Economics C125: Environmental Economics

Concern of the environment brought by:
1. Higher income (awareness + consumption)
2. High population density

Two major issues:
1. What is the right amount of pollution?
2. How can we get polluters to control emissions?

microeconomics: science of scarcity + coping with the consequences of scarcity
→ scarcity arises because the resources available are not enough to meet all existing desires

Air pollution: byproduct of energy consumption; impurities in fuels lead to emissions of sulfur dioxide + particulate matter (combustion)

Water pollution: result of organic material deposited in waterways
→ point source: clear, identifiable, + measurable
→ non-point: area sources
→ biological oxygen demand

Toxic chemicals: wastes + discharges like pesticides + lead

"Brown" issues: foregoing environmental problems (above); pollution from industrial sources
"Green" issues: not directly involving pollution in a conventional sense

Positive economics: value-free; explain behavior
→ **Mendelsohn approach**: land values depend on factors that determine agricultural productivity (climate, soil, altitude, etc.)
→ **Ricardian approach**: price of land capitalizes a beneficial climate, different climates result in different land values

Normative economics: economic tools for policy
→ **Nordhaus**: modest action
→ **Stern**: vigorous action

Instrumental value: serve as an instrument in achieving some useful objective; notion of use
Intrinsic value: life itself is valuable

Biocentrism: biological world center
Anthropocentrism: material gratification to humans (utilitarianism)
Precautionary Principles: abstain if there are potential damages
Sustainability: long-term health to also meet needs of next generation
1. substitution + replacement
2. obligation to future generations

Utility: N people indexed by $i = 1, \dots N$; composite material good, x; quality of environment, e.
The function is represented as $U_i(x_i, e)$
The assumptions are **completeness**, **transitivity**, + **nonsatiation**.

Voting as a Social Choice Mechanism:
1. **Pareto Criterion**: if all individuals prefer one alternative than another (or everyone is indifference except one individual), society should prefer that one (unanimity)
   → not all allocations can be compared; thus there is a bias towards the status quo.
2. **Unanimity with Side Payments or Transfers**: move resources for compensation
   → **Potential Pareto Improvement**: if there exists a vector of transfers $z = (z_1, z_2, \dots z_N)$ which sum to zero such that $(a', z) = (x_1' + z_1, \dots x_N' + z_N)$ is Pareto prefered to a'', then a' is a potential improvement over a''
   → **Kaldor-Hicks Compensation Principle**: if transfers could be made to achieve unanimity, then the choice is socially desirable even if transfers are not made (cost-benefit analysis)
3. **Majority Rule**: does not take into account of the intensity of the preference
4. **Supermajority**: over 50% majority so things are not so easily changed
5. **Voting with more than Two Alternatives**: majority rule, plurality, Borda count, exhaustive voting
   → **Condorcet winner**: an alternative that beats out all others in pairwise majority voting
   → cycling problem

Social Welfare Functions: Let W be a single number associated w/ distribution of utilities. If in comparing 2 consumption bundles, $W(U_1(a'), U_2(a'), \dots U_N(a')) > W(U_1(a''), \dots U_N(a''))$ is equivalent to a' being socially preferred to a'', then W is a social welfare function; assume only utility matters
1. **Benthamite or Utilitarian**: $W(U_1, U_2, \dots U_N) = \sum_i \theta_i U_i$, $\theta_i \geq 0$
   → weights can be equal or not; maximizing total utility
2. **Egalitarian**: $W(U_1, \dots U_N) = \sum_i U_i - \lambda \sum_i [U_i - \min_i(U_i)]$
   → consider max total utility + compare each utility w/ your minimal amount
3. **Rawlsian**: $W(U_1, \dots U_N) = \min_i(U_i)$
   → just care about the poor; wants lowest utility to be maximized

Arrow's Basic Requirements for Social Choice Mechanism

1. Completeness: compare all social alternatives
2. Unanimity
3. Nondictatorship: no one's preference should be exactly the same as society's
4. Universality: any possible individual rankings
5. Transitivity: if $a>b$ + $b>c$, then $a>c$
6. Independence of Irrelevant Alternatives: depend only on how individuals rank the choices without regard to other alternatives

Arrow's Impossibility Theorem: There is no rule satisfying all requirements for converting individual preferences into a social preference ordering

Criticism of Utilitarian Perspective:

1. Assumes we have utility functions that represent our preferences + that they are immutable
   → but they can change over time e.g. with more education
2. Not all individuals are considered in the social welfare function (ex: future generations)
3. Society choices should depend on what is right rather than on preferences

Two concepts of Efficiency

1. Efficiency in obtaining the right overall amount of pollution control
2. Efficiency in allocating pollution control responsibility to specific polluters

Pareto Efficiency: weak definition of the "best" outcome; no one could be made better off without making someone worse off; also known as allocative efficiency

→ **Pareto optimum:** A is to be preferred to B if in A, at least one is better off + no one is made worse off; anything that lies on the Pareto frontier
   ↳ advantage: no need to compare utilities across people
   ↳ many situations where criterion cannot rank by social desirability

→ **Pareto frontier:** all allocations for which there are no allocations that are Pareto preferred
   ↳ Pareto improvement is a Pareto preferred allocation

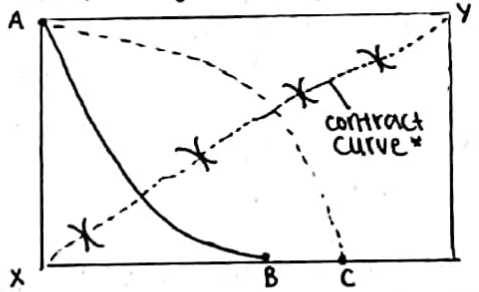
First Welfare Theorem (Competitive markets → Pareto optimum)
In a competitive market/economy, market equilibrium is Pareto optimal

Second Welfare Theorem (Pareto optimum → competitive markets)
In a competitive economy, any Pareto optimum can be achieved by market forces, provided the resources of the economy are appropriately distributed before the market is allowed to operate

→ Conditions/Assumptions of Competitive m
1. Complete property rights, no externalities
   → complete, exclusive, transferable, well-defined, + secure
   → failure: open access
2. Full information
3. No transaction costs
4. All atomistic agents max U or π

Efficiency in Exchange

1. Marginal rates of substitution are equal among consumers
   → Graphically on an Edgeworth box



*indifference curves are tangent

- Prices must satisfy 2 requirements
  1. Budget line must pass through the initial endowment
  2. There must be an allocation at which the indifference curve of both parties are tangent to the budget line
     → slope of the budget line is negative the price ratios

→ mathematically
Utility of i: $z_i = f^i(x^i)$ where $x^i = (x^i_1, x^i_2 \dots x^i_n)$
Pareto criterion: $z^0_i \le f^i(x^i)$
Supply constraint: $\sum_{i=1}^{m} x^i_j = b^0_j$
Lagrangian:

$$L(x,\lambda,\mu) = f^1(x^1) + \sum_{i=2}^{m} \lambda_i [f^i(x^i) - z_i^0] \leftarrow \text{utility constraint}$$
$$+ \sum_{j=1}^{n} \mu_j [b^0_j - \sum_{i=1}^{m} x^i_j] \leftarrow \text{supply constraint}$$

FOC: $\frac{\partial L}{\partial x^1_j} = f^1_{x^1_j} - \mu_j = 0$ for $j = 1, \dots n$

$$\frac{\partial L}{\partial x^i_j} = -\lambda_i f^i_{x^i_j} - \mu_j = 0 \text{ for } j = 1, \dots n + i = 2, \dots n$$

Thus $\frac{f^1_{x^1_j}}{f^1_{x^1_k}} = \frac{f^i_{x^i_j}}{f^i_{x^i_k}}$ or $MRS_a = MRS_b$

Efficiency in Production

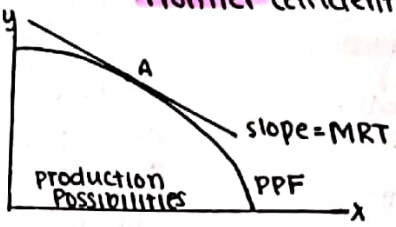
1. Marginal rates of transformation are equal among producers
   → MRT: rate at which output of one good has to be sacrificed to produce more of another good
   → mathematically

$\pi = P_x X + P_y y - C$

$y = \frac{\pi + C}{P_y} - \frac{P_x}{P_y} X$

MRS = MRT

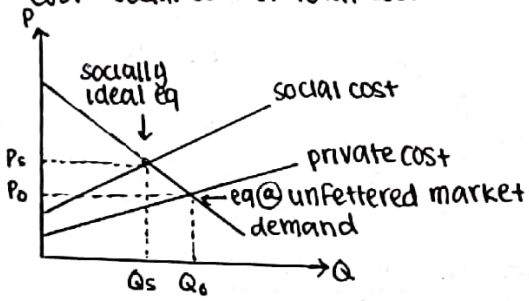
→ Graphically: Pareto or Productions Possibilities Frontier (efficient combo of 2 goods)



2. Equimarginal Principle: in controlling emissions from several polluters, all emitting same pollutant (source + marginal damage), efficiency requires marginal cost of emissions be the same

Market failure is the divergence between equilibrium + social optimum, providing rationale for gov't interv.
Potential reasons for gov't intervention:
1. Facilitate information creation + access
2. Provide public goods / services

Externalities occur when a person's or firm's action affect another entity without its permission
→ consumption externality: externality enters the utility function through no choice of consumer
→ pecuniary externality: when prices change
→ monetary evaluation (external cost) + private cost = social cost or total cost



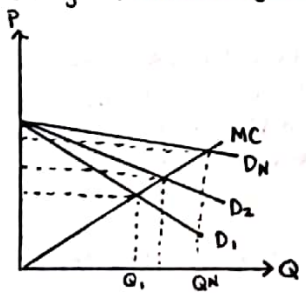
	rival	nonrival
excludable	Private goods (hamburger, garbage)	Club goods (water pollution, public beath)
nonexclud.	open access resources (fishery)	Public goods (national def, greenhouse gas)

Nonrivalry: goods can be consumed concurrently by more than one individual; consumption by one does not take away from anyone else's
Nonexcludability: goods can be accessed freely; not technically feasible (or too costly) to forbid access to some individuals
* these characteristics are not perfectly applied

Public goods are g+s that can be consumed by several individuals simultaneously
Pure public goods are characterized by non-excludability + non-rivalry
→ Excludability (feasible + practical to selectively allow consumers to consume the good) has to do with whether it is possible to use price rationing individual use of the good
  ↳ Laws: garbage disposal or air pollution
  ↳ Technology: Great Plains fenced with barbed wire
  ↳ Space: non-excludable locally but excludable globally
  ↳ thus contingent on laws, tech, + perspective but not a core problem w/public goods
→ Rivalry (consumption diminishes availability for other use; social opportunity cost associated with consumption) has to do w/desirability to ration individuals through price or other
  ↳ does not Δ w/tech but there may be congestion
  ↳ for non rivalrous goods, cannot use standard price mechanism (P=MC) but try to max social welfare w/Pareto efficiency
    → additional person without congestion means MC=0; but no profits

Provisions of Public Goods

→ For rival goods, individual demand is aggregated horizontally; as the # of people goes to ∞ you will get an infinitely elastic demand



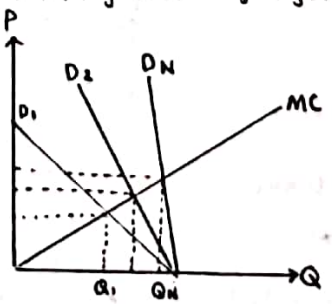
$D_1 = a - bQ$
$MC = c + dQ$
$Q_1 = \frac{a-c}{b+d}$

$D_N = a - \frac{bQ}{N}$
$MC = c + dQ$
$Q_N = \frac{a-c}{\frac{b}{N}+d}$

* each individ. will not pay > a so P=a

* Pure public goods
$\Sigma_i MRS_i(G^*) = MRT(G^*)$

→ For nonrival goods, everyone can consume the good so you can vertically aggregate, as the # of individ. goes to ∞ you get infinitely inelastic d.



$D_N = Na - NbQ$
$MC = c + dQ$
$Q_N = \frac{Na-c}{Nb+d}$

* This does not reflect price because it is the summation of different WTP

Provision Mechanisms

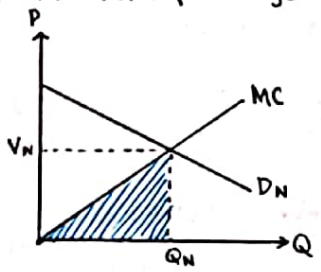
1. Public provision by taxes
2. Donations, fundraising
3. Volunteer Activity
4. Signaling (tax deductions or organizations)
5. Finance public goods by paying for private good ads + naming
6. Special institutions

Market mechanism can supply the optimum because of excludability
→ assume there is some way to pay for the production
→ must consider:
  ↳ homogenous preferences
  ↳ heterogeneous preferences
  ↳ different market structures
  ↳ different pricing structures

*private good is a numeraire

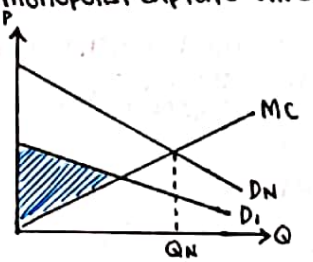
Pareto Optimal position would be $\Sigma MRS_i(G^*) = MRT(G^*)$ or $\Sigma MB_i = MC$
→ sum of all demands equal marginal cost
→ sum of MRS equals the MRT (**Samuelson condition** for efficient provision of a good)

How much of a public good will be provided? Cost?



