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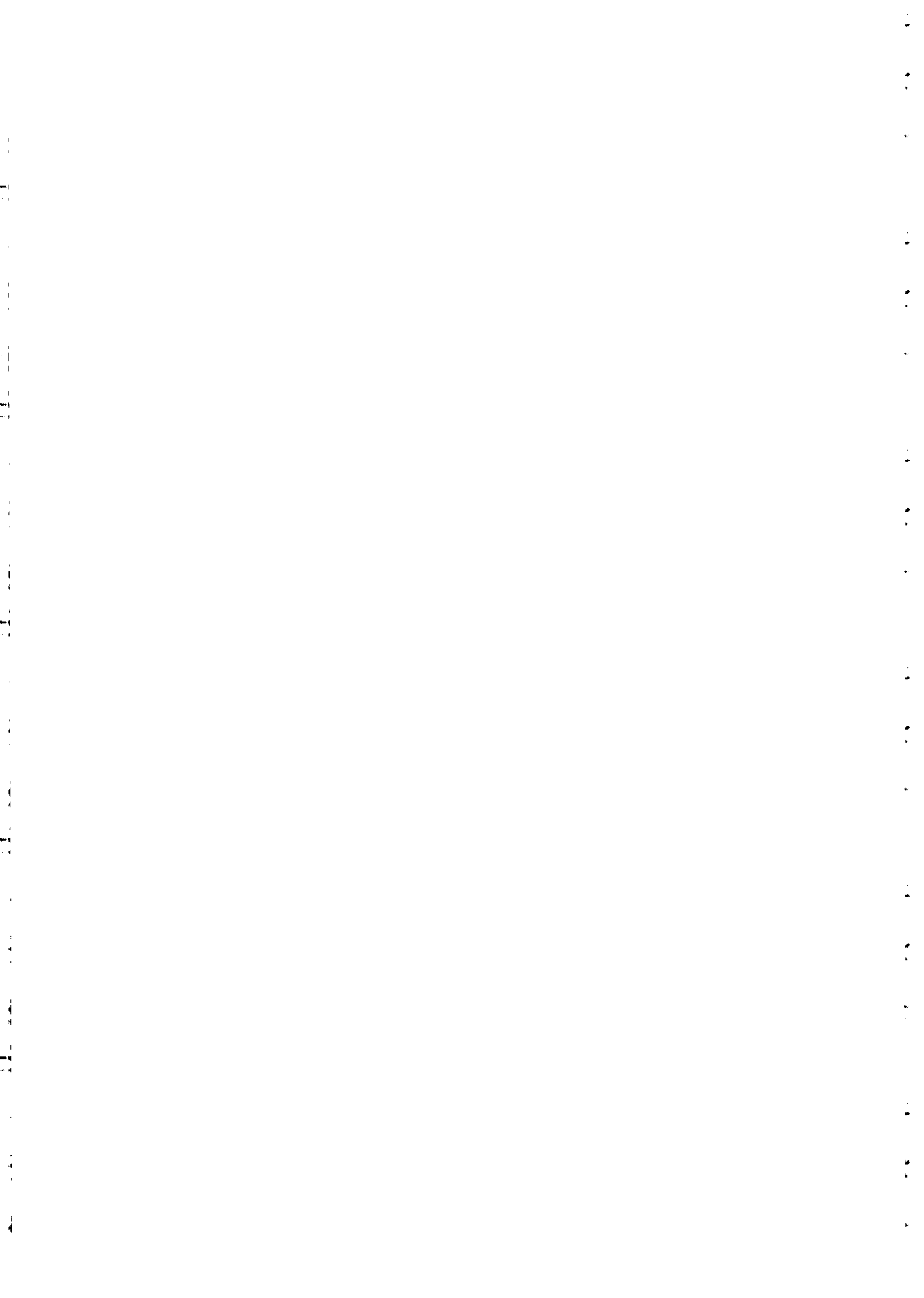
**"Fifth Course on Mathematical Ecology
including and introduction to Ecological Economics"**

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ECOSYSTEMS AND MARKETS

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Ecosystems & Markets

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Background reading

- Nature's Services: Societal Dependence on Natural Ecosystems, G. Daily (ed), Island Press, Washington DC, 1997
- GM Heal, Nature and the Marketplace, Island Press, Washington DC, 2000
- Various references in the slides

Economic Issues

- Economics is about markets
 - how they allocate society's resources
 - when they do this well & when badly
 - what are the alternatives to markets
 - what is produced & consumed
 - who is rich & who is poor

Economic Agents

- **The main players in an economy are:**
 - **Consumers and Producers**
 - Consumers buy goods and services and decide on their choices.
 - They decide what to sell, how much to sell, and how much proceeds to buy goods and services. Typically sell labour and own housing.

