Paper incineration	Clean	Clean
Heat recovery (MJ/kg)	20	40
Mass to landfill (g)	10.1	1.5
Biodegradable	Yes, BOD to leacheate, methane to air	No, essentially inert
Source: Based on M. Hocking (1991)		

Figure 6: Recycling and the Lifecycle analysis

Example Lifecycle Analysis Electric Vehicles

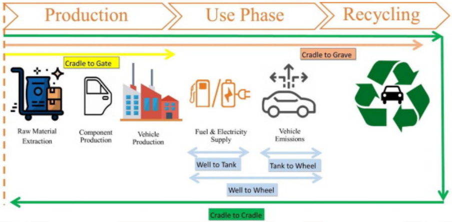

Figure 7: Life Cycle Electric Vehicles

Lifecycle Analysis CAFE

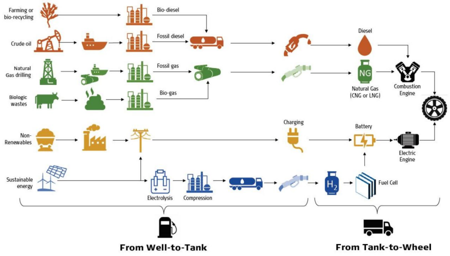

Figure 8: Well to Wheel CAFE

Historical Background of the Malthusian Trap

- **Thomas Robert Malthus (1766-1834):**
  - British economist and demographer.
  - Published *An Essay on the Principle of Population* (1798).
- **Core Idea:**
  - Population growth tends to outpace the growth of food production.
  - This leads to periodic crises (famine, disease, war) that limit population size.
- **Historical Relevance:**
  - Pre-industrial societies experienced cyclical periods of population growth followed by collapse.
  - Agricultural advances (e.g., crop rotation, irrigation) temporarily alleviated pressures but did not break the cycle.
- **Impact:**
  - Influenced debates on overpopulation, resource scarcity, and sustainability.
  - Criticized as overly pessimistic following the Industrial Revolution and modern technological advancements.

Assumptions and the Malthusian Model

Key Assumptions:

- **Population Growth:** Population grows exponentially ($P(t) \sim e^{rt}$) in the absence of resource constraints.
- **Food Production:** Resources, particularly food, grow linearly due to limited land and technology ($Q(t) \sim at$).
- **Feedback Mechanism:**
  - When population exceeds resource capacity, per capita income declines.
  - Declining income leads to increased mortality and reduced fertility, stabilizing population at subsistence levels.

Model Dynamics:

- **Population and Resources:**

$$\text{Population Growth Rate} \propto (\text{Income per Capita} - \text{Subsistence Level}).$$

- **Equilibrium:** Population stabilizes where income per capita equals the subsistence level.

The Malthusian Trap

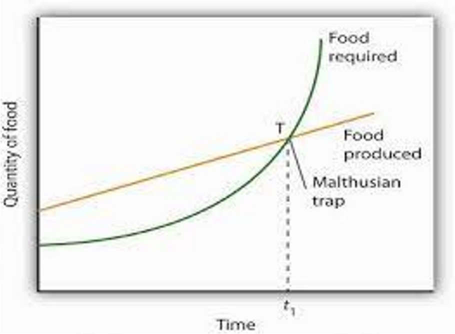

Figure 9: What Malthus thought.

What Actually Happened?

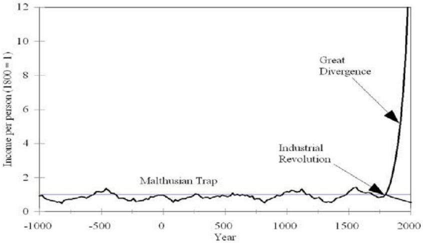

Figure 10: Food supplies grew.

Kuznets Curve

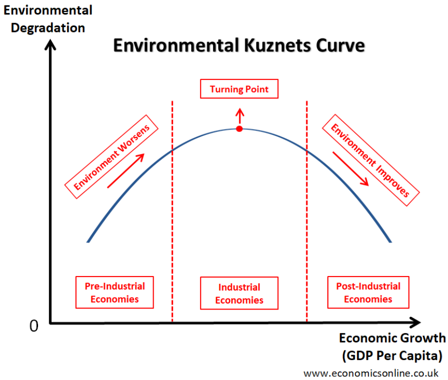

Figure 11: How environment and development interact.

Traditional Circular Flow

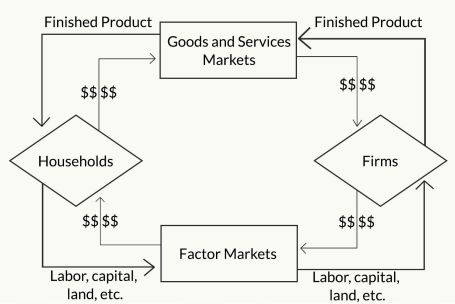

Figure 12: What's missing here?