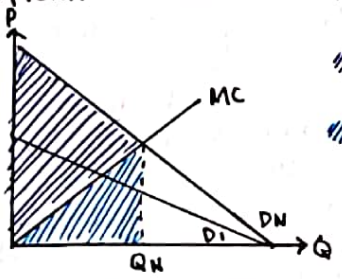
V_N = cost to provide the public good to a community with N members

Monopoly Provision (non-rivalry w/excludability)
→ entry fee = individual surplus or max WTP
→ monopolist capture all surplus



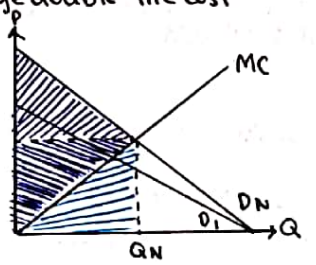
entry fee for each individual

Government Provision (nonrivalry w/exclud)
→ charge individuals total cost divided by N
→ no profit; maximize consumer surplus



consumer surplus
total cost

Provision by a Concessionaire (nonrivalry w/exclud)
→ private company w/ gov't contract
→ charge double the cost



consumer surplus
producer surplus
total cost

	Entry Fee	consumer Surplus
monopoly	monopoly charges an entry fee equal to the area under the individ demand curve up to Q	monopoly captures all the CS
Government	Gov't charges an entry fee equal to the area under the MC curve divided by n	CS is the area under the aggreg. demand + above the MC
Concessionaire	Entry fee is in between that of a monopolist + the gov't (competitive revenue divided by n)	CS between that of monopoly + gov't outcomes

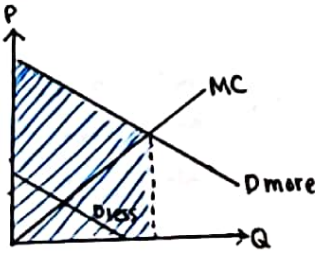
Demand is the relationship between quantity + marginal WTP
→ **willingness to pay**: the area bounded by the demand + vertical axis
→ **consumer surplus** is the WTP for Q* less any payment the consumer makes for the commodity

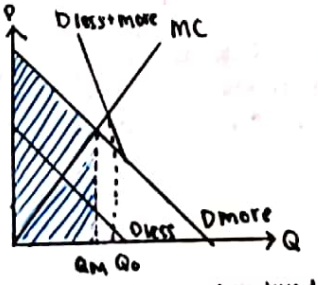
Producer surplus is the difference between revenue + cost; area of the supply curve + the horizontal price line

Total surplus is WTP less production cost
→ Qualifications:
  1. TS may not exist
  2. Depends on price of other goods + income

* MB one less = MC of one more; MB less = MWTP more

Preference heterogeneity for excludable public goods
→ If two groups have different demands for public goods, then the group w/lower demand is excluded if MC is high, thus underproviding the good + leading to suboptimal outcomes
  ↳ Gov't can mandate charge to be cost divided by n, allowing lower group to pay
  ↳ monopolist can charge each WTP but informational issues





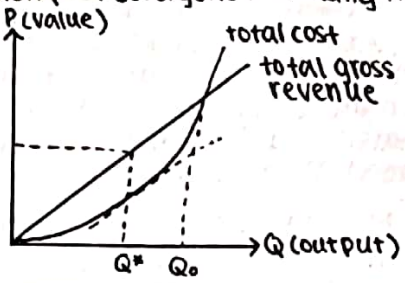
Utility = u(w-g, g+$\bar{G}$)
→ w is income
→ g is individual provided public good
→ $\bar{G}$ is public good provided by others
→ w-g is money for private goods
→ g+$\bar{G}$ is the public good provided

Lindhal tax/equilibrium: personalized prices that equal individ valuation of public good; pay WTP where aggregate D + intersect; demand curves provided voluntarily by individuals
→ **free riding**: strong incentive to understate your preferences to pay little
→ possible to create consensus with club goods

Club goods are goods you receive if you belong to a club; allow fundraising + addresses equity considerations; informational issues
→ differentiated provision: people pay diff fees for different products
→ established to accommodate people with diff preferences (excludable)
→ high degree of preference = high membership fee

A local public good is one that benefits/affects only consumers in the local community rather than the total population of consumers
→ dimension of location: individ consume all public + private goods at the same location
→ space dimension gives some excludability
→ bundling of the consumption of housing (residents) + consump of local public goods
→ ex: police, hospital, parks, schools, courts
↳ associated w/tax

Open access means anyone may access them; common property (everyone owns the property + has access) + common pool (everyone is drawing from a common pool)



→ Tragedy of the commons: when there are no owners of resources or if owners are public entities which exert no control over use, there is a risk that resources will be overused
→ w/no social value, cost of nat resources = worth
↳ MC of effort (slope of cost curve) > MR of effort (slope of revenue curve)

Samuelson asserts there is no market type solution exists in economies w/public goods (pure)
→ no mechanism that forces people to accurately report preferences

Tiebout: if public goods are local, then a market type solution may exist — at least approx
→ "voting with the feet": people choose their preferred community by moving locations, thus also reveal their demand for a public good
→ municipalities: clubs that provide a combination of service + taxes
↳ goods are excludable + preferences are heterogenous — people will sort themselves

Freedom-to-choose Assumptions:
1. Consumers are perfectly mobile
→ some people do not have the opp to go to a comm. w/similar preferences
2. Full information
3. Large number of communities: many options
4. All income from dividends (exogenous)
5. No spillovers among communities: public good in one place does not affect the level of public good in another
6. Average cost of providing a good (public) is U-shaped: there exists an optimal or cost-minimizing population size
→ cost (y) population size (x)
7. communities w/pop sizes below/above the cost-minimizing size seeks to expand/contract

Tiebout model:
* efficient provision of public goods in this model under these assumptions — comm. will be optimal in size, preference, + gov't budget balance
→ N individ, L is labor, Y is output
↳ Y can be transformed into a private good (x) or a pure public good (g)
→ Y tech: $f(0)=0; f'(L)>0; f''(L)<0$
→ Preferences: $u(g, x_i)$
→ Aggregate resource constraint: $Nx_i+g=f(N)$
→ Equal-Treatment Allocation: $x_i=\frac{g}{N}=\frac{f(N)}{N}$
↳ define x, g, +N; Y will be determined
↳ per capital productive good (Y) + non-congestible good (public local) is decreasing in ↑N

* negative correlation found between home price + tax rate

Planner Problem: $\max_{x_i,g,N} u(g,x_i)$ st $Nx_i+g \le f(N)$

Lagrange: $L=u(g,x_i)-\lambda(Nx_i+g-f(N))$

FOC: $\frac{\partial u(g,x_i)}{\partial x_i}-\lambda N=0$

$\frac{\partial u(g,x_i)}{\partial g}-\lambda=0$

$\rightarrow N\frac{\partial u(g,x_i)}{\partial g}=\frac{\partial u(g,x_i)}{\partial x_i}$ samuelson condition

$\lambda(f'(N)-x_i)=0 \rightarrow f'(N)=x_i$; MPL = allocation of private goods (w)
→ combining w/constraint, $g=f(N)-Nf'(N)$

Henry George Theorem: if workers/consumers are paid the MPL, then at optimal N (pop), the return of fixed factors (i.e. land) exactly covers the cost of the public good.

Criticisms of Tiebout
→ Bewley (1981): counter ex, i.e. finding perfect substitutes for a full community
↳ migration creates spillovers based on economies of scale
↳ identifies set of sufficient conditions for Tiebout equilibrium to exist + be efficient

Sufficient Conditions for Tiebout Equilibrium
1. Public services (Fully rival/congestible) rather than public goods (non-rival)
2. Number of regions = number of consumer types
3. Gov't are profit-maximizing + participatory (migration responses to choice of public goods + tax rate); zero profit at equilibrium
4. Free trade among regions

* These conditions are restrictive!

Environmental Justice: in equilibrium, rich people can locate in better places than the poor

Both Tiebout + club model consider the market type solution to problem of providing public goods
→ **local public good**: variable rental price for land + housing, plus possible head or income taxes
→ **club goods**: fixed admission price to each consumer of a club
Striking parallel when club goods are characterized by congestion (optimal size of club + community)
Congestion is when the utility of each individual declines w/ the number of users (rivalrous)
→ club w/optimal size depends on amt of public goods/amenity size + number of users
↳ ex: toll road, TV, access to copyrighted works, service by social or religious clubs

	No congestion	Congestion
homogeneous agents	monopoly gov't or concessionaire can lead to optimal Q	need to determine optimal Q as well as optimal N
heterogeneous agents	monopoly can lead to suboptimal outcomes	clubs of different sizes can be optimal

Environmental Amenities: Club or Public Good?
→ depends on the good (clean beach can be a club good + a park or clean river can be a public)
→ there are often spillovers
↳ characteristics of environmental groups/goods do not necessarily fit in municipality
↳ create need for federal intervention
→ use of environ. resources in one area may affect another area

Environmental Federalism: regulations at federal or the state level
→ fed gov't aims to establish minimum standards that apply to all populations + take future into acc.
→ groups w/strong preferences than average can est. clubs to pursue their objective

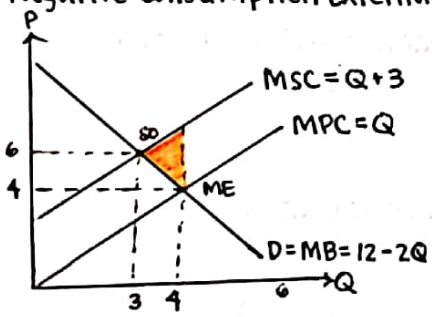
Optimal level of excludable public good characterized by congestion:
1. Total benefits depend on amenity size (X) + number of users (N)
$\frac{\partial B(N,X)}{\partial N} < 0$ + $\frac{\partial B(N,X)}{\partial X} > 0$
2. cost of provision incr. w/x + if costs are shared:
$\max_{X,N} B(N,X) - \frac{C(X)}{N}$ or equivalently
$\max_{X,N} B(N,X) \cdot N - C(X)$
3. First order condition w/respect to N
$\frac{\partial N \cdot B(N,X)}{\partial N} - \frac{\partial C(X)}{\partial N} = 0$
$B(N,X) + N\frac{\partial B(N,X)}{\partial N} - 0 = 0$
$B(N,X) = -N \cdot MB_N$ (samuelson)
Total benefit of an additional member is equal to the congestion cost inflicted by that extra member.

An **externality** occurs when there is an impact on a third person who is not part of the exchange (cannot exclude the first two from imposing external impact nor stop them from entering into the exchange)
→ **pecuniary externality** occurs when prices change due to actions of others; no inefficiency

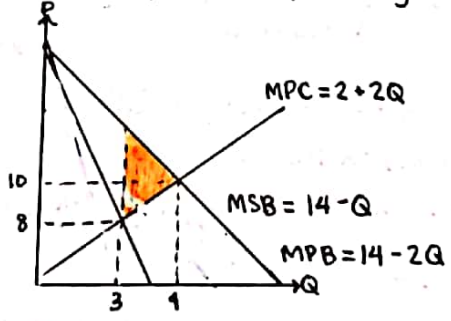
Impact/Effect	Positive	Negative
Production	bees + orchards	Pollution of a close to a laundry
Consumption	cleaning up beaches	playing stereo loudly; congested highways

→ cost is above MB (cost of a unit to society is greater than the benefit) or MB can be gained from ↑Q
→ type of market failure
↳ competitive markets are inefficient

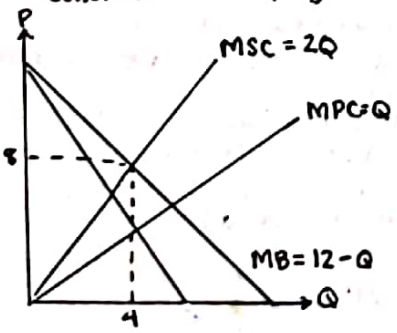
Negative Consumption Externality



Positive Production Externality



Theory of "Second Best": what is advisable in an economy without distortions is no necessarily a good idea when there are distortions; second best option when market failure exists
→ **corollary**: when there are 2 market failures, correcting only one may worsen market efficiency
→ consider a monopoly w/neg. externalities:



"Internalizing" the Externality
* breakdown of the "polluter pays" principle
1. **Coase**: private negotiations
2. **Liability law**: regulation on how far + on what conditions polluter compensates the damaged party
3. **Pigovian tax**: charge causer w/MEC through a tax
→ emissions fee = MD

Coase Theorem: initial distributions of rights does not matter in a case which there are no impediments to buying + selling pollution rights

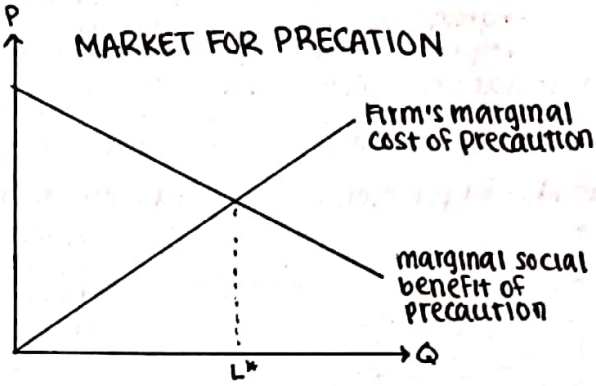
→ Assumptions
1. **Agents are rational**: producers max profit + consumers max utility
2. **Markets**: → **no transaction costs + perfect information**
3. **Good**: **clear + enforcable property rights**

*wealth effects: being endowed with the right makes you different, generating diff. in final bargaining

Implications: (1) Negotiation can reach the efficient level without gov't intervention + (2) efficient level obtained is independent of the initial allocation of rights

Problems: (1) **Free-riders** + (2) bargaining with groups (**coalition** or **Grand bargain**)

Liability: compensate the damage; take account potential damages risky activity can create
→ pro: less info, incentivize, equimarginal principle
→ con: political (money, time), accomodate complexities, commoditizing the environment
→ legal resp: polluter may pay for damages even if it has the right
→ **negligence rules**: sometimes responsibility of polluter is uncertain thus we est. whether the polluter had negligent practices or not
→ **inalienable rights**: some things cannot be exchanged



To have optimal outcomes, we must **internalize the externality** but reducing pollution also entails costs
→ **Cross-Benefit analysis**: compare damages w/one more unit of pollution against abatement costs
→ **Problems**: damages are difficult to measure (a lot of uncertainty); intertemporal complications (damages or benefits from emission levels received by future generation)

Environmental Policies:

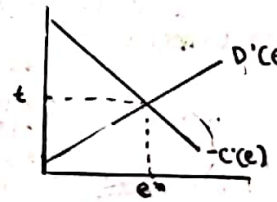
1. **Pollution Standards**: impose a cap on pollution per product; Prescriptive regulations
→ technology + performance standards
→ pro: more flexibility + certainty
→ con: info costs, incentive to distort info, hard to satisfy equimarginal p, only polluters pay

2. **Price + market instruments**: provide a price for emitting one unit of pollution which reflects social costs
→ **Pigovian tax**
→ **pollution permit tax**
→ **subsidy**

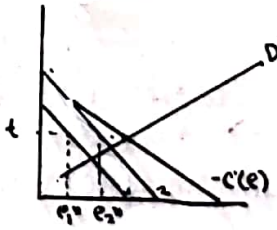
*have economic incentives (less info, damages paid, + equim. principle)

*Crucial difference: **Salience** (how they are visible to firms that are regulated)

Pigovian tax: a fee = aggregate MD from emissions when evaluated at the optimal level
→ Damage function: $D(e)$ where $e=\sum_{i=1}^{n} e_i$, $D'>0$ + $D''\geq 0$
↳ cost of reducing pollution for firm i is $C_i(e_i)$ w/ n firms + e amt of emissions
→ Regulator's objective: $\min \sum_{i=1}^{n} C_i(e_i) + D(e)$, constr. $e=\sum_{i=1}^{n} e_i$
→ FOC: $D'(e) = -C_1'(e_1) = \dots = -C_n'(e_n)$
↳ damage coming from the sum of emissions
↳ MD = MAC + MAC must be equal across all firms
→ Firm's objective given tax: $\min C_i(e_i) + te_i$
↳ FOC: $-C_i'(e_i) = t$
↳ social optimum if regulator imposes $t=D'(e^*)$