Economic Agents

- **Producers** combine inputs to produce outputs.
 - They produce goods and services. Production process combines inputs with difference between the value of the outputs and inputs.

Economic Concepts

- **Commodity Space**
 - Euclidean space R^n representing each of the commodities in the economy.
- **Preferences**
 - Consumer preferences are a transitive ordering over the commodity space, representable by an ordering function called a utility function, $U(x): R^n \rightarrow R$.

Economic Concepts

- **Price**
 - price of a good or service in a market
- **Value**
 - of a vector of goods is interpreted with a price vector.
 - For firms, inputs negative, outputs positive so $x \cdot p = \text{profit}$ where x is production plan and p is price vector.

Economic Concepts

- **Competitive market** - market in which no individual agent can influence the price
- **Endowment** - what consumer owns at the start of the market. Wealth is $p \cdot w_i$

Economic Concepts

- **Pareto efficient** - impossible to make one person better off without making another worse off
- All opportunities for mutual gain will be exploited. Markets and trading are mechanisms for realizing mutual gains

First Theorem of Welfare Economics

- If all markets are competitive, and there are no production externalities, a competitive equilibrium allocation is Pareto efficient.
- Formalizes Adam Smith's concept of an invisible hand (which Alfred Marshall took heavily in his thinking about market selection, the biologists' invisible hand).

Invisible Hand

- *Every individual who pursues his private interest promotes that of society, no man has much reason to suppose that he can promote his own security or happiness by a course of conduct which was not profitable to the community, while pursuing his own interest, and which promotes that of society more effectually than when he really intends to promote it.*

Equity & Efficiency

- Pareto efficiency is a way to compare distributions and not a measure of equity.
- It states that if no Pareto improvements (mutual gain) are expected, then the current distribution of income is in a way that is efficient.

B's welfare depends on A's production decisions. A's utility depends on B's production decisions.

Inefficient

Asymmetric

Economic Questions

- Does a market have an equilibrium?
- Does it approach its equilibrium?
- In answering these one encounters issues similar to dynamical ecology.
- Overall similarities: about complex systems, equilibria, non-equilibria, competition.

Competitive Equilibrium

- A set of prices for production and consumption plans at which
- Demand = supply in every market
- All consumers maximize positions on their preference orderings subject to budgets imposed by their wealth
- All producers maximize profits

Competitive Equilibrium

- Necessary conditions for competitive equilibrium but not sufficient. Equilibrium is not reached if there is a change in demand or supply that moves the market.
- Natural dynamic...

Dynamics

- $dP/dt = D(p) - S(p)$ where...
- $D(p)$ is the number of units demanded by people with income y and price p .
- $S(p)$ is vector of quantities supplied and sold at price vector p .

Demand & Supply

- Firms choose to produce and sell until their picking up the price p .
- Max $p \cdot x$ subject to $x \in X$ where X is the set of production possibilities. This is done according to the firm's technology. Called the production possibility set.

Demand & Supply

- Likewise individual choices result from picking c^i to
- Max $U^i(c^i)$ subject to $p \cdot c^i = w^i$ from the budget constraint
- Then $dP/dt = \frac{dD}{dP} / \frac{dS}{dP}$ where $\sum c^i$ is demand and $\sum x^i$ is supply

Existence of Equilibrium

- A very complex question. Need conditions on preferences, endowments and production sets. Restrictive conditions are
- Convexity of production possibility sets
- Every consumer must be able to purchase positive amounts of some goods - a condition on distribution of endowments.

A convex set has the property that any line joining 2 points in the set lies itself in the set.



Convex Non-convex

Convexity matters because it lets us use separating hyperplane theorems. Critical in establishing existence and efficiency of competitive equilibrium.

