Imperfect Information and Insurance Markets

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Presentation Outline

Why Insurance is Relevant in Environmental Economics?

- Climate change increases the likelihood of natural disasters and the need for insurance
- Insurance models give a useful way to assess the risk of climate change
- Imperfect information is a real world condition that raises the cost of regulation

Why Insurance is Relevant in Environmental Economics?

- Climate change increases the likelihood of natural disasters and the need for insurance
- Insurance models give a useful way to assess the risk of climate change
- Imperfect information is a real world condition that raises the cost of regulation
- Often, the answer to why people don't do anything about the climate change is insurance

Risk from Climate Change

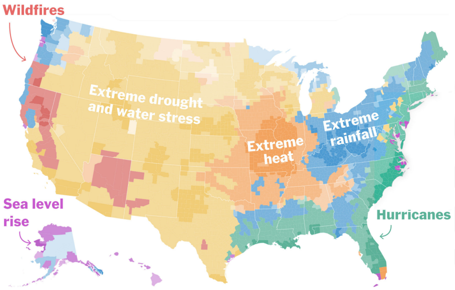

Figure 1: Climate change is increasing premiums... and no one is safe!

A Simple Hypothetical

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- Would you rather have a fifty percent chance of winning 100 dollars and a fifty percent chance or losing 10 dollars or a fifty percent chance of winning 60 dollars and fifty percent chance of winning nothing?
- People are risk averse and loss averse

Utility Functions in Insurance

- **Utility Function (U)**: A mathematical representation of consumer preferences over different levels of wealth (W).
- **Risk Aversion**:
  - Consumers prefer a certain outcome over a gamble with the same expected wealth.
  - Characterized by a concave utility function.
- **Common Utility Functions**:
  - *Linear Utility* ($U(W) = aW + b$): Risk-neutral behavior.
  - *Quadratic Utility* ($U(W) = W - \frac{1}{2}aW^2$): Increasing marginal disutility.
  - *Logarithmic Utility* ($U(W) = \ln(W)$): Diminishing marginal utility.

Von Neumann-Morgenstern Utility Theory

- A framework for expected utility under uncertainty.
- **Expected Utility Formula**:

$$E[U(W)] = \sum_i p_i \cdot U(W_i)$$

  where:
  - p_i = probability of outcome i.
  - W_i = wealth in outcome i.
- **Key Axioms**:
  1. *Completeness*: Preferences are complete.
  2. *Transitivity*: Preferences are consistent.
  3. *Independence*: Preferences are independent of irrelevant alternatives.
  4. *Continuity*: Preferences are continuous over probabilities.

Expected Value and Variance

- **Expected Value (Mean)**:

$$E[X] = \sum_i p_i \cdot x_i$$

  where:
  - X is a random variable.
  - x_i are possible outcomes.
  - p_i are probabilities of outcomes.
- **Variance**:

$$\text{Var}(X) = E[(X - E[X])^2] = \sum_i p_i \cdot (x_i - E[X])^2$$

- **Standard Deviation**:

$$\sigma_X = \sqrt{\text{Var}(X)}$$

- **Interpretation in Insurance**:
  - Expected value represents the average expected loss or gain.
  - Variance and standard deviation measure the risk or uncertainty

Application in Insurance Markets

- **Insurance Demand**:
  - Risk-averse individuals are willing to pay a premium to avoid uncertainty.
  - Insurance transfers risk from the individual to the insurer.
- **Premium Determination**:
  - *Actuarially Fair Premium* ($\pi = p \cdot L$): Premium equals expected loss.
  - Includes administrative costs and profit margin in real markets.
- **Maximizing Expected Utility**:

$$\text{Maximize } E[U(W)] = (1-p)U(W-\pi) + p \cdot U(W-\pi-L+I)$$

where I is the insurance payout.

Stochastic Dominance in Insurance Markets

- **First-Order Stochastic Dominance (FSD)**:
  - A distribution F *first-order stochastically dominates* distribution G if:

$$F(x) \leq G(x) \quad \text{for all } x, \text{ with strict inequality for some } x$$

  - *Implication*: All individuals prefer F over G (regardless of risk preference).
- **Second-Order Stochastic Dominance (SSD)**:
  - F *second-order stochastically dominates* G if:

$$\int_{-\infty}^{x} F(t)dt \leq \int_{-\infty}^{x} G(t)dt \quad \text{for all } x, \text{ with strict inequality for some } x$$

  - *Implication*: All risk-averse individuals prefer F over G.
- **Application in Insurance Markets**:
  - Insurance policies can change the distribution of wealth.
  - Risk-averse individuals choose insurance to achieve a preferred wealth distribution via SSD.