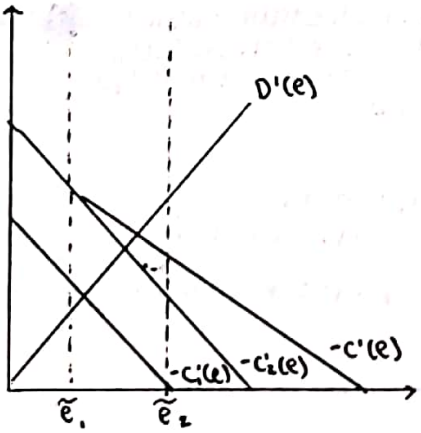


SINGLE POLLUTER



MULTIPLE POLLUTERS

Is a Pigovian tax efficient?
1. **Equimarginal Principle**: marginal cost of abatement is equal (to MD) across all firms; sum of MAC = aggregate MD
2. **Leads to minimum cost of abatement**



Prescriptive regulations (command + control): involve environmental regulator stipulating the action that the polluting agent should take
→ **performance standard**: stipulation of the max emissions allowed per unit of economic activity
↳ leaves some discretion / flexibility
↳ Firm's objective: $\min C_i(e_i)$ where $e_i \leq \bar{e}$
→ Lagranglian: $L=C_i(e_i) - \lambda(\bar{e}-e_i)$
→ FOC: $-C_i'(e_i)=\lambda_i$
↳ **not efficient** because equimarginal principle does not hold
→ MAC is not equal across all firms
→ can set up diff. standards for diff. firms
↳ firms would protest

Tradable permits market: allow polluters to buy + sell the rights

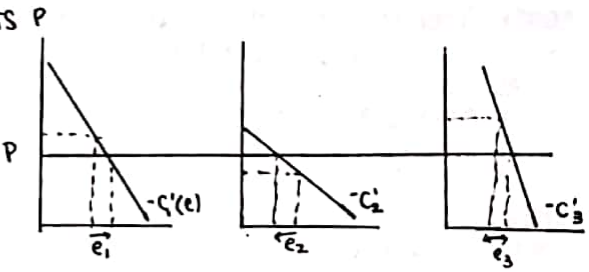
→ **cap + trade**: regulator sets a cap on overall emissions + allow trading among polluters to determine who emits that

→ **grandfathering allocation** of permits: each firm receives $\bar{e}_i$ permits (half of its initial emissions $\hat{e}_i$)

↳ permit price determined on equilibrium market

↳ Firm's objective: $\min C_i(e_i) + p(e_i - \bar{e}_i)$

↳ FOC: $p = -C_i'(e_i)$



→ to obtain Pareto Optimum, regulator must impose optimal pollution $p^* = -C_1'(e_1^*) = \dots = -C_n'(e_n^*) = D'(e^*)$

→ no impact on efficiency, but strong impact on distributional efforts

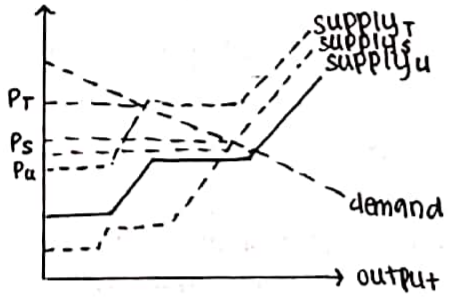
↳ grandfathering means the firm that pollutes the most gets the most initial permits

↳ **equal treatment**: all firms receive the same amount of permits

→ similarities w/ Pigovian: if there is perf info on costs + damages, efficiency occurs through Equimarginal principle which is better than the standards

→ requirement: emissions ceiling must be well-chosen

Subsidies for pollution reduction: pay firms to emit less (politically popular); outcome depends on SR or LR



→ **short run**: no entry

→ Firm's objective: $\min_e C_i(e_i) - s^*(\hat{e} - e_i)$ where $\hat{e}$ = initial pollution

→ FOC: $-C_i'(e_i) = s^* = t^* = D'(e)$ = Pareto Optimum

→ LR w/ heterogeneous firms

↳ subsidy + tax raises MC

→ subsidy lowers AVC + taxes incr. it but subsidy applies only if the firm is operating

↳ subsidies incentive more production which may allow older firms to continue to operate

→ more firms in industry bc they will operate at min ATC

Discrepancy between internalize externalities + actual policy

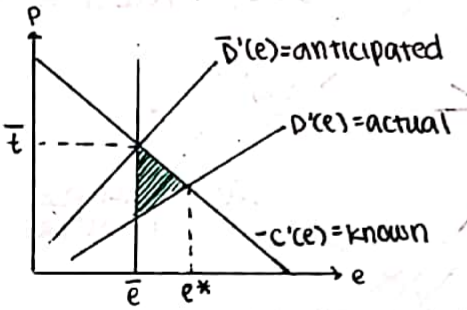
1. Influence of lobbyists on politicians
2. **unbalanced influence between firms + politicians**
   - → free rider: difficult to collectivize + take action
   - → small firms: high stakes + monetary power
3. **Environmental NGOs**: less powerful in influencing gov't directly but raises public awareness through mobilization campaigns

Regulation with Uncertainty

→ regulator needs to know MD + MAC of each firm to achieve Pareto Optimum

↳ firms have an incentive to hide or lie about their abatement costs $\min_e TC(e) = C(e) + re$

What if damages are unknown?

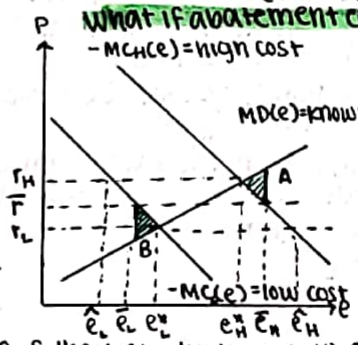


→ Pigovian tax $\bar{t}$ or quantity reg. $\bar{e}$

→ DWL = colored

→ unknown marg. damages make both environ. policies sub-opt. while keeping them equivalent

What if abatement costs are unknown?

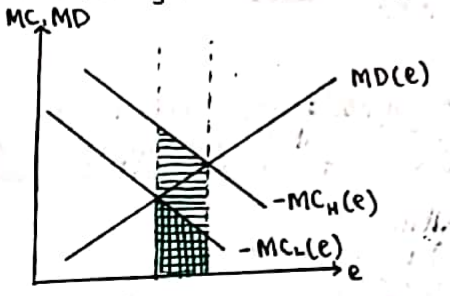


→ 50% one chance

→ regulator chooses average $\bar{r}$

→ low cost produce too little + high cost produces too much

Truth-revealing mechanism: suppose regulator asks firms if they are high or low cost



→ pay for telling the truth

↳ must be less than the inefficiency from dishonest firms

↳ high cost will always tell the truth for permits because it wants more

→ ≝ high cost's benefit from telling the truth $C_H(e_H) < C_H(e_L) - R_L$

→ !!!! low cost's benefit from lying $C_L(e_L) - R_L < C_L(e_H)$

↳ min. regulator should give to prevent it from lying

→ $C_L(e_L) - C_L(e_H) < R_L < C_H(e_L) - C_H(e_H)$

Proposition (Weitzman): with uncertainty over marginal cost of emissions/abatement:

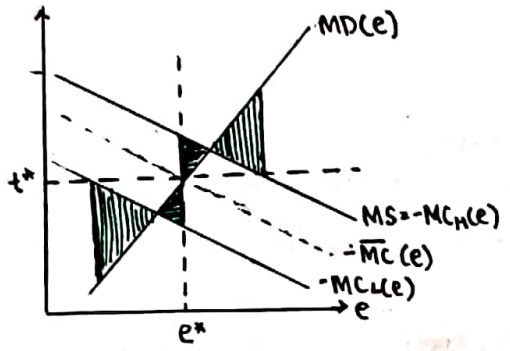
1. Quantity regulations are preferred if marginal damages are more steeply sloped than marginal abatement costs
2. Emission fees are preferred if marginal abatement costs are more steeply sloped than marginal damages

Many regulations are based on threshold damage

→ high curved or quadratic MD: quantity regulation

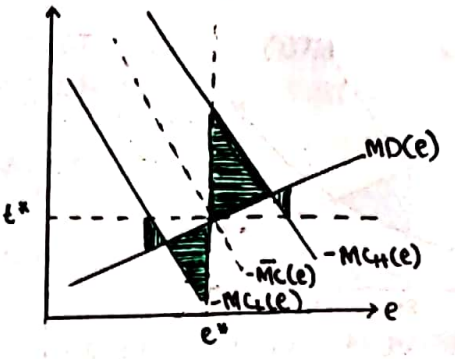
→ constant MD (every unit has more or less D) or sure MC but unsure e: emissions fee

Weitzman Proposition

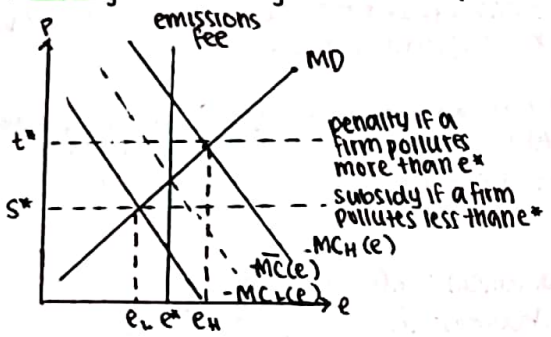


▤ quantity inefficiency

▥ price inefficiency



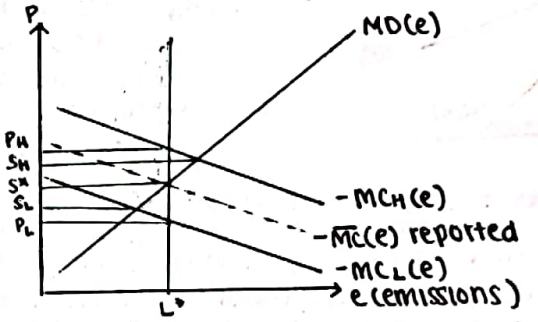
Hybrid Price/Quantity Regulation: flexibility into regulation; **quantity regulation** coupled with a **a subsidy** for emitting less than required $s(e^*-e)>0$, + a penalty for emitting more $p(e-e^*)>0$.



→ incentive to underreport MAC from taxes
↳ want a lower tax rate
→ incentive to overreport MAC from permit systems
↳ gain more emissions permit

Step 1: Firms reveal their MAC to regulator
Step 2: Regulator auctions off a certain amount of permits L* + announces a subsidy rate s* for firms emitting less than allowed by permits they hold.

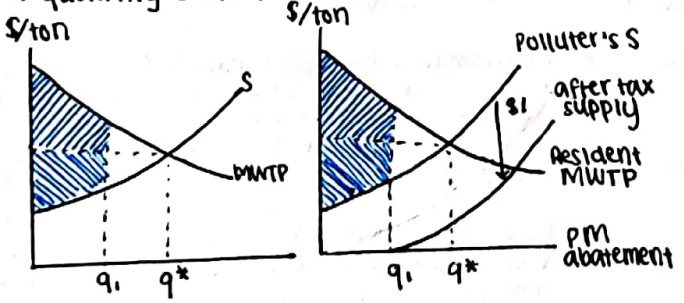
suppose a market for emissions permits with a known market place with many identical firms



* If understated, prices for permits will incr. but no one will choose a subsidy because the amount is lower (subsidy rate would be higher telling the truth)
* If overstated, the firm will emit less + take the subsidy because demand will drive prices of the permit up (subsidy rate would have been lower w/honest reporting, resulting in lower permit prices)

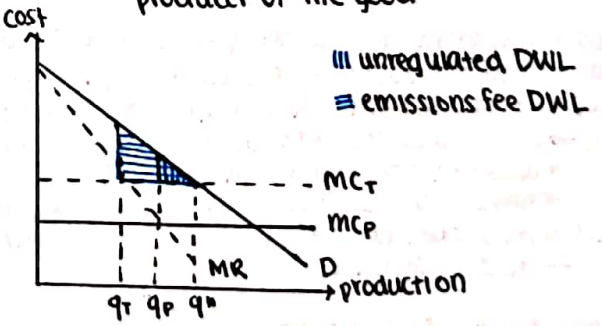
Benefit-Cost analysis: is the measurement of social surplus with consumer + producer surplus, consistent with the potential Pareto improvement criterion, looking at net gains aggregated over all individ.
→ Find the project w/the largest surplus by finding the economic value (monetize) of each
→ problems: assumptions are made (distribution of income + compensation principle applies, measuring damages to the environment, implementation (political/social appeal, theory of second best, philosophical objections (reduction to a single metric)

→ **One market**
↳ **particulate matter** (PM): microscopic solid or liquid matter suspended in the atmosphere
↳ quantity control vs. tax



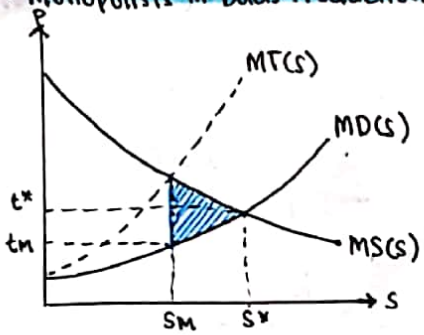
→ **secondary market**: can ignore as long as prices do not change in those markets
→ **discount factor**: convert costs in time period t into costs for today
↳ **social discount rate**: not easily observable but generally agreed as < market price (public choice)
↳ **exponential** v. **hyperbolic** (gradual) **discounting**
→ **dynamic inconsistency**: realize choice was bad
↳ **intergenerational decisions**

→ **Existing market imperfections**
↳ **theory of "second best"**
↳ **monopolists in goods production**
→ many producers of pollution but one producer of the good



↳ **monopolists in goods production**
→ sole producer of the pollution
→ common for local pollution
→ t= MD at levels of smoke
→ firms anticipate tax by reducing emissions so tax burden lowers
→ under produce
→ under pollute

↳ **Monopolists in Bads Production**

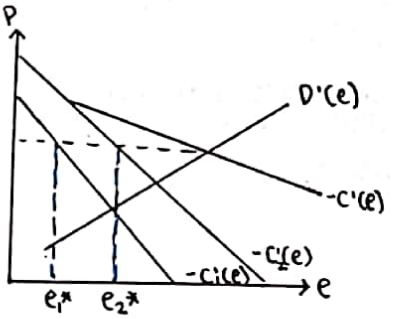


$T(s) = s \cdot MD(s)$

$MT(s) = s\frac{dMD(s)}{ds} + MD(s)$

monopolist produce where MT = MS
→ firm adjusts its own behavior by reducing emissions to pay less of a tax in the future
→ regulated firms can distort economic decisions