Existence of Equilibrium

- Convexity conditions may not be satisfied in some economic applications.
- Non-linearities in structure and effects may preclude convexity.

Existence of Equilibrium

- Repetitive structure may be required in some cases of dynamic equilibria.
- If a system has a continuum of equilibria, the specific one is not moot.
- Uniqueness of equilibria is complex. Local uniqueness known.

Stability of Equilibrium

- Also a complex issue, but understood in some cases.
- $dP/dt = f(P)$ can be used to study behavior, to find cycles, and to find equilibrium.

Public v Private Goods

- Apples = common
- Apples are *non-rival* and *excludable* means my consumption of an apple prevents you from consuming it. Excludable means that the seller can exclude from taking it anyone who did not pay for it.

Public v. Private Goods

- Software: if you install it and then pass disk on, you are not a consumer, does not prevent you from the sale, cannot prevent those who have not paid from using the product.
- Air quality, biodiversity have some resemblance to software.

Public v. Private Goods

- The public good nature of software, many knowledge based products, and indeed many goods, has led to the "new economy" emphasis on intellectual property rights.
- IPRs try to convert public to private goods, especially in software and knowledge industries via patents and copyrights.

Private & Social Costs & Benefits

- Private costs are those that corporations, those who produce the good, or those who consume the actual good bear.
- Social costs are those that in addition to private costs accrue to people who are not the producer or consumer.
 - Driving a car. Private costs include gas and maintenance.
 - Social costs include pollution.

Private & Social Costs & Benefits

- Private benefits are those that individuals who consume the good, such as timber, or those who produce some saleable environmental products, such as carbon credits, receive.
- Social benefits are those that in addition to private benefits are enjoyed by others, such as carbon sequestration, biodiversity conservation, etc.

Markets and the Environment

- Markets do not always work with the conditions of the environment.
- Less satisfied with the way we manage the "failure".
- Investigate how markets can be used to promote environmental conservation.

Markets and the Environment

- Goods that are public goods are typically under-provided by the market relative to efficiency. YES
- Reason - lack of incentive on part of producers who cannot appropriate all the gains from their provision - "free rider" problem.

Markets and the Environment

- If the social benefits of a good exceed the private (economic) ones, it is also under-provided, as the provider has too little financial incentive.
- If the social costs exceed the private then a good is over-provided - e.g. transportation.

Policy Responses

- Policy responses to differences between private and social costs are either:
 - taxes (or subsidies) equal to the difference between the private and social costs
 - the introduction of property rights. Based on the view that an excess of social over private costs arises from the inability to own certain key resources, such as the atmosphere.

Property Rights and Tradable Gases

- Emissions of CO₂ and other greenhouse gases can be seen as a negative externality
 - social cost > private cost
 - The basis for a market-based solution

Greenhouse Gases

- Alternative view: emissions of greenhouse gases are a negative externality that can be avoided without government action
- On this view, emissions of greenhouse gases are a negative externality that can be avoided without government action
 - someone's property rights are violated
 - it we have to obtain permission and compensate them for the violation
- Leads to tradable carbon permits.

Fusion of Market Economics with Environmental Policy

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Biodiversity as a Commodity

- Conservation involves paying for biodiversity. What are we buying?
- What are the economic functions of biodiversity?
- What kind of commodity is it? Public or private good?
- Can the market appreciate biodiversity?

Biodiversity provides or enhances

- Ecosystem productivity & resilience
- Insurance
- Knowledge
- Extent & Scope of Ecosystem Services

Biodiversity as a Commodity

- What kind of commodity is biodiversity in its role as a provider of these services and can markets adequately manage our interactions with biodiversity?

Biodiversity, Productivity & Resilience

- We know that diverse grasslands and other ecosystems are more productive and resilient and so more valuable in grassland plant communities.
- Diversity here means even representation of functional groups and variety within such groups.

Biodiversity, Productivity & Resilience

- Chapin et al. (1986) demonstrated that diversity was a poor predictor of one term, grain yield, but a good predictor of ecosystem structure and process. Chapin argues that "ecologically similar systems may appear similar under one particular set of environmental conditions." (Science 231: 152-157)

Biodiversity, Productivity

- Also, Chapin et al. (1986) demonstrated that productivity was a good predictor of ecosystem structure and process.
- Wild rices and wild turkeys and animals critical to original biodiversity of existing commercial grasslands.
- About \$1 billion added each year to value of US agricultural output as result of plant breeders' use of genetic diversity.