First order Stochastic Dominance

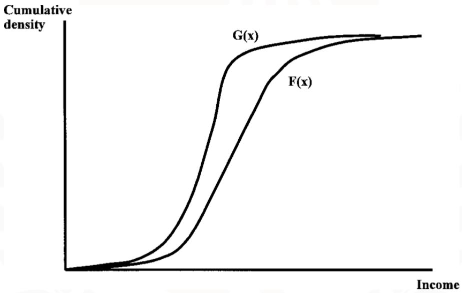

Figure 2: It's always better to take F(x)

Types of Utility Functions

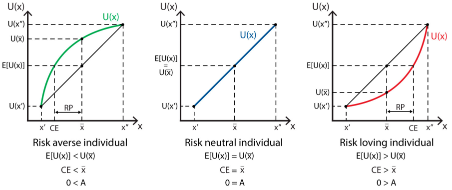

Figure 3: Which one are you?

Definitions

- Certainty equivalent: The amount of money given with certainty that equals a gamble
- Risk premium: the difference between the expected payoff and the certainty equivalent (the price of risk)
- Actuarially fair premium: nsurance premium set at a price that exactly equals the expected payout an insurer will make on a policy

Jensen's Inequality

- For risk neutral: E(U(w))=U(E(w))
- For risk loving: $E(U(w)) > U(E(w))$
- For risk averse: $E(U(w)) < U(E(w))$

Jensen's Inequality

- For risk neutral: E(U(w))=U(E(w))
- For risk loving: $E(U(w)) > U(E(w))$
- For risk averse: $E(U(w)) < U(E(w))$
- Because of this, between risk neutral insurers and risk averse agents, a contract always exists to improve welfare for both parties. Why?

Jensen's Inequality Visualized

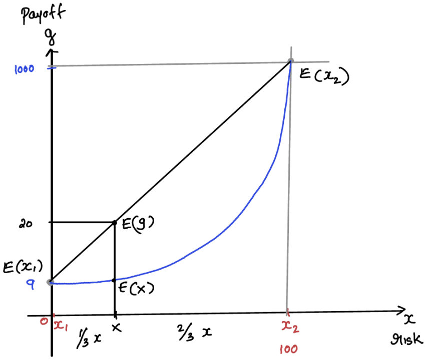

Figure 4: Concavity means an insurance contract exists...

Worked Example: Flood Insurance Problem

Scenario:

- An individual has an initial wealth of $200,000.
- There is a 2% chance of experiencing a flood causing $50,000 in damages.
- The individual is considering purchasing flood insurance.

Objective:

- Calculate the **Expected Utility** without insurance.
- Determine the **Certainty Equivalent** of the risky prospect.
- Compute the **Risk Premium**.

Assumption:

- The individual's utility function is $U(W) = \sqrt{W}$.

Solution to the Flood Insurance Problem

1. **Expected Utility Without Insurance**:
   - **Wealth if No Flood**: $W_{\text{no flood}} = \$200,000$
   - **Utility**: $U(W_{\text{no flood}}) = \sqrt{200,000} = 447.21$
   - **Wealth if Flood Occurs**: $W_{\text{flood}} = \$200,000 - \$50,000 = \$150,000$
   - **Utility**: $U(W_{\text{flood}}) = \sqrt{150,000} = 387.30$
   - **Expected Utility**:

$$E[U] = (0.98)(447.21) + (0.02)(387.30) = 446.07$$

Solution to the Flood Insurance Problem

2. **Certainty Equivalent (CE)**:
   - Find CE such that $U(CE) = E[U]$:

$$\sqrt{CE} = 446.07 \implies CE = (446.07)^2 = \$199,780$$

3. **Risk Premium (RP)**:
   - **Expected Wealth**:

$$E[W] = (0.98)(\$200,000) + (0.02)(\$150,000) = \$199,000$$

   - **Risk Premium**:

$$RP = E[W] - CE = \$199,000 - \$199,780 = -\$780$$

   - **Interpretation**: The individual is willing to pay \$780 more than the expected loss to avoid the risk.