Environmental Circular Flow

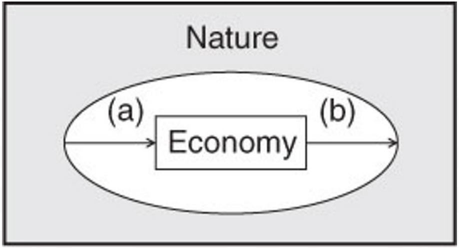

Figure 13: The environment!

Complex Circular Flow with Environment

FIGURE 2.1 The Environment and the Economy

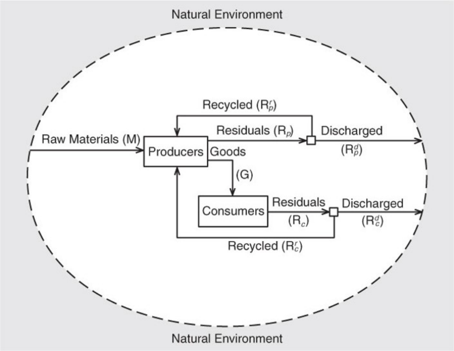

Figure 14: How can we make the diagram more complex?

Equations in the Circular Flow Model

- **Core Components:**
  - **Economic System:** Production and consumption processes.
  - **Environmental System:** Renewable and non-renewable resources, and waste assimilation.
- **Key Equations:**
  - **Output Equation:**

$$Q = f(L, K, R)$$

    where:
    - Q: Output of goods and services.
    - L: Labor input.
    - K: Capital input.
    - R: Natural resource input.
  - **Resource Flow:**

$$R_t = R_{t-1} - h_t + g_t$$

    where:
    - R_t: Resource stock at time t.
    - h_t: Resource extraction at time t.
    - g_t: Natural regeneration of renewable resources at time t.

Equations in Circular Flow Model

- **Waste Assimilation:**

$$W_t = \phi(Q_t)$$

  where:

  - W_t: Waste generated at time t.
  - ϕ: Function linking output to waste.

- **Environmental Capacity:**

$$E_t = E_{t-1} - W_t + A_t$$

  where:

  - E_t: Environmental quality at time t.
  - W_t: Waste generated.
  - A_t: Assimilative capacity of the environment at time t.

- **Key Insight:** The economy and the environment are interdependent, with feedback loops between resource use, waste generation, and environmental quality.

Environmental Production Possibilities Curve

- Tradeoff between environmental quality and production of the economy
- Tradeoff determined by technology and social choice
- Increased production today may shift curve inward

FIGURE 2.2 Production Possibility Curves for Current and Future Generations

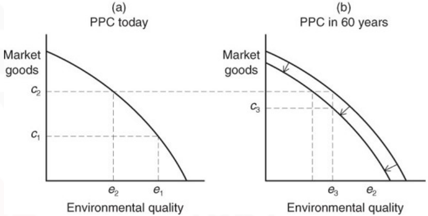

Figure 15: Environmental Production Possibilities Curve over Time.

What is the Ehrlich Identity?

- **Definition:** The Ehrlich Identity, also known as the IPAT equation, is a formula used to estimate the impact of human activities on the environment.
- **Equation:**

$$\text{Impact (I)} = \text{Population (P)} \times \text{Affluence (A)} \times \text{Technology (T)}$$

- **Key Components:**
  - **Population (P):** Total number of people.
  - **Affluence (A):** Consumption per person.
  - **Technology (T):** Environmental impact per unit of consumption.
- **Purpose:** Identifies the drivers of environmental degradation and provides a framework for analyzing potential solutions.

Understanding the Components

- **Population (P):**
  - Larger populations increase demand for resources and waste generation.
  - Example: Rapid urbanization in developing countries.
- **Affluence (A):**
  - Higher income levels lead to increased consumption.
  - Example: Rising per capita energy use in industrialized nations.
- **Technology (T):**
  - Both a cause and solution to environmental problems.
  - Example: Fossil fuel power plants (negative) vs. renewable energy (positive).

Key Insight: Changes in any one factor can significantly alter the environmental impact.

Example: Carbon Emissions

Scenario: Global CO_2 Emissions Analysis

- **Population (P):** World population grows from 7 billion to 9 billion.
- **Affluence (A):** GDP per capita increases by 50%.
- **Technology (T):** Energy intensity decreases by 20%, but fossil fuels dominate energy mix.

Result: $I = P \times A \times T \implies$ Significant increase in CO_2 emissions despite efficiency gains.

Takeaway: Technological advancements must outpace the growth in population and affluence to mitigate environmental impacts.

Impact of Trends on Environment

- Economics is about tradeoffs. How should we think about them?

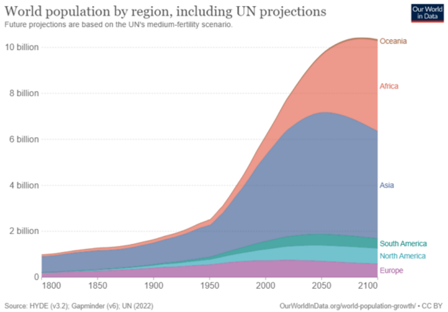

Figure 16: Growing population and sustainability

Thank You So Much!

List of References