Biodiversity & Insurance

- Asian rice from 100 grassy hills (diversity) = action of 100 hills = 100% daily 97%
- Vulnerability of genetically homogeneous animals & crops grown on massive scale

Biodiversity & Genetic Knowledge

- Taxol from Yew trees
- Rosy Periwinkle & leukemia
- Thermophilic bacteria & Yellowstone
- Discovery of novel genetic and molecular structures.

Biodiversity & Ecosystem Services

- Biogeochemical cycles & ecosystems provide essential infrastructure to human societies (Daily 2000)
- Drink & food
 - Water purification (hydrological cycle)
 - Pollination
 - Decomposition (nutrient cycle)
- Climate control.
- Carbon cycle.

Ecosystem Services & Infrastructure

- Similar to natural systems, can be degraded or lost
- Human infrastructure (e.g., water treatment, flood control) systems and services are often degraded
- Without them, many natural systems are valueless.

Diversity and Ecosystem Function

- Key study: Tilman et al. (1996)
- Several species of grasses in different environments
- Passenger pigeon community

Biodiversity & Productivity

- Chapter 10: Biodiversity and Ecosystem Function
- diversity is an important component of ecosystem function
- argues that species diversity is ecologically important
- appear similar under one particular environmental conditions." (Science)

Scale of Human Activity

- Double rate of fossil fuel use
- Appropriate 40% of WPP, 50% incident fresh water.
- Double proportion of CO₂ in atmosphere
- Extinction rates.

Markets as Mediators

- Need institutions for monitoring of medium term impacts
- Example of market: counterexample fisheries, Watersheds, Ecotourism, etc. positive cases.
- When can markets control efficient impacts on planetary infrastructure?

Biodiversity & Markets

- Can we commercialize contributions of biodiversity?
- Can the economic contributions of biodiversity be used to generate incomes to the owners that provide incentives to conserve?
- Can they make conserving tropical forests more attractive than clearing them?

Biodiversity & Markets

- Real prices in competitive markets allocate private resources efficiently (production of all activities is Pareto efficient, i.e. operationally efficient) if:
 - no externalities
 - no public goods
 - no imperfectly competitive markets
 - no imperfectly distributed resources
 - no imperfectly distributed information
 - no imperfectly distributed knowledge

Biodiversity & Markets

- Public goods are non-excludable and non-rival in consumption
- Private goods are excludable and rival in consumption

Biodiversity & Markets

- Search for biodiversity is a public good
- Law & order are public goods
- Knowledge a public good

Biodiversity and Markets

- Conflicting interests: productivity vs. insurance value of public goods
- Establishing property rights in genetic information may be difficult
- Example - *Brachiaria*

Biodiversity and Markets

- May be possible to organize institutions to govern
- Example - satellite broadcasting of TV
Was initially non-rival and non-excludable. As pay-per-view and scrambler technology, a charge for access to broadcast via conditional access descrambler.

Biodiversity and Markets

- Genetic knowledge may be underpinned by similar basic research via terminator genes.
- These can make the productivity and insurance values embedded in new genetic varieties a private good, forcing farmers to repurchase every year. This knowledge is now "excludable".

Biodiversity and Markets

- Need to consider equity issues
- May erode biodiversity if not done with equity. Result of market oriented outcome is reduced biodiversity

Biodiversity Insurance

- Insurance is a market based mechanism for addressing biodiversity loss. Role of insurance is still emerging and unclear to date.
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Biodiversity Insurance

- We need to consider equity issues in insurance. Role of insurance is still emerging and unclear to date.
- Only in this way will market based mechanism provide adequate incentives for biodiversity conservation. Role of insurance is still emerging and unclear to date.
- Privatization of genetic resources may be positive in this context.