↳ **Attribute-based Regulations** equalize compliance costs by having specific standards for different types of goods, designated by their attributes
→ aims to change one characteristic of a product related to the externality: "**targeted characteristic**"
↳ takes some other characteristic ("**secondary attribute**") into consideration when determin. compli.
→ can create perverse incentives to distort attribute upon which compliance depends
→ difficult to measure regulation-induced costs



→ **If the attributes predict MC of compliance + is perfectly unresponsive to policy incentives**, the ABR is a good proxy for diff. standards
↳ ABR is not efficient otherwise + can create distortions that are similar to DWL from distortionary taxes
→ simple model of ABR
↳ Consumer's utility: $U_n(a_n, e_n) = F_n(a_n, e_n) + X_n$
↳ Budget constraint: $I_n \geq P(a_n, e_n) + X_n$
↳ regulatory const: $e_n \geq \sigma(a_n) + \gamma$
↳ perfect comp: $P(a,e) = C(a,e)$

$F_n(a_n, e_n)$ = durable good a given e; X_n = utility from numeraire

* e = emission efficiency
* a = good

→ Planner's objective: maximize social welfare
↳ external damages are linear in emissions, thus there is a positive externality from mandating a minimum efficiency (marginal effect of e is constant: φ)
↳ objective: $\max W = \sum_{n=1}^{N} F_n(a_n, e_n) - C(a_n, e_n) + I_n + \varphi \sum_{n=1}^{N} e_n$
↳ FOC: For all $n = 1, \dots N$, $\frac{\partial F_n}{\partial a_n} = \frac{\partial C}{\partial a_n} \rightarrow -\varphi = \frac{\partial F_1}{\partial e_1} - \frac{\partial C}{\partial e_1} = \dots = \frac{\partial F_N}{\partial e_N} - \frac{\partial C}{\partial e_N}$ (equimarginal principle)

→ Consumer's optimization
↳ objective: $\max L_n = F_n(a_n, e_n) - C(a_n, e_n) + I_n + \mu_n[e_n - \sigma(a_n) - \gamma]$
→ where μ_n = shadow price of the regulation for type n
↳ FOC: $\frac{\partial F_n}{\partial a_n} - \frac{\partial C}{\partial a_n} = \mu_n \sigma'(a_n) + \frac{\partial F_n}{\partial e_n} - \frac{\partial C}{\partial e_n} = -\mu_n$
↳ ABR creates a pair of **wedges** between marginal utility + MC for a + e—acts as a pair of taxes
→ only if $\sigma'(a_n) = 0$ (no attribute basing), then allocation of a is optimal
→ μ_n can differ across individuals
→ Ex: weight-based regulation of cars → heavier cars → less fuel efficient + more dangerous

→ Limits of Benefit-Cost Analysis:
1. **Strong assumption of distribution of income**: if income Δ, D+S change + so will measure of surplus
2. **Kaldor-Hicks compensation principle applies**: for a project to be Pareto improving, winners should compens. losers
3. **measuring costs + benefits is hard** (philosophical + mathematical)
4. **Distortions in the economy** (tax, regulations) mean distorted measure of surplus

Incidence is identifying which parties actually bear the costs or enjoy the benefits of regulation or public project
1. **Backwards Incidence**: firm absorbs cost of a regulation
→ when regulation pertains to a narrow slice of mar
→ unilateral policy under globalization
→ need to be competitive in foreign competition
2. **Forward Incidence**: firm passes cost to consumers
→ inelastic demand curve

Cost-effectiveness Analysis: take environ. goals are given + focus ways to achieve goals from cost POV
→ avoid monetizing environ. benefits
→ **Cost-effectiveness ratio**: cost per unit of obj.
↳ define ambient targets (US Clean Air Act) + evaluate costs → choose lowest cost altern.
→ **Multicriteria analysis**: several metrics used but difficult b/in determining how various outcomes are traded off by society

Clean Air Act Amendment
→ CAA (1963) signed by Johnson to regulate air quality to limit 6 criteria pollutants: SO_2 (contributes to acid rain), Particulates (TSP, PM2.5, PM10), NO_2, CO, Ozone (from NOx + VOC), lead
→ National Ambient Air Quality Standards (NAAQS) Amendment est. for each pollutant (1970)
↳ each county must satisfy 2 requirements a year:
1. Annual average concentration below a given threshold
2. Second highest daily concentration below a given threshold

*TSP annual average 75 ug/m³ or second highest daily conc. of 260

→ Regulation under the CAA
  ↳ "Non-attainment" are counties that fail to meet requirements
    → must submit a State Implementation Plan for how they will bring nonattainment into compliance
      ↳ may require expansion of old plants or construction of new plants include state-of-the-art pollution abatement equipment
      ↳ plant-specific standard: cap emissions from old plants
  ↳ Polluting plants in attainment counties were subject to much laxer regulation
→ Amendments in 1990s
  1. PM10 will be regulated independently from other TSP, essentially creating a new category of regulation
  2. Encouraged market-based regulatory instrument (Cap + Trade CAT)
    → standards may not work for nonattainment counties so solution of specific types of pollutants
    → National CAT for SO_2 (Acid Rain Program)
    → several regional CAT for NOx + VOC (to address ozone)
      ↳ NOx Budget Programs in the Northeast + RECLAIM in LA
  3. Not strict enough to make people reduce pollution (also factors like pop growth + econ activity)

Model of Technology Adoption
→ CAA 1970 est. pollution standard (max emissions) for plants in non-attainment counties
  ↳ if exceed the cap, there are financial consequences (**shadow prices** that work as a tax)
    → can either cut production or buy new technology
    → regulation encourages clean technology, lowering pollution but not output
→ Polluting firm can choose from (assume capacity constraint)

↳ **Old Technology** (high VC, no FC, high pollution)

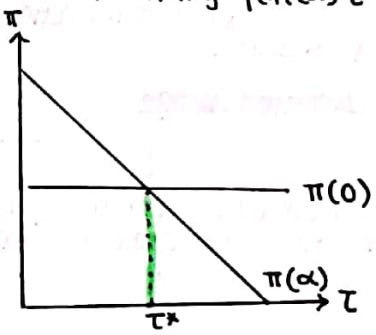
output: $q=(1-\epsilon)e$
pollution: $z=(1-\epsilon)^{1/\alpha}e$ $\Big\}\ q=z^{\alpha}e^{1-\alpha}$
* ϵ: share of inputs used for abatement instead of pollution
* e: quantity/output
* α: elasticity of pollution ($z=\alpha q$) with respect to abatement

$\min \tau z$ + we constrained by $q=1$
→ $\mu(\alpha)=h(\alpha)\tau^{\alpha}w^{1-\alpha}$
profit: $\pi(\alpha)=\bar{q}[p-\mu(\alpha)]$

↳ **New Technology** (low VC, high FC, no pollution)

$\alpha=0 \rightarrow q=e \rightarrow \mu(0)=w$
* μ is unique costs
capacity constraint: $q=\bar{q} \leftrightarrow \mu(\alpha)\le p$
→ $\mu(0)<\mu(a)\in p$
* q is the same, VC + FC change
profit: $\pi(0)=\bar{q}(p-w)-F$
→ adopt this IF $\pi(0)>\pi(\alpha)$
→ VC saving: $\bar{q}(h(\alpha)\tau^{\alpha}w^{1-\alpha}-w)>F$

→ increasing τ (tax) under CAA should:
  ↳ incr. clean technology adoption
  ↳ lower pollution at regulated plants + their VC
  ↳ but incr. total costs because of p
→ with decreasing returns to scale, we may also a reductions in output
→ π depends on tax/price of emissions which depends on the unit cost



*IF $\tau>\tau^*$ you adopt

Impacts of CAA
1. ozone concentration goes down
2. TSP concentration goes down
3. CO reduces labor, emissions, + employment (1970)
  → output grows as pollution decreases
  → sector unemployment of 15% relative to unregulated sectors
  → wage earnings fall about 5% in regulated sectors (wage loss not permanent)

South Coast Air Quality Management District (LA)
→ worst air quality in county
→ CAA 1990 requires CAT for NOx levels
  ↳ nonattainment counties outside SCAQMD used standards
→ CAT yields 20% lower emissions
  ↳ standards not exploiting the fact that lower MAC firms can exert more effort

Standards vs. CAT in practice
→ with CA 1990 replacing standards w/CAT, we can compare + see which regulatory ⇒ reductions
  ↳ CAT not launched everywhere
  ↳ flexibility for heterogeneous firms to trade permits allow those w/high MAC to buy more

NOx Budget Program (Northeast)
→ states tried CAT program due to nonattainability
→ **second best setting**
  ↳ some firms were regulated by gov't + chose to adopt clean tech because they can pass the cost to consumers
→ lower MAC firms adopt clean tech while high MAC firms opted for permits
→ NOx emissions 14% higher in privately owned firms due to asymmetric economic conditions; TC not Δ

CAA launched unprecedented air p. regulations
→ **1970-1977**: command + control in nonattainment
  ↳ regulation should trigger clean tech + emissions drop in nonattainment counties, but employ. costs
→ **1990**: CAT worked better to reduce emissions
  ↳ **pre-existing distortions** disrupt goals (Northeast)
    → concentrate pollution (incr. MD); especially w/local pollution
      ↳ move to another state where the standards is not deregulated

Economic Dimensions of Climate Change:

1. **Global externality**: global impact → different kind of regulation
   → anthropic changes occur through natural perturbations which can be slower
   → emissions of GHG induce some changes in the climate
2. **Long term**: a lot of inertia; decisions in the past have damages in the future
3. **High uncertainty**: many people have different views
4. **Thresholds + irreversibilities**: no evolving linerally; climate equilibrium can completely transform
   → cannot avoid a potentially dangerous situation if you don't know where it is

Weather: what we experience in terms of temperature, rainfall, wind, etc.; can change quickly

Climate: ave. weather (ave. temp. over a year); distribution of weather data; not measured directly

Global warming: incr. in ave. temp. over the Earth surface (first vocab but has transformed to →)

Climate change: perturbation of a climate equilibrium bc of incr. of GHG in atmosphere

Climate change has 1. **heterogeneity in spatial dimension**: some places get warmer/colder
2. **multiple impacts**: rising sea levels, heat waves, migration, productivity

Integrated Assessment Model

climate [carbon cycle → Stock of GHG → climate dynamics → temp. change
emissions z_t

economy [production + consumption ← Damages

Stock: amt of GHG already present in atmosphere from previous consump. + production

flow: incr. the stock; stock known from climate scientists

* only consider ave. temp. change

→ longer causality chain than that in local pollution

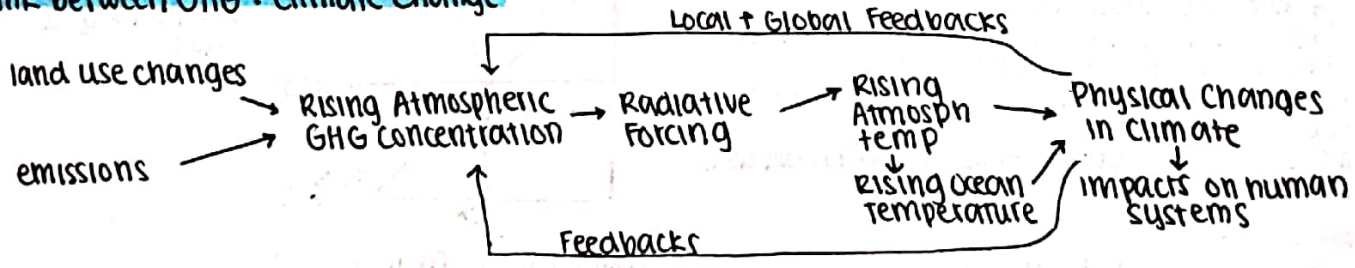
Energy Balance Model

→ Earth is an **open system** that receives energy from the sun through its radiations
  ↳ some radiation is absorbed + others are reflected back
→ Equilibrium between absorption + reflection results in ave temp on Earth

Greenhouse effect: process by which thermal radiation from a planetary surface is absorbed by atmospheric GHG + reradiated in all direct.
→ GHG incr = elevation of ave. surface temp.
1. water vapor: 36-70%
2. CO_2: 9-26%
3. methane: 4-9%
4. Ozone: 3-7%

surface + lower atmosp.

Link between GHG + Climate Change



→ **Radiative forcing**: measurement of the capacity of a gas or other agents to affect energy balance, thereby contributing to climate change
  ↳ Positive: incr. energy in atmos → incr. temp; negative forcing does the opp.
  ↳ complications: lag, climate variability, physical changes
  ↳ rank: CO_2, ozone, albedo, aerosols
  ↳ **geoengineering**: putting diff. radiative forces to cancel out; controversial
→ **Global warming potential** (GWP): relative measure / index of how much GHG trap heat in atmosp
  ↳ calculated over specific time period (20, 100, 500 yr) + expressed as a factor of CO_2
  ↳ depends on radiative forcing + lifetime in atmosphere
→ **climate sensitivity**: measure of sensitivity of ave. temp. to an incr. in GHG concentr. in atmosp.
  ↳ equilibrium temp. change in response to changes in atmosp.
    → often expressed as the eq temp Δ in °C associated w/ doubling conc. of GHG (CO_2 equivalent) relative to its preindustrial level
  ↳ long-run response which depends on many feedbacks
    → hard to reach consensus – diff economic models – maybe average all?