Impact of Insurance Purchase

Full Insurance at Actuarially Fair Premium:

- **Actuarially Fair Premium**:

$$\pi = p \times \text{Loss} = 0.02 \times \$50,000 = \$1,000$$

- **Wealth After Paying Premium**:
  $W_{\text{insured}} = \$200,000 - \$1,000 = \$199,000$
- **Utility with Insurance**:

$$U(W_{\text{insured}}) = \sqrt{199,000} = 446.09$$

- **Comparison to Expected Utility Without Insurance**:

$$U(W_{\text{insured}}) > E[U_{\text{without insurance}}] = 446.07$$

- **Conclusion**: Purchasing insurance increases the individual's expected utility.

Climate Change from an Insurer's Perspective

Impact of Climate Change on Insurance Industry:

- **Increased Frequency and Severity of Natural Disasters**:
  - Higher occurrence of hurricanes, floods, wildfires, and droughts.
  - Leads to more claims and larger payouts.
- **Risk Assessment and Pricing Challenges**:
  - Historical data may no longer be a reliable predictor of future risks.
  - Need to integrate climate models into actuarial analyses.
- **Regulatory and Compliance Considerations**:
  - Emerging regulations on climate risk disclosure.
  - Requirement to assess long-term solvency under climate scenarios.
- **Product Innovation**:
  - Development of new insurance products (e.g., parametric insurance).
  - Offering incentives for risk mitigation and sustainable practices.

Sources for Climate and Insurance Data

International Organizations:

- **Intergovernmental Panel on Climate Change (IPCC)**:
  - Comprehensive climate assessment reports.
  - Website: `https://www.ipcc.ch/`
- **World Meteorological Organization (WMO)**:
  - Global climate data and analysis.
  - Website: `https://public.wmo.int/`

National Agencies:

- **National Oceanic and Atmospheric Administration (NOAA)**:
  - Climate data records, weather events.
  - Website: `https://www.noaa.gov/`
- **U.S. Geological Survey (USGS)**:
  - Natural hazard data (earthquakes, floods).
  - Website: `https://www.usgs.gov/`

Sources for Climate and Insurance Data

Insurance Industry Reports:

- **Munich Re NatCatSERVICE**:
  - Database on natural catastrophes.
  - Website: `https://natcatservice.munichre.com/`
- **Swiss Re Institute**:
  - Research on insurance and climate risks.
  - Website: `https://www.swissre.com/institute/`

Academic and Research Institutions:

- **Climate Data Archive at NCAR/UCAR**:
  - Climate models and data sets.
  - Website: `https://www2.cisl.ucar.edu/`
- **NASA's Goddard Institute for Space Studies (GISS)**:
  - Climate change research and data.
  - Website: `https://www.giss.nasa.gov/`

What is Imperfect Information?

- Imperfect information occurs when some agents know things others don't
- A major cause of market breakdown and failure
- Particularly relevant in insurance when insurers don't observe risk

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- A major cause of market breakdown and failure
- Particularly relevant in insurance when insurers don't observe risk
- Maybe the insured can even... increase risk?

Principal-Agent Problems

- In many cases, a principal (like an employer or instructor) wants a desired outcome from the agent (employee or student), but the interest may not aligned

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Principal-Agent Problems

- In many cases, a principal (like an employer or instructor) wants a desired outcome from the agent (employee or student), but the interest may not aligned
- How to align them? Incentives!
- I want you to put forth your full effort in the course, but I can't observe your effort, so I give grades as an incentive.
- What if it's a bad incentive?
- What if it's such a bad incentive that it created bad behavior?

Mathematical Formulation of the Principal-Agent Problem

- **Principal-Agent Setup:** A principal (e.g., an employer) hires an agent (e.g., an employee) to perform a task. The agent's actions affect the outcome, but the principal cannot directly observe the agent's effort.
- **Agent's Utility:** The agent derives utility from compensation w and disutility from effort e:

$$U_{\text{agent}} = w - C(e)$$

where $C(e)$ is the cost of effort, typically increasing with effort.