Biodiversity & Markets

- Knowledge of medicinal plants is public good
- "Although the medicinal plants are not likely to become pharmaceutical information, gathering such information is likely to lead to the development and understanding of novel molecular targets, which may ultimately lead to the development of new therapeutic agents". (Carte *Bioscience* 96)

Step 1/2/3/4/5

Knowledge & Markets

- In a free market economy, basic knowledge is provided by research funded by the state or by foundations
- Only the development of more applied knowledge can be provided by the market

Biodiversity & Markets

- Where is there market potential amongst the services provided by biodiversity?
- Marketing ecosystem services:
 - Carbon sequestration
 - Watershed services
 - Ecotourism.

The Kyoto Protocol

- Agreement to reduce greenhouse gas (GHG) emissions
- A key feature of the Kyoto Protocol is that:
 - Countries have specific emission targets
 - If they exceed their target they pay more and
 - if they fall short they receive credits

The Kyoto Protocol

- Buying and selling permits for emitting GHGs by the amount of price of the permit. This puts a price to the so-called "right to emit" price right which is then used to regulate the supply of permits.
- Establishes property rights in the atmosphere, at least in the interests of emitting GHGs.

The Kyoto Protocol

- Provides countries with tradable permits and those exceeding their target have incentives to reduce emissions with the greater, the greater the value of the emission permit.
- Based on US 1990 Clean Air Act, successful in reducing GHG emissions through this mechanism.

Carbon Sequestration

- CDM (or Kyoto protocol) may pay countries for additional sequestration
- Payments per ton (over) by permit price
- Permit prices: \$10 - \$100 per ton and
- Sequestration rates for most tropical forests from 5 - 15 tons/ha/yr. Together imply

Carbon Reforestation

- Payments of \$25 - \$100/ha/yr
- Reforestation costs are \$900/ha
- By comparison, most profitable ranches in Costa Rica make \$125/ha/yr
- How much land would be reforested?

NYC Watershed

- Before 1996 NYC water-borne fecal coliforms unprocessed
- Cleansing by microorganisms in Catskill watershed
- Damaged by sewage & agriculture
- Replacement cost \$10¹⁰ over ten years
- Cheaper to restore ecosystems @ \$1.5x10⁹.

Watersheds

- Now over 100,000 in the US, but in public lands, there is concern about development, grazing, and effects on flow & water quantity
- Similar movement in other countries
- Possible that ecosystem services provision could alone justify conservation of several B/D hotspots, and Caribou on riparian area in US.

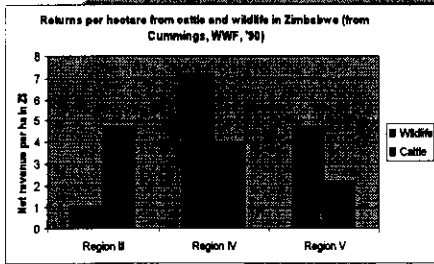
Ecotourism

- Main source of income in some of the poorest African countries, especially in biodiversity hotspots
- Return to nature conservation in many states and attracts tourists to natural ecosystems
- Generates revenue of over a billion dollars a year, or more than a trillion annually.

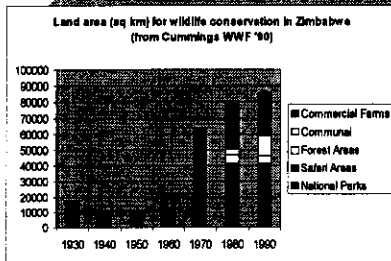
Ecotourism

- Increasingly important in Africa, especially in the 1990s, but also in those areas where there is a high level of use.
- Leading to stable and increasing situation of many previously endangered species.

Ecotourism



Ecotourism



Ecotourism

- In southern Africa over 8% of private land area is now devoted to wildlife conservation.
- The main driver here is commercial game ranching for tourism.

Mitigation Banking

- Introduced in the 1990s
- Designated areas where banks are allowed to be established
- If more than one bank is established there is a reserve against future need for mitigation banking. Led to a market in wetlands.

The Market for Woodpecker

- Mitigation for the loss of Special Use (S.U.) and Wildlife Service (W.S.) land in the endnager's
- Target number of woodpecker as long as this number of woodpecker is free to use land as a

The Market for Woodpecker

- Used with the woodpecker (Pica pica) and the Paper in the
- Excess over the number of woodpecker banked & sold
- Breeding pairs traded
- Incentive to "farm woodpecker"

Summary

- In cases of water, forests and so on, when we are not doing business directly, we provide a lot of environmental conservation.
- They have already generated substantial conservation without any government intervention, working in a completely decentralized way.