Feedback mechanisms

→ radiative forcing → Climate system → climate changes →
Feedback loops (+/-)

* can amplify (positive) or diminish (negative) eff. of climate forcing

Brief History of Climate Change
→ First Climate Change Model by Arrhenius (1896)
→ "Global Warming" by Broecker (1975)
→ "Climate Change" by Charney (1979)
→ Intergovernmental Panel on Climate Change (1988)
→ Kyoto Protocol (1997-2012)

GHG Emissions
1. most emissions came from land use Δ ↑ then fossil fuels
2. **Sinks:** where C goes when emitted
   → ocean, atmosp, unknown
3. manuf. + electricity production: ↑ CO_2
4. Agriculture: CO_2 from methane ↑ nitrous oxide

Last IPCC Report (2013):
1. Incr. in ave temp, sea level, concentration of GHG in atmosphere
2. Average ice cap decrease
3. Anthropogenic GHG incr. from pre-industrial era because of economic + pop growth
4. Unprecedented concentration of CO_2, methane, + nitrous oxide in past 800,000 years
5. Affect climate system throughout; likely cause of global warming
6. Likely that warming will be 1.5°C in 2100 + probably over 2°C

Climate quality can be seen as a **stock** (concentration of GHG)
→ **Inertia:** developed countries emit a lot of CO_2 + it is hard to change behaviors
→ tradeoff between development + environment
→ GHG contribute to inertia bc it stays in the atmosphere for a long time

→ $GHG_t = (1-\gamma)GHG_{t-1} + Z_t$
↳ γ: decay rate of CO_2 equivalent emissions
↳ GHG_{t-1}: result of past emissions (cannot undo)
↳ Z_t: current emissions; can control

Two Dimensions: Reduction + Time
1. **Control rate:** how do we reduce Z_t
   → consume + produce less
   → use abatement tech.
      ↳ end-of-pipe tech: not Δ process but the end result (CC capture + storage)
   → replace fossil fuels by renewable energy (solar, wind) to produce same output

2. Trade off between wait-+-see + fast action
   → stock of GHG incr. makes it harder for future generations to take action
   → uncertainty about damages
      ↳ wait + learn more about damages + tech so policy will be better

Intergenerational Problem of Climate Change
1. **Sacrafice by present generation:** high cost of climate policy
2. **Benefit to future generation:** less damage + CO_2

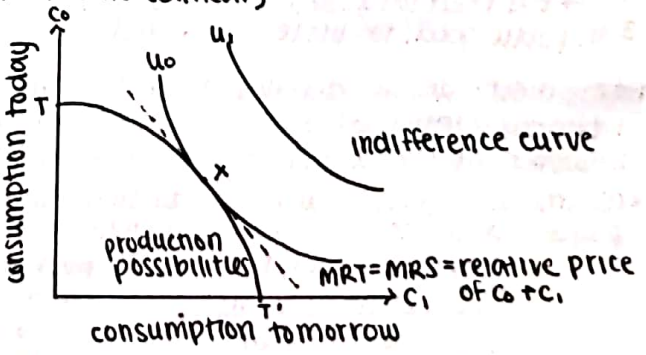
*consider: what if future generation is richer than us?

Benefit-Cost Analysis in Multiple Time Periods
Net Present Value (NPV) $= \sum_{t=0}^{T} \beta_t [B_t - C_t]$ where β_t is the **discount factor**
→ If $\beta = 1$, all generations are equal + if $\beta = 0$, only current generation matters
   ↳ low discount factor means future welfare is valued much less than present
      → implication: future benefits of climate mitigation policies might be small
      → consequence: BCA might conclude to do nothing
   ↳ high discount factor implies future welfare is at most as highly valued as present
      → implication: future benefits of climate mitigation might be high
      → consequence: act now

*climate-policy ramp

How do we determine the social discount factor?
→ **Nordhaus Approach:** consider how markets actually trade off time
→ **Stern Approach:** consider how markets should trade off time (ethical)

* people do trade off time + generally prefer consumption today (reflects impatience + risk factors)
   ↳ discount rate is positive
* gov't value all generations equally ($\beta = 1$)



Discount rate = consumer's rate of time preference = marginal productivity of capital

Exponential Discounting:
→ Discount factor $\beta_t = \frac{1}{(1+r)^t}$ where r = discount rate or market interest rate
   ↳ future doesn't matter much unless r is really close to zero
      → benefit side is small
      → good for projects that will see benefits in next 10 years or so
         ↳ far future = no change
   ↳ not good to use for gov't

Social discount rate: % per year discount in future utility or welfare; importance of welfare of future generations relative to the present
- → should be lower than market interest rate but not observable because
- → not include risk premium because environmental policy expenses are small compared to gov't exp.
- → **hyperbolic discounting**: SDR decreasing over time because people view the distant future differently than the near future (close = discount at a higher rate)
  - ↳ **time inconsistency**: decision today is different than tomorrow

Social discount factor is determined by
1. **consumer's rate of time preference** (willing to defer consumption)
2. how **productive investments** are (MPK)
3. both of these + the discount rate at equilibrium

Intergenerational discount rate: $r = \eta g + \delta$
- → η: absolute value of the elasticity of the marginal utility of consumption
  - ↳ $\eta = 1$ then 1% incr. in income reduces marginal utility of consumption by 1%
- → g: average annual growth rate
- → δ: preference for today's generation relative to next

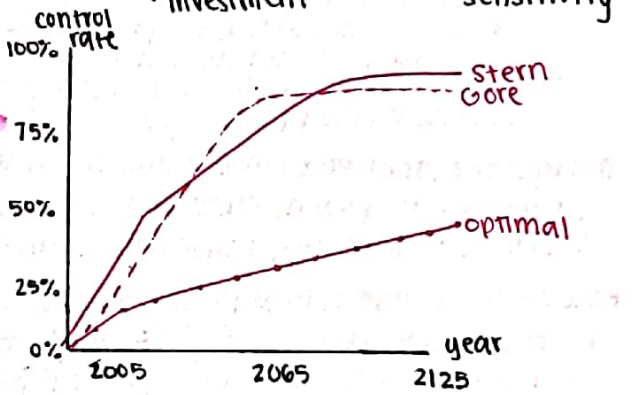
Nordhaus: $\delta = 0.015$, $\eta = 2$, $g = 0.02$, $r = 5.5\%$
- → emission control rate in 2015 should be 15% w/carbon tax of $35 per ton

Stern: $\delta = 0.001$, $\eta = 1$, $g = 0.013$, $r = 1.4\%$
- → emissions control rate in 2015 should be 53% w/carbon tax of $360 per ton

Problem: **heterogeneous time preferences**
- → **technocratic solution**: trust experts
- → **democratic solution**: vote to median's optimal plan

Integrated Assessment model: Nordhaus' DICE
1. Production: $Y_t = \frac{1 - \Delta_t}{D_t} A_t K_t^{\delta} L_t^{1-\delta}$
   - → fixed L + cost of abatement
2. Capital: $K_{t+1} = (1 - \delta_K) K_t + I_t$
3. Investment: $I_t = Y_t - C_t$
4. Emissions: $E_t = \sigma_t (1 - \mu_t) A_t K_t^{\gamma} L_t^{1-\gamma}$
   - → σ = relationship between output + emissions
   - → μ = policy/emission control rate
5. Climate sensitivity/Radiative Forcing: $m_{t+1} = (1 - \delta_m) m_t + E_t$
6. Damage: $D_t = a_0 + a_1 T_t + a_2 T_t^2$
7. Temperature: $T_{t+1} = T_t + \sigma (f_t - \lambda T_t)$

temperature → Damages · Cost of Abatement · Emissions → stock of GHG → climate sensitivity
· Production → L + K
↳ investment



Criticisms
1. Treatment of uncertainty: various perimeter values but uncertainty is more fundamental
2. Very stylized economic + climatic models + nice integrated framework, but was not tested to see if it could predict past data
3. Results are in assumptions
   - → DICE: high discount rate, low est. of damages (low carbon policies)
   - → stern + Gore: low discount rate, high est of damages (high carbon policies)

Difficulties for a global carbon policy:
1. Climate Δ is a global public bad (nonexc + nonrival)
2. 193 sovereign states: diff costs (equity)
   - → no international agency can est. + enforce
   - → in coalitions, people try to free ride
   - → but need large scale coordination
3. In public good, too little is provided

3 fundamental constraints to an international environmental agreement (IEA):
1. must be profitable to all potential memb
2. Must agree on particular design of IEA
3. must be enforced by parties themselves

Two types of free-riding
1. not to be a member of IEA (fringe)
2. not to comply w/terms in IEA but be memb

Game Theory: decision depends on other agents
1. **Non-cooperative GT:** assume binding agreements are not possible
2. **Cooperative GT:** assume binding agreements possible + hence first-best solution (rare)

*assume: 2 players, simultaneous decision, binary decision (abate or not)
payoff: specific to any combo of actions

Action alt. for B

Action all for A		pollute (b_1)	abate (b_2)
poll. (a_1)		2, 2	4, 1
abat. (a_2)		1, 4	3, 3

Nash equilibrium: max own benefit w/likely action of other country
- → each country will pollute = suboptimal
  - ↳ (abate, abate) gives higher payoffs
  - ↳ IEA: emissions not decr, carbon leakage

Need penalties + enforcement
- → IEA must be **self-enforcing**
  - ↳ N total countries + M cooperating
    - → M abate where aggregate payoff is highest, + defecting max its individual payoff
  - ↳ **internal stability**: no signatory country can gain by unilaterally withdrawing from the agreement

↳ **External Stability:** no non-signatory country can gain by unilaterally acceding to the agreement

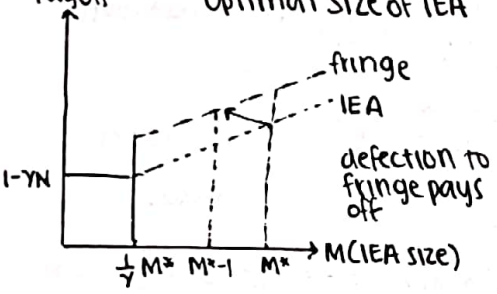
Self-Enforcing IEA size: $\pi = e_i - \gamma \sum e_j$
→ e_i is the private payoff for polluting (0 or 1)
→ second part is the damage from pollution emitted by all countries
↳ γ: marginal damage from emissions (same for all countries) $\frac{1}{N} < \gamma < 1$

Cooperative Solution: countries coordinate + adopt the same action (max welfare
→ If countries all abate, $\pi = 0$
→ If countries all pollute, $\pi = 1 - \gamma N$
↳ $\gamma > \frac{1}{N}$ so $1 - \gamma N < 0$ → abatement good

Noncooperative Solution: each country decides on own
→ for country 1, $\pi_1 = e_1 - \gamma e_1 - \gamma \sum_{j \neq 1} e_j$
↳ take out domestic damage
→ last part is fixed so payoff is $1 - \gamma N > 0$
↳ payoff higher if country 1 pollutes

Formation of IEA:
1. **membership stage:** countries sort into agreement + into the fringe
2. **Emissions Stage:** IEA act cooperatively whether or not to abate; fringe decide too
3. Solve by **backward induction.**
→ If M pollute then payoff is $1 - \gamma N$ + if they abate, payoff is $-\gamma(N - M)$
↳ $\gamma(N - M) \geq 1 - \gamma N \rightarrow M \geq \frac{1}{\gamma}$ → IEA members abate

Payoff — Optimal Size of IEA



Pessimistic Result:
→ Larger γ is
↳ larger the environmental damage
→ potential large gains from abating
↳ greater need for cooperation
→ greater diff b/t coop + noncoop.
↳ smaller the IEA
→ countries differ in costs/benefits — harder to est. coalition
↳ one way to help is to create linkages (WTO, NAFTA)

United Nations Framework on Climate Change
→ 3 groups of signatories
1. **Annex I countries:** industrialized countries
2. **Annex II:** indust. countries that pay for abatement in developing countries
3. **Developing countries**

Kyoto Evaluation
→ Pros:
1. met target even w/o CDMs
2. **market-based** approach (trade help comply)
3. Focused on most indust. countries that have emitted most in past century
4. **Monitoring + control system**

→ Cons:
1. US, China, India
2. Credit excess or **hot air** in Russia
3. High risk of **carbon leakage**
4. High risk of defection
5. Valid for 5 yrs

Kyoto Protocol: indust. countries agree to reduce GHG by 5.2% from 1990 levels
→ each Annex I had individ target
→ US not join b/c of China + economic harm

Implementation Mechanism:
1. **Joint Implementation:** cooperate in abatem. projects + countries investing in others get **Emissions Reduction Units** (ERUs)
2. **Clean Development Mechanism** (CDM)
→ favor coop + develop. in developing countries
→ indust. get CER credits (1 ton CO_2 equiv) + market to exchange

Unilateral policy: one country/region make/regulate emissions on their own in a non-cooperative framework
→ Problem is **carbon leakage**, the effect of regulation in one sector has on emissions in other sectors not subjected to that regulation
↳ other countries emit through other means → can lead to an incr. in total emissions (GHG global)
↳ most at risk sectors
1. High energy-intensive sectors (low transportation cost): cement, chemicals, steel
→ easily traded; can import a cheaper good thus CL through trade + substitution
→ not electricity sector b/c of high transport costs

Carbon leakage rate: incr in CO_2 emissions outside of countries taking domestic mitigation action divided by reductions in emissions in those taking action
→ rate > 100%: emissions reduction ↑ emissions
↳ fringe does not face large costs
→ think about tech differences
→ i.e. coalition reduces by 10% which causes fringe to incr. by 5% → 50% leakage rate
→ Kyoto Protocol: 5-20%

Sleechten + Verardi: impacts of IEA on CO_2
→ compare climate Δ, acid rain, + ozone treaties
→ identification problem
↳ reverse causality: EU countries (not big polluters) participate
↳ timing
→ local + global pollutants can be complement
↳ more ambitious for local

Why is there a risk of carbon leakage?
→ global world: trade + mobile capital
→ environ. regulation = loss in foreign price compet.
↳ foreign competitors benefit
↳ shift to imported goods (not necessarily more output)
→ cannot ignore w/unilateral policy
↳ impact domestic production + consump.

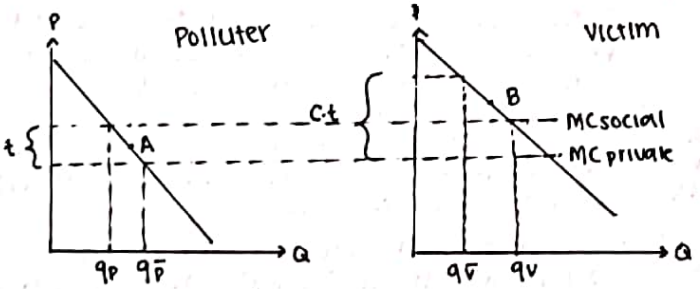
Mechanisms of Carbon Leakage

1. Production of pollution-intensive goods relocate to a country w/ lax environ. regulations
   - → benefit: transfer technology
   - → either firms delocalize or production falls under regulations + import from countries w/ lax regulations incr.
2. Channeled through world prices of energy
   - → country w/ reg. reduce own consumption
     - ↳ demand for energy falls + price falls
   - → country w/ lax reg. incr. consumption
   - → if Q is fixed, then the leakage rate is 100%

- Carbon footprint is the quantity of emissions related to consumption (CO_2 emissions caused by residents consuming or investing): carbon footprint$_i$ = Domestic emissions$_i$ + $\Sigma_{j\neq i}$ imported emissions$_{ji}$ − $\Sigma_{j\neq i}$ exported em$_{ij}$
  - → Aichele + Felbermayr: "Kyoto + CF of countries" *foreign pollution for benefit of domestic
    - ↳ Emissions Trading Scheme/System (ETS)
    - ↳ US has less domestic emissions than imported ones
    - ↳ Kyoto: domestic emissions saving ave. 7% but carbon footprint not △
      - → carbon leakage from incr. net imports of carbon

Potential Solutions of Carbon Leakage

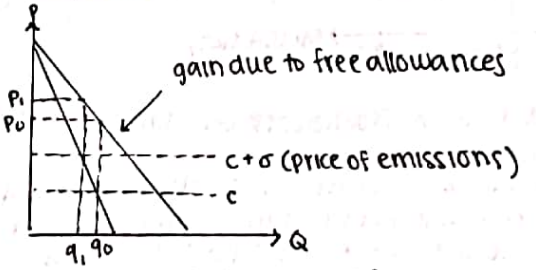
1. Border tax adjustments: supplement lack of environ. regulations in trading partner by imposing a tariff on imports of polluting goods; reduce trade
   - → tax at the same level of tax on domestic goods
   - → subsidize exports to keep competitiveness
   - → countervailing tariff where I victim country levy a tariff on imports produced w/ pollution equal to the total damage
     - ↳ must assume polluting country only affects victim, have the same MD + AD, pollution produced is proportional to production, + the good is both consumed in the countries
     - ↳ transboundary pollution: pollution that migrates beyond jurisdiction
     - ↳ however, polluter will not tax themselves so victim can only reduce externality by reducing their consumption
     - ↳ suboptimal: consumers in victim country precluding from consumption even if they value it more



- ↳ pollution will decline but surplus also
- ↳ first best (q_P + q_V) vs. w/ tariff ($q_{\bar{P}}$ + $q_{\bar{V}}$)
  - → not the same!