Principal-Agent Problem

- **Principal's Payoff:** The principal's payoff depends on the outcome x, which is affected by the agent's effort e and a random component ϵ:

$$x = f(e) + \epsilon$$

The principal's utility is:

$$U_{\text{principal}} = x - w$$

- **Incentive Compatibility Constraint (ICC):** The agent chooses effort e to maximize their utility. The principal must design a contract so the agent's optimal effort aligns with the principal's interest:

$$e = \arg\max_{e} (w(e) - C(e))$$

- **Participation Constraint (PC):** The agent must receive at least their reservation utility U_0 to participate:

$$U_{\text{agent}} \geq U_0$$

Example of the Principal-Agent Problem

- **Setup:** A company (principal) hires a salesperson (agent) and cannot directly observe the effort they put into generating sales.
- **Outcome (Sales):** Sales, x, depend on the agent's effort e and a random factor ϵ, where:

$$x = 10e + \epsilon$$

  with ϵ representing market conditions.
- **Agent's Utility:** The agent's utility is given by:

$$U_{\text{agent}} = w - \frac{e^2}{2}$$

  where $C(e) = \frac{e^2}{2}$ represents the disutility of effort.
- **Principal's Compensation Scheme:** The principal offers a contract where the agent's wage w depends on sales as:

$$w = 5 + 0.5x$$

- **Agent's Optimal Effort:** The agent maximizes their utility by

Principal-Agent Problem in Environmental Economics

Example Scenario:

- **Principal**: Government agency aiming to reduce pollution.
- **Agent**: Factory owner who emits pollutants during production.

The Problem:

- The government cannot perfectly monitor the factory's emissions.
- The factory owner has private information about the actual level of emissions.
- The owner may have an incentive to under-report emissions to reduce compliance costs.

Objective:

- Design an incentive scheme to ensure the factory reduces emissions to acceptable levels.

Analyzing the Principal-Agent Problem

Approach:

1. **Contract Design**:
   - Implement a *performance-based* contract.
   - Use observable indicators (e.g., periodic inspections, pollution permits).
2. **Incentive Compatibility**:
   - Ensure that it's in the factory owner's best interest to comply.
   - Introduce penalties for non-compliance and rewards for meeting targets.
3. **Mathematical Representation**:
   - Let e represent the effort (emission reduction) by the agent.
   - Agent's cost: $C(e)$, increasing in e.
   - Principal's benefit: $B(e)$, increasing in e.

Solution:

- Maximize the principal's expected utility subject to:
  - *Participation Constraint*: Agent's utility $U_A \geq \bar{U}_A$.
  - *Incentive Compatibility Constraint*: Agent chooses e that maximizes their own utility given the contract.

What is Moral Hazard?

- Moral hazard occurs when people are insured against risk and so take on more of it
- Think about the way people treated insured things... rental cars, my phone
- Think about Silicon Valley Bank and why people buy houses close to the water

Mathematical Formulation of Moral Hazard

- **Definition of Moral Hazard:** Moral hazard arises when one party in a transaction has an incentive to take on riskier behavior because they do not bear the full consequences of that risk.
- **Setup:** A principal (e.g., insurance company) cannot observe the level of care or effort taken by an agent (e.g., policyholder), leading the agent to potentially act less cautiously.
- **Agent's Utility:** The agent chooses effort e to maximize their utility:

$$U_{\text{agent}} = w - C(e) + \mathbb{E}[\text{insurance benefits}]$$

  where $C(e)$ is the cost or disutility of effort.
- **Principal's Expected Payoff:** The principal's expected costs depend on the likelihood of an accident or loss, which is reduced by the agent's effort:

$$\mathbb{E}[U_{\text{principal}}] = \text{premiums} - \mathbb{E}[\text{insurance payout}]$$

Mathematical Formulation of Moral Hazard

- **Incentive Problem:** Without observing e, the principal cannot directly control the agent's level of caution, leading to higher expected payouts.
- **Optimal Contract Design:** The principal may implement a cost-sharing contract (e.g., deductible or co-pay) to align the agent's incentives with taking adequate effort.

Conclusion

Moral hazard occurs when the agent is shielded from risk, incentivizing behavior that increases risk for the principal, who must design contracts to mitigate this.