Summary

- In the case of carbon sequestration and mitigation trading, we have used market regulations to create a market.
- In the former case, a required reduction in the emissions of greenhouse gases leads to a demand for emission permits.
- In the latter a required minimum number of a species creates a market for that species.

Summary

- When does it make sense to conserve environmental systems?
- Key issues: How do you value environmental services? Can they be privatized and sold?
- Are they public or private goods?

Summary

- Economic externalities do not exist in a perfectly competitive market. Making them internalize through a tax or a subsidy can guide services to the socially optimal level.
- Water is a private good, but water conservation is provided as a public good even though the conservation itself is a public good.

Summary

- Carbon emissions are a global externality. Introducing a carbon tax or a cap-and-trade system can internalize the externality and reduce emissions.
- But only using a carbon tax or a cap-and-trade system - to decide the optimal level of emissions - a given target reduction. To determine the market to determine the optimal level of emissions.

Conclusion

- Markets are not perfect in the real world. Externalities and public goods are common.
- Properly designed government interventions can also be a part of the solution.

Valuation

- Placing an Economic Value on Ecosystem Services

Valuing the Biosphere

- We could not value the services of natural ecosystems
- Does this translate into economic value?
- Economics more concerned with *possibilities values or importance*
- Oscar Wilde: "A cynic is someone who knows the price of everything & the value of nothing".

Price and Importance

- Price does not always reflect importance. Unimportant goods can be valuable more than important goods can be.
- Market prices only reflect the amount of supply that is demanded.
- Water - supply so large that it is demanded in any amount at any price.

Price and Incentives

- An example is the 2008 financial crisis
- Agricultural production in developing countries is not high.
- Food problem in agriculture is not too much rather than too little.

Price and Incentives

- When the price of a good falls, the quantity demanded increases and the quantity supplied decreases.
- Present price of a good is not too high or too low, but it is not too low or too high.

Price and Incentives

- Developing countries have a high demand for food, but the supply is not high.
- Prices reflect the demand and supply in the existing social order.

Price and Social Value

- Price reflects value to marginal buyer, buyer on verge of not buying, who would drop out if price rose small amount.
- Analogy with swing voters who determine an election outcome.

Valuing the Bazaar

- *Price tells us how much society would gain if a little more of the good were made available.*
- Partial derivative of social welfare w.r.t. availability of good. Lagrange multiplier associated with constraint imposed by availability of good.

Price and Social Value

- Small increase in supply would not change price much, so new buyers would value good at present price.
- If they valued it a lot more they would already be buyers; if they valued it a lot less, then a small drop in price would not bring them in.

Price and Value

- Value will still be considered important, but what consumers consider important will be relative to the opportunity cost of their consumers.
- So prices will indicate the consequences of their choices.

Prices as Value

- If you are providing a service of nature (ecotourism, medicinal plants) for value.
- Value C-sequence (C-sequence) of water purification services (for example, market prices). Place some value on the ecosystem support by looking at market prices for ecotourism & bioprospecting.

Services with no market

- Heuristics: Value of the ecosystem bought and sold by the market (C-sequence) price.
- Farms are bought and sold on the market. Land price per acre is used to see how fertile the land is. Indirectly have estimated a price for soil fertility.

Replacement cost

- New York decided to restore Catskills watershed as alternative to restoring watershed with 90 mg/day pollution plant. Cost about \$9 billion.
- Can we say that because the cost of replacing the watershed would have been \$9 billion, this is its value?

Replacement cost

- Will not always make sense. Sometimes defense cost could be too high. Watershed is not replacement cost option.
- If Catskills provided replacement with replacement cost of billions, City would not have replaced. Replacement cost would not be a proper indicator of the value of service.

Replacement cost

- Even in New York, the value of a watershed is not \$9 billion. City never chose to buy this or other watersheds between \$1.5-2 billion.
- Saved \$(9-1.5) billion by environmental conservation. Not same as placing value on watershed: it is collating consequences of a conservation policy.