- → "Green Protectionism"
  - ↳ potential burden for low income countries
  - ↳ A priori, no compatible w/ WTO rules
    - → Process + Production Methods: cannot restrict import based on way they were produced—only characteristic of the good
    - → Tuna v. Dolphin: label for consumers
  - ↳ Maybe: Shrimp v. Turtle

2. Cap-+-trade scheme allocates free permits
   - → Why?
     - ↳ regulation easily acceptable by firms: profits unaffected
     - ↳ not hurt foreign comp. + market share
     - ↳ efficient solution w/ no costs
     - ↳ less incentive to delocalize
   - → when?
     - ↳ imperfect comp: π are non zero
     - ↳ elastic demand, incomplete regulation (backwards incidence)
   - → monopolist: profits ↓ but not by much



- → Profit-neutral allocation of free permits depend on the degree of competition
  - ↳ more firms, lower profit, less free permits
    - → hard to compensate a monopolist
  - ↳ also depends on carbon leakage risk
    - → low risk, no pressure from foreig comp, pass cost to consumers
  - ↳ Nicolai: N firms, no abatement, one pollution for one production, cournot (take q produced by other firms as given)
    - → isoelastic demand function: $P(Q) = \alpha Q^{-1/\beta}$ with $Q = \Sigma_{i=1}^{N} q_i$
    - → regulator's obj: reduce e by z $Q(\sigma) = zQ(0)$

- → ETS for CO_2
  - ↳ 1st + 2nd phase: free allowances so firms learn
  - ↳ Electricity: forward incidence (cost to consumers)
  - ↳ cement/steel: backward incid (π ↓)
- → Pre-Existing Distortions
  - ↳ Grandfathering regime: pre-determined criteria based on historic use
    - → windfall profits: benefit large polluters
  - ↳ Dynamic updating
    - → portion of output in previous period
    - → incentivize production + invest in abate

	Auctioning/ carbon tax	Grand-fathering	Dynamic updating	BTA w/ auctioned permits
Rate of firm exit	high	slow	slow	slow
Incentivize production	No	No	Yes	Yes
Welfare loss or gains	high loss	relatively high loss	Gains if SCC is high	high gains if SCC is high

Regulation Design in Complex, Real World:

1. Incomplete regulation
2. Pre-existing distortions can effect efficiency
3. Free allocation may create windfall π
4. In some sectors, may lead to further conc.
   - → generate welfare loss

Trade liberalization changes our consumption + production choices, thus probably the impact on the environment (ambiguous because there are positive + negative externalities)

Environmental Policies implications on trade:
- → decrease competitiveness.
- → carbon leakage.
- → unilateral policies w/ Border Tax Adjustments
- → Strategic Environmental Policies.
  - ↳ dumping to attract sectors
  - ↳ NIMBY policies (waste)

*recently, trade + trade outflows continue to grow more than output.
- ↳ more interconnected
- ↳ decrease cost of transportation
- ↳ decrease cost of communication

How does trade liberalization impact pollution levels, social welfare, + the location of polluting activities?
→ difficult to answer because trade liberalization does not leave environ. policies unchanged

Example
1. Country A: 2 y or 3x → comparative advantage in x
2. Country B: 4 y or 2x → comparative advantage in y

> specialization

Heckscher-Ohlin model of International Trade: countries will have a comparative advantage in goods produced with endowed factors that are in relative abundance
- → implication: comparative advantage in the polluting sector results in incr. pollution levels after spec.
  - ↳ outcome is efficient if the environmental policies in polluting sector is optimal
  - ↳ gov't of each country imposes tax @ MD of consumers
    - → $X = Z^{\alpha} L_X^{1-\alpha}$ where Z is pollution + L is labor ($Y = Ly$)
    - → if price of labor incr. with a tax → more sectors push to K market → more pollution

    *no profit +@ full employment
  - ↳ Pollution is good when it acts like a factor of production
    - → τ (price of emissions) $= \partial GDP / \partial Z$ (level of the economy)
    - → given the national income function $GDP(p, L, Z) = \max_{x,y} \{px + y : (x, y) \in T(L, Z)\}$
  - ↳ Pollution is bad when consumers welfare (MD) are affected
    - → $\tau = N\,MD(p, R, z)$ where N are identical consumers

Scale of the economy is all the wealth (from sector x + y); trade will cause it to incr. $S = p_x^* x + p_y^* y$
- → Pollution in the economy: $z = e \varphi_x S$ where
  - ↳ z = emission intensity (share + scale of sector x in GDP); ↑ in country A when trading
  - ↳ $e = z/x$: how much pollution needed for one x
- → **Scale Effect** (ΔS): growth ⇒ more production ⇒ more emission
  - ↳ growth + trade liberalization are often positively correlated; for given tech, incr. in economic activity incr. emissions which validates environmentalist fears
- → **Composition Effect** ($\Delta \varphi_x$): Hecksher-Odin-Samuelson framework
  - ↳ country w/ compara. adv. in dirty industry (lax policies) will pollute more
- → **Technique Effect** (Δc): emission intensity can vary from Δ in regulation
  - ↳ firms can upgrade tech after liberalized trade
  - ↳ richer pop prefer a higher level of environmental quality

	scale effect	comp effect	tech effect		Total
Country A (CA in dirty)	↑	↑	↓	=	↑?
Country B (CA in clean)	↑	↓	...	=	↘

*according to some research studies, the comp effect is the strongest

Welfare implications for Local Pollution
1. If pollution is local + regulation is efficiently set so $t = MD$, then trade is beneficial
2. Pollution havens is not a problem

Problem w/ summer Note: corruption, inefficient gov't that do not raise t efficiently, lack of control to avoid waste dump illegally

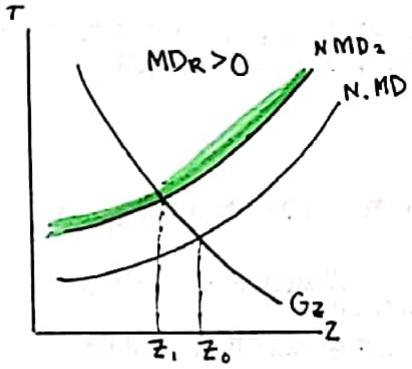
Basel Convention (1989): prevent dumping of hazardous waste from developed countries to developing w/o regulations set (ENFORCE)

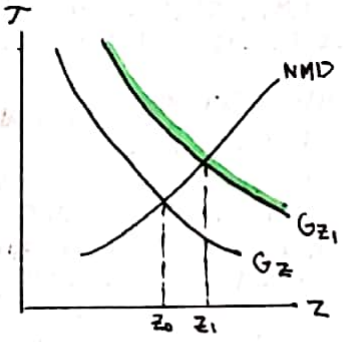
Welfare Implications for Global Pollution
1. **Free riding**: set tax to cover own consumer's MD but not other countries
   - → regulation from Nash eq too low ⇒ incr. worldwide pollution
2. Relocate polluting sector to those w/ CA in dirty industries
   - → poor country w/ lax reg. improves welfare + rich country w/ strict reg decr. welfare
3. Hard to determine **pollution havens** — ambiguous results
   - → must factor tech, factor endowments, + historical links

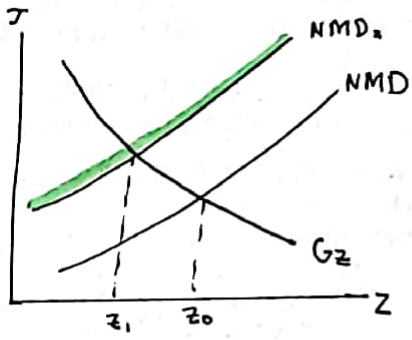
Pollution Haven Effect: tightening up pollution reg will have an effect on plant location + trade flows (some evidence) vs. **Pollution Haven Hypothesis**: reduction in trade barriers will lead to a shifting of pollution intensive industries from countries w/strict to weaker reg. (little evidence)
→ concerns over "race to the bottom"
→ use of trade policy for environ. purposes

Trade is good if you regulate pollution optimally!

Types of Goods: (in environmental quality ex)
1. **Normal Good**: Q consumed ↑ as income ↑ 2. **Inferior Good**: Q ↓ as I ↑ 3. **Luxury Good**: Q^D ↑ > %ΔI ↑

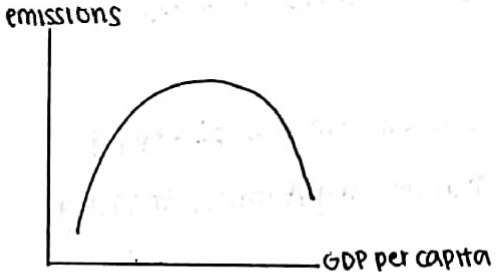






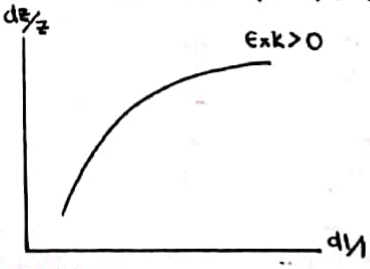
*result is ambiguous if both MD curve + G curve shift in opp. directions simultaneously

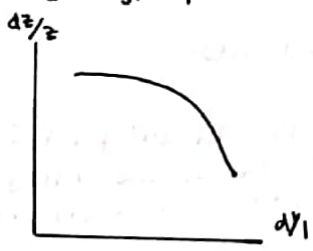
Environmental Kuznet Curve: environmental quality first decreases + then increase as per capita income in a country increases (Kuznet: income inequality + percapita income)
→ some argue developing countries are in the 1st part
→ **Caution**
1. This empirical regularity may not work for all countries
2. Curves are generated using data for countries in the same year
↳ interested in evolution of pollution in the same country over the years
3. Just a theory?



General equilibrium model: population N=1, no pollution regulation (T=0), dirty sector x pollutes so that pollution is $z = x(p, T, K, L)$ where emission intensity e=1 + T=0
→ **Income**: all wealth you can get in both sectors which depend on endowment + level of L+K in both sectors so that $I = A G(p, K, L, z)$ where e=1 + z=0
→ Incr. in co/income: $I + \Delta I = (A + \Delta A) g(K + \Delta K, L + \Delta L)$
↳ $\Delta I = \Delta A g(K,L) + MP_K \Delta K + MP_L \Delta L$
↳ $\frac{\Delta I}{I} = \frac{\Delta A}{A} + \frac{MP_K K}{G} \cdot \frac{\Delta K}{K} + \frac{MP_L L}{G} \cdot \frac{\Delta L}{L}$
→ $MP_L = (Ag(K, L+\Delta L) - g(K,L))/\Delta L$
→ $MP_K = A(g(K+\Delta K, L) - g(K,L))/\Delta K$
*GDP grows with incr. in tech, human capital, or capital

Growth via Capital Accumulation
→ $\frac{dI}{I} = s_r \frac{dK}{K}$ where s_r = share of K in nat. income
→ $\frac{dz}{z} = \epsilon_{xK} \frac{dK}{K}$ where ϵ_K = **elasticity of x output w/respect to the endowment of capital**; $\epsilon_{xK} = \frac{\partial x}{\partial K} \cdot \frac{K}{x}$
↳ implicitly means polluting sector is more capital intensive thus ϵ_{xK} will be positive
→ $\frac{dz}{z} = \frac{\epsilon_{xK}}{s_r} \frac{dI}{I}$ ⇒ pollution incr. w/income





Growth via human capital Accumulation
→ $\frac{dI}{I} = s_w \frac{dL}{L}$ where s_w = share of L in nat income
→ $\frac{dz}{z} = \epsilon_{xL} \frac{dL}{L}$ where ϵ_{xL} = **elasticity of x output w/respect to endowment of labor** so that $\epsilon_{xL} = \frac{\partial x}{\partial L} \cdot \frac{L}{x}$
↳ will end up being negative
→ $\frac{dz}{z} = \frac{\epsilon_{xL}}{s_w} \cdot \frac{dI}{I}$

Rybczinski Theorem of International Trade: human capital accumulation stimulates the clean industry

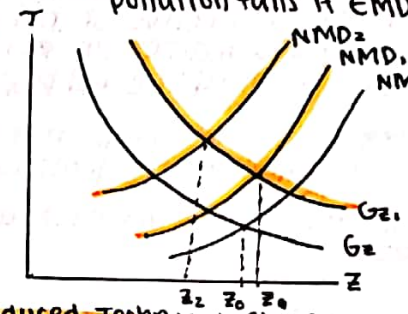
Growth via Innovation
→ **productivity**: incr. output given the current factors of production
↳ 2 effects: reduce cost of pollution allowing an incr. output over time keeping L+K constant + improvement on the quality of a product
↳ productivity growth is measured at the residual
→ **Hicks-neutral improvement in TFP A**: $dV_I = dA/A$
↳ incr. in A can impact emission intensity of sector x
→ ambiguous result: if e↓ then dz<0 but if e↑ then dz>0

→ Labor productivity growth will understate multifactor productivity growth when there is a simultaneous incr. in price of nonlabor inputs
→ Induced innovation: if a factor of production becomes relatively more expensive, firms will try using less of it + substitute to save (steer innovation to saving on expensive factor)
→ Intellectual spillovers: innovators cannot appropriate all benefits of innovation
→ Prices of pollution are formed by energy prices, + regulation
  ↳ directed technical change: ↑ fuel prices induce firms to redirect technical Δ away from dirty innovation to clean innovation

How can we rationalize the Environmental Kuznet Curve?