Example of Moral Hazard in Insurance

- **Setup:** An individual (agent) has health insurance, reducing their personal cost of medical expenses.
- **Agent's Choice of Effort:** The agent chooses a level of effort e (e.g., lifestyle choices) to reduce health risks, with a disutility cost:

$$C(e) = \frac{e^2}{2}$$

- **Insurance Coverage:** The insurance company (principal) covers 80% of medical costs, leaving the agent responsible for 20%.
- **Agent's Expected Utility:** The agent's expected utility considering insurance is:

$$U_{\text{agent}} = \text{income} - 0.2 \cdot \mathbb{E}[\text{medical costs}] - \frac{e^2}{2}$$

Example of Moral Hazard in Insurance

- **Principal's Expected Costs:** The insurance company's expected cost increases if the agent reduces e, leading to a higher probability of claims.
- **Solution (Cost-Sharing):** To incentivize higher effort, the insurance company could introduce a deductible or raise the co-payment, motivating the agent to choose a higher e that reduces expected medical costs.
- **Result:** With increased cost-sharing, the agent is incentivized to maintain a higher level of care, aligning their interests with the principal's by reducing risky behavior.

Conclusion

Cost-sharing reduces moral hazard by encouraging the agent to bear part of the risk, leading to a higher optimal level of effort e and lowering expected insurance payouts.

Moral Hazard in Flood Insurance

- After purchasing insurance, the individual may take fewer precautions against flooding.
- Examples include:
  - Not investing in flood-proofing measures (e.g., barriers, elevated structures).
  - Building or residing in higher-risk flood zones.
- This behavior increases the probability or potential severity of flood damage.

Analyzing Moral Hazard in the Earlier Example

Impact on Expected Loss:

- **Without Moral Hazard**:
  - Probability of flood: $p = 2\%$
  - Expected loss: $E[\text{Loss}] = p \times \$50,000 = \$1,000$
- **With Moral Hazard**:
  - Individual takes fewer precautions.
  - Probability of flood increases to $p' = 3\%$.
  - Expected loss increases: $E[\text{Loss}] = p' \times \$50,000 = \$1,500$

Implications for the Insurance Market:

- **Higher Premiums**:
  - Insurers may raise premiums to cover increased expected losses.
- **Welfare Loss**:
  - Inefficient allocation of resources.
  - Potential for increased overall risk in the market.
- **Need for Mitigation**:
  - Implement deductibles, co-payments, or require preventive measures.

National Flood Insurance Program

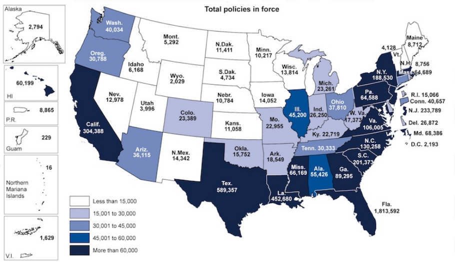

Figure 5: Florida man... took out insurance?

SBF Coin Flip Story

- Jane Street encourages its interns to engage in bets
- Interns could not lose more than $100 in a day, setting a hard cap on losses.
- Another intern, “Asher,” bet SBF on the maximum loss of any intern that day, agreeing to pay losses above $65. SBF would pay the difference if no intern lost more than $65.

SBF Coin Flip Story

- SBF creates a scheme to exploit Asher's position:
  - Offers other interns $1 to flip a coin for $98.
  - If someone loses $98, Asher owes SBF $33 ($98 - $65).
- Expected value for SBF: Win $130 (net) or lose $66 (net), both with 50% probability.
- The other interns also gain $1 expected value per flip, making it a compelling offer.
- SBF continues raising the stakes:
- Offers coin flips at 99, $99.50,99.75, creating repeated positive expected-value bets for both sides.
- Wins multiple flips, increasing Asher's losses and creating a tense environment.

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- SBF continues raising the stakes:
- Offers coin flips at 99, $99.50,99.75, creating repeated positive expected-value bets for both sides.
- Wins multiple flips, increasing Asher's losses and creating a tense environment.
- If someone offers you a bet, ask why they're offering it!

What is Adverse Selection?

- Adverse selection occurs when individuals sort based on private information unavailable to counterparty
- Imagine an insurer was mandated by the government to provide insurance to everyone
- The market works well because ill and well people get insurance
- New insurer comes along offering lower premiums for light coverage
- All healthy people take the light offer and market collapses

Market for Lemons

Figure 6: I don't know anything about cars...