Travel cost method

- Estimate value by asking individuals how many times they visit a forest and how far they travel to get there. The more visits and the further they travel, the more they value the benefits that I value.

Survey method

- Survey method with direct questions about value of environmental assets.
- Contingent valuation method - Valdez.
- Not based on actual market transactions - all the previous approaches are.

Market prices

- Economists derive value of a service by market prices and market prices from government transactions.
- Market-based prices of goods in a society of a small number of people, a service, and do not include the overall contribution of the service.

Non-marginal changes

- Could we value less of a significant part of life support system?
- E.G. significant change in hydrological cycle that would result from a changed climate system, reducing substantially water supplies to large regions of the earth.

Non-marginal changes

- Would have to know how price of water rises as supply falls and demand curve for water. *Do we have that?*
- As price of water rises, food production, food prices, income levels, etc. would all change. Change demand curve. Change in complex non-linear interdependent system.

Valuation and conservation

- ***Valuation is neither necessary nor sufficient for conservation. We conserve much that we do not value, and do not conserve much that we value.***

Incentives and conservation

- Preserving biodiversity is a public good. *incentives*
- To conserve biodiversity, governments can give owners incentives. Making conservation more attractive than other uses.
- Conserving forests is more attractive than clearing to plant coffee or cocoa beans.

Incentives and conservation

- To encourage biodiversity conservation, governments can give owners incentives. Making conservation more attractive than other uses.
- Markets are better at providing public goods. Wilson, "give the world a green market economics a green thumb".

Cost-benefit analysis

- Only benefits with market prices are included for cost-benefit analysis.
- When non-market values are included, the benefits to be compared with costs.

Non-economic values

- When non-economic value of nature and nature's services are often mean something different from market prices or social gains from having a small amount more of it.
- value: 1... 2 *amount of money for which a thing can be exchanged*... 3 *one's principles or standards, one's judgement of what is valuable or important in life.*

Different value systems

- Natural systems, particularly animals, have a right to exist quite independently of their contributions to human societies.
- Responsibility to pass on the Earth in next generation. It is good a state as the state in which we received it from our predecessors - stewardship.

Non-economic values

- Impact on the human psyche: the provision of aesthetic beauty and intellectual stimulation that lift the human spirit.
- Painting, poetry, literature draw on beauty of nature and attributes of natural world that inspire and daily renew humanity of our fellow citizens and provide them with inspiration.

Non-economic value: biological

- We often find we have an instinctive and emotional response to a world which has a diversity of species and intricate relationships.
- We are made from the same ingredients. Our genetic make-up is the same and we are still adapted to the world in which our hunter-gatherer ancestors thrived and died.

Different values

- Non-economic aspects of value do not conflict with economic aspects.
- Value an object for its own sake, for all property. It is not just for its economic value. It is a source of aesthetic pleasure.
- May feel a profound responsibility to conserve species without any clear economic justification.

Reaching agreement

- Economic aspects of value are for a common good and are not the end in themselves.
- I feel that the extinction of any species is a grave loss. It is not just for its utility: this is an intrinsic value. I may disagree: hard to argue for the value of my perspective is right. It is a matter of one's judgement of what is important in life.

Reaching agreement

- On economic principles or values of government or reaching agreement
- If I claim principles are more important to me than certain systems and you disagree then we are disagreeing over numbers and not over principles of morality

Policies for conservation

- *Regulation* - Make prices that conserve environment benefits society, if possible
- *Principles* - Make only simple matters a matter of principle
- *Incentives & Subsidies* - Prices reflect fully social costs are naturally led by invisible hand to make conservative choices.

Basis for conservation policy

- Reliance on self-interest by ensuring that prices reflect social costs
- Use of market mechanisms whenever possible.
- Valuation incentives

Conclusion

- Is valuation of ecosystem services becoming more important?
- Basic valuation methods are not sufficient to estimate the true value of ecosystem services.
- Only scientific analysis can help to determine the relative importance of different ecosystem services.
- Valuation can be used to inform policy and conservation.

Conclusion

- Providing incentives for conservation is a key to sustainable resource management.
- More important to focus on providing incentives via market mechanisms rather than government subsidies as a by-product.
- Using market forces is a more efficient way of providing incentives.