1. Sources of Growth vary over time
   → suppose that policy is not very responsive to income + no regulation is needed
   → countries grow via K accumulation in early stages of develop. + then via human capital
     ↳ shift source of growth from K to L
     ↳ pollution levels decline
   → key: composition effect

2. Income Effect
   → Δ in demand for environmental quality as income rises (normal good)
   → if gov't sets policy efficiently then impact on emission levels depend on ε MD,R (income elas of MD)
     ↳ ↑ I = ↑ D of pollution + ↑ S of pollution
     ↳ pollution rises if εMD,R < 1
       pollution falls if εMD,R > 1



3. Threshold Effects
   → arise in political process or abatement opport.
   → reg.: at low levels of activity, pollution is unreg. or policy is inefficient
     ↳ pollution grows in early stages
     ↳ policy binds when threshold is reached
   → abatement: firms only abate if reg. is sufficiently high
     ↳ incr. returns to abatement as scale ↑
     ↳ MAC decr. over time
     ↳ can reduce pollution even if reg. remains at the same level
     ↳ scale creates its own technique effect
       → learn by abating for ex
     ↳ lack of spillovers

4. Induced Technical Change
   → high energy prices + reg results in clean tech innovation
   → Limited spillovers
     ↳ developing countries far from tech frontier
     ↳ diff. to invest due to credit constraints
     ↳ intellectual property (patents)

We regulate energy markets because they are associated w/environmental goods
→ 60% GHG (burning coals = acid rain, TSP = health prob/infant mortality, nuclear safety)
→ however energy is cheap, not salient, + subject to strange pricing

Standard economic theory assumes:
1. Individuals maximize their utility function
2. Preferences are time consistent, affected only by payoffs, + independent of framing

But evidence suggests individuals
1. Rely on heuristics (rule of thumb)
2. Are influenced by framing and reference points
3. Overproject from the current state of the world
4. Are time-inconsistent
5. Exhibit "other-regarding" preferences

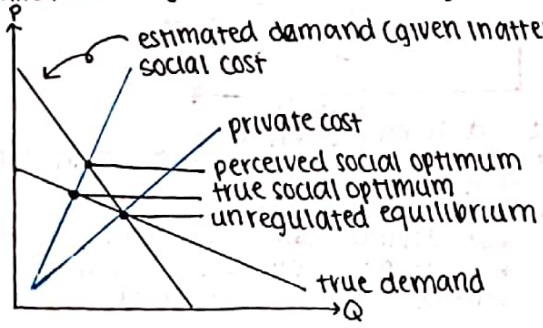
Agents exhibit:
1. Bounded Rationality: agent's rationality is limited by info, cognitive ability, + time
   → Prospect Theory (Kanneman + Tversky): reference dependence/endowment effect
     ↳ people place higher values on which they were endowed with
     ↳ absent of this effect, WTP = WTA conditional on random assignment
   → Loss aversion: prefer to avoid losses than to acquire gains
   → defaults: if preferences are complete + rationality is not bounded, then defaults should not affect choices when costs of deviating from default are low
     ↳ ex: organ donation, 401K participation
   → framing: affect the way you answer a question due to implicit suggestion
     ↳ ex: GF/BF survey, dental hygiene + floss scale
   → salience: individuals optimize imperfectly when incentives are not transparent + feedback is limited; inattention to components of price
     ↳ tax salience (Chetty, Looney, Kroft): when tax is included in posted price, demand falls
       → Δ in excise tax induce bigger demand response than tax Δ's
2. Bounded Self-Control: lack of will-power to make rational decisions; individuals make choices that are not in their long-run self-interest.
   → standard theory assumes a discount factor between any 2 periods that is independent of when utility is evaluated (1 day + one week vs. 1 yr + 1 yr + 1 week)
   → overproject: think future self is better/more attentive (gym membership)
   → evidence of inconsistent preferences (hyperbolic) discounting) + limited self-control

3. **Bounded Self-Interest**: we believe people have other-regarding preferences (charity, volunteer, etc.)
→ Economists try to explain this phenomenon w/self-interest preferences
↳ warm glow (happy to do good) + reputational motivation
→ **Conspicuous conservation**: we may take costly action to signal our preferences for the environ. due to Δing social norms from the concern of damage + climate change.
↳ **signaling theory**: when peers care about environ → incentive to show you do too (ex: Prius sales in democratic locations)
→ but remember: correlation ≠ causation
→ testing: people prefer Prius over other hybrids due to its distinct look
↳ can induce private provision of goods (policy → make behavior conspicuous; firms → 2nd degree price discrimination + product differentiation)
↳ can lead to inefficient conservation investment
→ low hanging fruit passed as visible green projects (solar panels in cloudy areas)
→ crowd out

We assume creation of markets like incentives can resolve environmental problems
→ but people do not respond to incentives in consistent + systematic ways
↳ policy may be ineffective or inefficient
With environment goods, markets are lacking so **competition + arbitrage** cannot enforce rationality
markets should enforce discipline but people do not account for their mistakes (no adaptation / evo.)

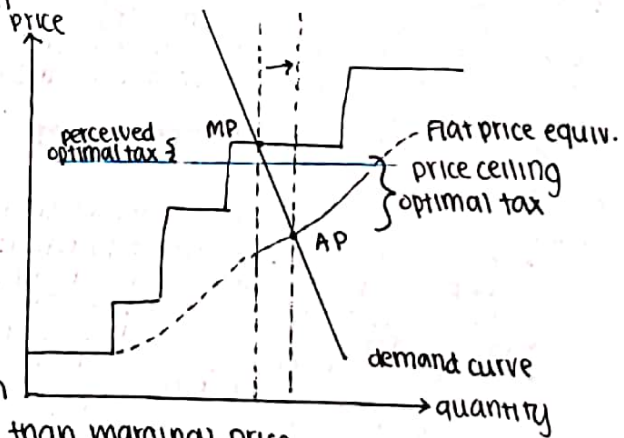
Three Applications of Behavior Economics in Energy Demand

1. **Salience**: many households utility goods (electricity, water, gas) are not particularly salient



→ w/limited attention, consumers may not respond to taxes the way regulators would hope
→ **automatic bill payment**: permit timely payment of recurring bills via automatic credit card transaction w/o requiring individ. to review the bill (utility becomes less salient)
↳ decreased saliency may lead to over consump. + less price elasticity
↳ grown rapidly over 15 yr (41% of payments)
↳ opportunity to test whether it matters for electricity consumption
→ Sexon (2015): when people switch to ABP, consump. ↑ 4% resid + ↑ 8% for businesses

2. **Heuristics**: electriary prices can be complicated + if consumers use simple rule-of-thumb to optimize instead of marginal price, then optimal policy will be different than what it should be
→ **electricity supply**: marginal cost of producing electricity is described as the "hockey stick" because it can get really expensive really quickly at high inputs/outputs
↳ if demand is high, prices get really high but gov't regulates w/price ceilings
→ electricity providers want to keep production down
→ utilities try to keep consumption down esp. during peak hours
1. **Real time pricing**: pay how much when it costs
2. **Behavior interventions**
3. **Non-linear pricing**: diff marginal cost for diff. segment of consumption
↳ point is to flatten usage so that demand crosses before the steep incr. in cost
→ i.e. charge 10¢ per kwh @ first 10 kwh
12¢ @ next 5 kwh
→ works like a tax
↳ **bunching**: if consumers respond to marginal price, we should see bunching in the distribution of discrete jumps in price
→ **inattention**: people may track a diff. metric than marginal price
↳ under non-linear pricing, consumers set MWTP = AP ≠ MP
→ optimal tax is larger than what would be expected from rational behavior



→ saliency problems reveal optimal tax should be larger than expected from rationality
↳ **silver lining**: politically infeasible to employ price instruments to address climate Δ so it may be good consumers base energy consumption on something other than price

3. **Reference Points**: info Δs people's reference points, indicating prospect theory applies in elec. demand
→ Opower experiment: Alcott finds electricity consumers respond to info. about their relative consump.
↳ 2% drop in treated households
↳ low cost
↳ behavioral interventions may be a better + more feasible way to reduce energy consump.

Demand for Associated Services: $U(\text{light}) = U(\text{energy} \times \text{light/energy})$

Energy consumption: $g = me$
Consumer cost: $\text{cost} = pme$
→ e = energy intensity (amt of energy needed to use your appliance)
→ m = demand for energy service
→ p = price of energy

variable input; direct consumption

efficiency w/which variable input (energy) is transformed into the service consumers care about (light); appliances

→ lower energy intensity saves energy + cost for consumer
↳ politicians like it b/c energy efficiency policies do not tax or impose direct costs on anyone (subs/info)

Energy efficiency gap: investment in energy efficiency is irrationally low
→ McKinsey graph: energy saving investments with negative prices — irrationality?
→ Fixed costs vs. variable costs
↳ variable C. are imp. in total cost of K goods so consumers care about reducing them
→ energy efficient products to lower VC

Model of Energy Efficiency Adoption (ex: Prius)
→ Adopts good if $\frac{pm_i(e_0 - e_1)}{1+r} - \varepsilon > c$

- $\frac{pm_i(e_0 - e_1)}{1+r}$: NPV of var. C. savings
- ε: extra user cost of adoption
- c: relative capital cost of adoption

→ e_0 = old energy intensity
→ c = incr. in capital costs
→ ε = incr. in user cost
→ p = price of fuel
* consumer discounts infinite stream of VC savings w/ interest rate, r

But adoption can be too low:

1. **Unpriced externality costs**
→ $\frac{(p+\varphi)m_i(e_0 - e_1)}{1+r} - \varepsilon > c$ where φ = externality cost of energy consump.
→ unregulated optimum is lower so adoption is too low relative to social optimum

2. **Investment inefficiencies** (irrationality)
→ $\frac{\gamma pm_i(e_0 - e_1)}{1+r} - \varepsilon > c$ where γ = invest. inefficiencies that cause consumers to undervalue efficiency
→ can come from imperfect info, inattention, + credit constraints

Inefficiencies which cause consumers to undervalue efficiency
1. **Imperfect info:** people do not know home insulation or how to weatherize + renters may face high costs to figure it out so landlords have no incentive to improve H
2. **Inattention:** focus on observable features w/o considering ancillary costs
3. **Credit constraints:** durable goods require upfront capital
→ some not able to secure loan to make energy efficient investment

Principle of Targeting
→ Tinbergen: need as many policy tools as market failures
→ If there are unpriced externalities + investment inefficiencies, then we need environmental taxes + policies to reduce investment inefficiencies

Energy efficient policies are good for addressing γ (standards + subsidies) but φ?
→ when no γ exists, then these policies will have larger welfare cost per unit of pollution abated compared to first-best Pigovian tax
↳ subsidies + standards Δ price for all consumers whereas taxes impact high-energy users the most
↳ **rebound effect:** subsidies + standards do not provide the right incentive for utilities; relative costs of energy in fact drops, encouraging more energy use (m_i↑)
↳ It is difficult to calibrate the stringency of efficiency standards correctly, so you may not get exactly the right amt of investment + abatement
→ w/Pigovian taxes, we just a tax at marginal social cost (if you know it)
→ If $\gamma < 1$, then these policies may be a good "second-best" tool, absent externality pricing
↳ address investment inefficiency + may help w/externality

Evidence on the Energy Efficiency Gap
1. Engineering estimates of potential returns to investments
2. Empirical estimates of returns to observed investments
3. Cost efficiency of energy conservation programs
4. Estimated demand patterns for energy-using durables

} not very strong evidence in support of the energy efficiency gap

If a good is necessary w/no clear substitute, there will be inelastic demand

How do we value environmental goods?

1. **Use value**: refers to the utility arising from direct or indirect physical use of a resource including commercial use, recreational use, + aesthetic use (direct utility gains or losses)
   - → **consumptive use value**: private benefits that are derived from resource consumption + contribute to resource depletion (visit park, farming, fishing, etc)
   - → **Nonconsumptive use values**: generally public good benefits that do not contrib. to resource depletion
   - → direct impact on health + welfare
   - → indirect impact on ecosystems

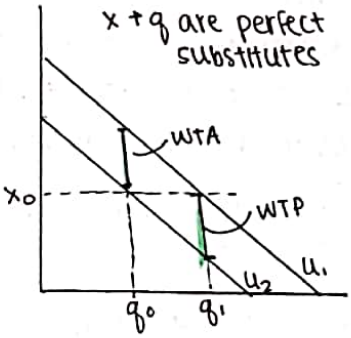
2. **Nonuse value**: utility derived from environ. resources w/o physical interaction (control.)
   - → **existence value**: utility derived from knowledge of mere existence
   - → **altruistic value/vicarious consumption values)**: utility derived from consump. of environ. resources by other people
   - → **bequest value**: utility derived from consumption of environmental resources by other individuals

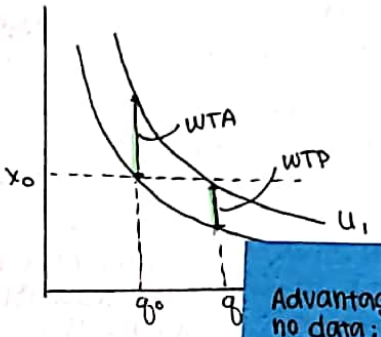
Willingness to pay (WTP) is the max money an individual would give up in exchange for all the benefits associated w/the good; area under demand curve (price = MWTP)

Willingness to accept (WTA) is the min total money an individ would accept to forgo all benefits associated w/the environmental good.