Private Markets and Adverse Selection

- SpaceX and private companies have massive returns
- These investments have traditionally limited to ‘Accredited investors’ who were in theory more sophisticated
- There is a bill in Congress to open up these bets to all. Sounds great, right? We can all invest in SpaceX!

Private Markets and Adverse Selection

- SpaceX and private companies have massive returns
- These investments have traditionally limited to 'Accredited investors' who were in theory more sophisticated
- There is a bill in Congress to open up these bets to all. Sounds great, right? We can all invest in SpaceX!
- No one is offering **YOU** the chance to invest in SpaceX
- Robinhood makes its money through payment for order flow
- If someone offers to trade with **YOU**, ask yourself why?

Introduction to the Market for Lemons

- **Concept of Market for Lemons:** Proposed by George Akerlof, the "Market for Lemons" illustrates how asymmetric information can lead to market failure.
- **Example Market:** In a used car market, sellers know the quality of the car (good or bad, also called a "lemon"), but buyers cannot differentiate.
- **Problem of Asymmetric Information:** When buyers cannot distinguish between high-quality and low-quality cars, they are only willing to pay an average price, not reflecting the true value of high-quality cars.
- **Outcome of Adverse Selection:** High-quality car owners may exit the market as they cannot get a fair price, leaving only lemons, which reduces the overall quality in the market.

Mathematical Formulation of the Market for Lemons

- **Types of Cars:** There are two types of cars: - High-quality (H) with value V_H - Low-quality (L) with value V_L, where $V_L < V_H$.
- **Proportion of Types:** Assume a proportion θ of cars are high-quality and $(1 - \theta)$ are low-quality.
- **Expected Value to Buyers:** Since buyers cannot distinguish quality, they are willing to pay the expected value:

$$P = \theta V_H + (1 - \theta) V_L$$

- **Adverse Selection Condition:** High-quality sellers will only sell if $P \geq V_H$. If $P < V_H$, high-quality cars exit the market, lowering θ and reducing P.
- **Equilibrium Outcome:** If buyers' expected price P is below V_H, only low-quality cars remain, leading to a market equilibrium dominated by lemons.

Introduction to the Rothschild-Stiglitz Model of Adverse Selection

- **Adverse Selection Definition:** Adverse selection occurs when one party in a transaction has more information about their own risk level than the other party, leading to market inefficiencies.
- **Context of the Model:** The Rothschild-Stiglitz model analyzes adverse selection in insurance markets, where individuals know their own risk level (high or low), but the insurer cannot distinguish between them.
- **Market Outcome:** Due to asymmetric information, low-risk individuals may exit the market, causing insurers to increase premiums, potentially leading to market failure.
- **Objective of the Model:** To determine whether competitive equilibrium can exist in a market with asymmetric information and to examine how different risk types are affected.

Mathematical Formulation of the Rothschild-Stiglitz Model

- **Types of Individuals:** Two types of individuals exist — low-risk (L) and high-risk (H) — with different probabilities of filing a claim:

$$p_L < p_H$$

- **Utility of Wealth:** Individuals have a utility function $U(W)$ over wealth W, with $U' > 0$ and $U'' < 0$ (risk-averse).
- **Insurance Contract:** Each contract offers coverage q for a premium P, aiming to maximize the expected utility of individuals:

$$U = p_i U(W - P + q) + (1 - p_i)U(W - P)$$

where $i = L, H$ denotes the risk type.
- **Separating Equilibrium Condition:** In a separating equilibrium, insurers offer a low-coverage, low-premium contract for low-risk individuals and a high-coverage, high-premium contract for high-risk individuals.

Mathematical Modeling of Adverse Selection

Model Setup:

- **Firms**:
  - Each firm knows its own type $\theta \in \{\theta_L, \theta_H\}$.
  - θ_L: Low-polluting, high abatement cost C_L.
  - θ_H: High-polluting, low abatement cost C_H.
- **Regulator's Problem**:
  - Maximize social welfare by reducing emissions.
  - Subject to incentive compatibility and participation constraints.

Incentive Compatibility Constraints:

- Ensure that each firm reports its true type:

$$U_\theta(t_\theta, q_\theta) \geq U_\theta(t_{\theta'}, q_{\theta'}), \quad \forall \theta, \theta' \in \{\theta_L, \theta_H\}$$

where t_θ is the transfer (payment), and q_θ is the quantity of permits allocated.

Thank You So Much!

List of References