MB of 1 less pollution = MD of one more pollution = −MWTP for 1 more pollution

* WTP limited by income + wealth





Advantages: investigate where there is no data; involve real resource decisions

Disadvantages: expensive to conduct; involve non-randomly selected samples; difficult to generalize

Measuring Demand

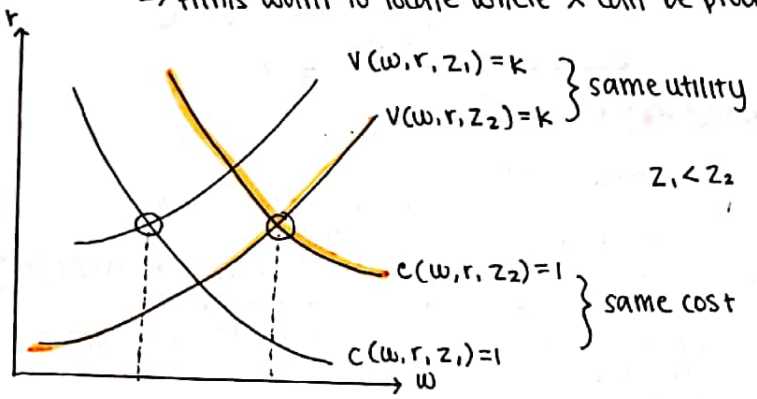
1. **Stated Preference**: asking people how they would trade off money for
   - → Opinion polls + surveys: subject to contro due to absence of re
   - → **Contingent Valuation Method**: relies on direct revelation of dema
     - ↳ **sampling bias**
     - ↳ **strategic bias** (not telling the truth): individuals may over
       to advance own agenda or hinder other's agenda
     - ↳ **framing bias**: people's answers vary depending on the context which a question is put
     - ↳ **Ill-formed preference**: not-well-formed preference for unfamiliar goods
     - ↳ **info bias**: failure to comprehend or to interpret questions correctly
     - ↳ sometimes not enough to just know their WTP (demographic, lifestyle, attitude)
       - → assess impacts of heterogeneity + over come sampling problems
   - → **Willingness to Vote**/official Referendum
     - ↳ people w/higher WTP likely to ban pesticides but some people may not be willing to pay much yet vote to ban or vice versa (seemingly inconsistent results)
   - → benefits transfer: no resources to conduct new study = survey literature + find similar analysis + transfer them to your application

2. **Revealed Preference**: observe real choices in some market + infer info on the trade-off betw. $ + environ.
   - → **hedonics**: see how price of conventional good varies as amt of closely related environ good Δ's.
     - ↳ infer value based on observed prices of bundle of characteristics (natural resources: recreational, consumptive, + aesthetic)
     - ↳ **rental price**: price of renting the land for a short period of time
       asset price: price of taking a title to the land in perpetuity
       *assume wages are exogenous
       - → **rural land**: rental value is the expected value of output from land less the cost of labor, seed, + other inputs (NPV of expected π from land)
         productive externality: how pollution may impact crop growth
         - ↳ **Local market**: output determined locally → clean pollution → incr. supply → decr. price → land price in clean region decr. → land price in dirty region incr. = land value not fully capturing value of clean air
         - ↳ **Regional/National market**: price unaff. by cleanup → land price in clean area will not change → land price in dirty area good proxy for WTP

→ **Urban Property value**: rental value is the expected services to the occupant of land (location, surr) (reflects the utility of people on the land)
  ↳ "**Open City**": potential migration; utility level of typical person same no matter where they live (mobility; Tiebout)
    → when air quality rises, value of land will rise to compensate it
    → cleanup = ↑ value of land = benefit landowners only
  ↳ Rise in prop values in dirty area only reflects value of clean aire when city is open

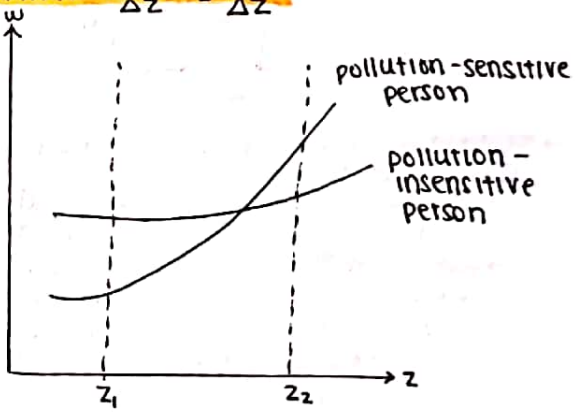
  ↳ "**Closed City**": no migration (fixed pop); u of typ. citizen determined by internal factors but u same for all residence
    → diff b/t property values of clean + dirty reflects damage in prop values
    → **observable**: property value ↑
    → **unobserv**: utility level ↑

Models of Wages, Land Prices, + Pollution: higher wages may compensate higher pollution levels
→ consumer's Preference: $\max_{x,L} U(x, L, Z)$ subject to $w = X + rL$ w/constant utility $V(w, r, z) = k$
  ↳ z = pollution, x = composite good, w = wage rate, r = land price
    → firms want to locate where x can be produced cheaply



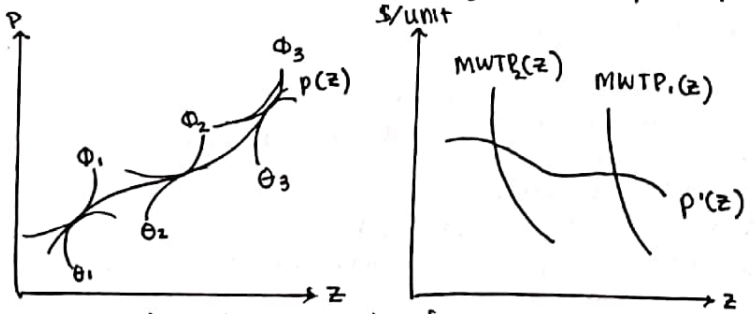
* **standard assumption**: higher pollution levels imply a lower production cost (less abatement
* pollution could make production more costly or have no impact on marginal cost
  → higher pollution = higher wages = ambig. effect on land prices
  → drive away labor but attract firms

Willingness to pay is derived from wage + rent change (net effect); utility is constant
$MWTP = \frac{\Delta w}{\Delta z} - L\frac{\Delta r}{\Delta z}$



Equilibrium Sorting
→ "**unobserved tastes**": characteristics of people that are important for behavior but unobserved by analyst
  ↳ people sort themselves into diff communities based on wage + pollution levels (Tiebout)
→ For nonmarginal Δ in pollution, people may move
  ↳ for marginal Δs, they will not move (need another variable in U func. for tastes)
→ Diff. in tastes must be taken to account in statistically estimating wage-pollution relationship
→ observe comm. choice: If city 1 is preferred then:
$V(w_1, r_1, z_1, \alpha_A) \geq V(w_2, r_2, z_2, \alpha_A)$ assumption that this is predictable w/observable variables (income, edu, etc.)

Hedonic Price Equation: $P = a_1 z_1 + a_2 z_2 + \ldots + a_n z_n$
→ a = hedonic price of the characteristic (parameter) + z = marginal price person is paying for environ good
→ what if hedonic price is not constant?
  ↳ each individual chooses only one consumption point along the hedonic price function



→ marginal price of z (P'(z)) differs from MWTP for z which differs across individ
  ↳ assume individ make choices along hedonic price function = variants of the same person w/diff. observable characteristics (income)

→ pros: 1) based on revealed preference (less bias)
2) using info from economic markets

→ cons: 1) requires detailed data from market (attributes of the good + environmental data)
2) can only evaluate impact for which there is variation
3) Assumes people react to environ. quality variation

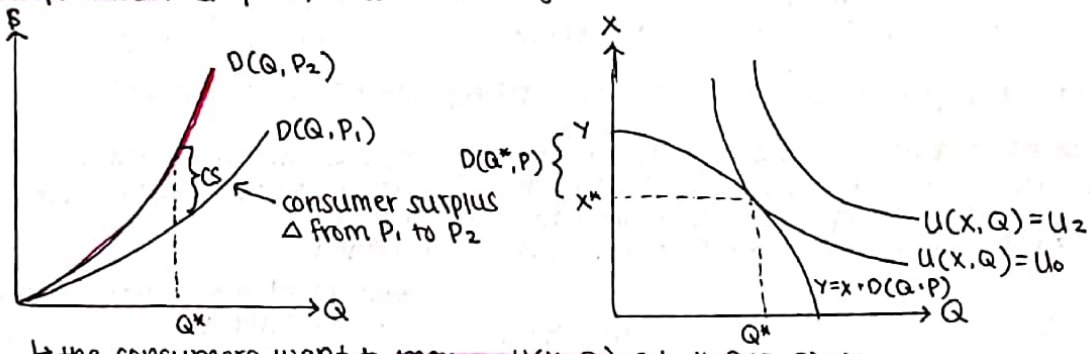
Value of Statistical Life: WTP for reducing the mortality risk
→ given behaviors + answers, people reveal finite amt to reduce mortality risk/tradeoff
→ hedonic price method for workers w/riskier jobs: $w = f(\pi, x) + \epsilon$
  ↳ w = wage rate; π = probability of death on job; x = other characteristics; ε = error term
→ problem: age, self-selection (value on own life)
→ VSL = $\Delta w / \Delta \pi$

*see lecture 24 for ex

2. Revealed Preference

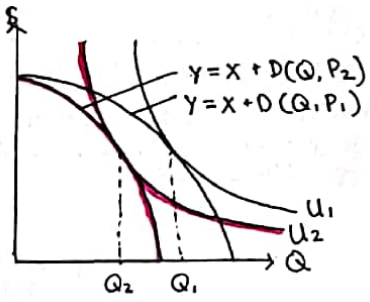
→ **Household Production**: purchases due to environmental goods (admission) to/or bads (noise control) to produce an experience that directly provides utility

↳ **Defensive expenditures**: money spent to defend against environmental bad
- → evaluate WTP for improvement in environmental quality
- → invest in these measures until MC = MB
- → **simple model**: Q=quiet, x = conventional good, y = income, P = noise



↳ the consumers want to $\max_{x,Q} U(X, Q)$ s.t. $X + D(Q, P) = Y$

→ What if P increases?
- ↳ Those who can afford incr. defensive expenditure = WTP
- ↳ if consumers cannot afford Q*, then budget constraint rotates downward
  - → utility + amount of quietness decr.
  - → as Q decreases, consumer saves on expenditures (def)
    - ↳ Δ in d. expend. will understate true MWTP (observed d. exp. will be less than MWTP to avoid the pollution increase)



→ How does D Δ when P increases?
- ↳ suppose P is infinitesimal
- ↳ $dD = \frac{\partial D(Q,P)}{\partial Q} \cdot dQ + \frac{\partial D(Q,P)}{\partial P} \cdot dP$
- → $\frac{dD}{dP} < \frac{\partial D(Q,P)}{\partial P}$ = WTP

↳ **Travel cost**: money spent to acquire an environmental good
- → 3 major dimensions: (1) demand depends on quality of good, (2) number + duration of trips during a period of time, + (3) treatment of substitute sites
- → **simple model**: V = visits to park, x = basket of market goods, P_0 = out-of-pocket expenses for a park visit, F = entry fee, L = hours worked, w = wage, price of x = 1, t = time
  - ↳ consumers want to $\max_{x,V} U(x, V)$ s.t. $wL = x + (p_0 + f)V$ + T(time) = $L + (t_t + t_v)V$
    - → $\max_{x,V} U(x, V)$ s.t. $wT = x + (p_0 + w(t_t + t_v) + f)V$
      - ↳ FOC: $U(x) = \lambda + U_V = \lambda(p_0 + w(t_t + t_v) + f)$

→ **Zonal travel cost model**: geog. zones around site as basic units of observ.
- ↳ identify origin of visitors + number of visits
  - → explained by travel cost + demographic/income characteristics of the zone

→ **Individ. travel cost model**: rely on observ. of behaviors of individ.
- ↳ expensive + data intensive; bias if sample is self-selected

→ **Methodological Considerations**
1. can we accurately value natural resources in the past + future?
2. values based on market transactions or surveys are not static, but are base on info available at the time — true value revealed in time
3. Estimating time is problematic (wage rate? leisure?)
   - → extra cost associated w/trip or average cost of operating vehicle?

Hedonic valuation: if markets work perfectly (full info, rational expectations), then the value of an environmental goods can be inferred from the price of associated goods

Application: climate change

→ Climate scientists: accumulation of GHG emissions in atmosph. Δ world climate — some Δ is unavoidable
- ↳ growing political support to reduce emissions to mitigate the climatic change

→ Economic impacts
- ↳ Damages: hard to estimate, measure expectations
- ↳ marginal social cost associated w/climate Δ (ex: fossils fuels)
- ↳ optimal carbon tax/policy response?

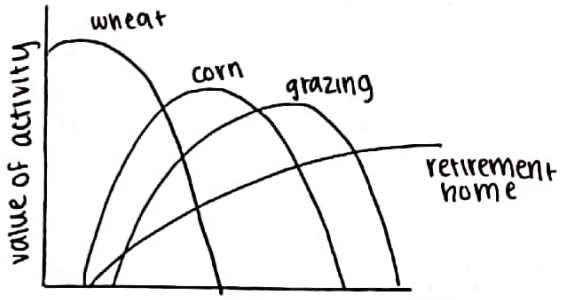
→ Primary impact of CC is on agriculture — one sector where it is difficult to completely protect yourself from temp Δ (especially in developing countries)
- ↳ temperature + water are inputs
- ↳ Production Function Approach: early evidence assess crop yields under diff. climates, holding inputs fix

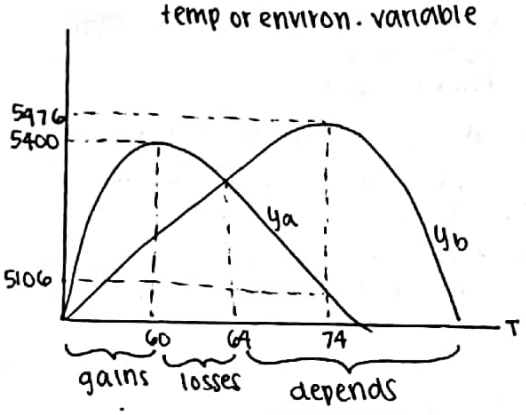
→ each crop has an optimal temp (deviations = large Δs)

↳ Other effects: availability of inputs, optimal crop choice, aggregate output, aggregate price, migration
→ adaptation: switch to a different crop when environmental conditions Δ
→ price effect: when yield incr, prices potentially decrease (ambiguous Δ in revenue)

↳ How to assess overall impact
→ hedonic price method: assume land markers perfectly forecast Δs + use the differences by different climates to identify economic value of climate

Mendelsohn, Nordhaus, Shaw (1994)





Ex: 100 farms w/1 acre + corn
y = corn output discount factor: $\delta = \frac{1}{2}$
p = sale price fixed price: F = 5000
a + b are corn varieties where
$Y_a = 180T - \frac{3}{2}T^2$ > when T = temperature
$Y_b = 148T - T^2$
elasticity of demand: $\epsilon_d = \frac{1}{2}$

Different Scenarios:

	No adaptation (crop a)	Adaptation (crop b)
Fixed Price	↓	?
Price Δ	?	?

Profit in infinite horizon w/no Δs:
$r = \sum_{t=0}^{\infty}(1 \cdot y_a(60) - 5000)\delta^t = \sum_{t=0}^{\infty}(1 \cdot 5400 - 5000)\delta^t$
$= 400\sum_{t=0}^{\infty}\delta^t = 400(1/(1-\delta)) = 800$

General Formula | **Infinite Horizon Discounting**
$a\sum_{k=0}^{n-1} q^k = a\frac{1-q^n}{1-q}$ | $a\sum_{k=0}^{\infty} q^k = \frac{a}{1-q}$ if $q<1$

If not starting from zero:
$a\sum_{k=2}^{\infty} q^k = a\left[\sum_{k=0}^{\infty} q^k - \sum_{k=0}^{2} q^k\right] = \frac{aq^2}{1-q}$

q^k = discount factor so $q = \frac{1}{1+r} < 1$; Hence,
$a\sum_{k=0}^{\infty}\left(\frac{1}{1+r}\right)^k = \frac{a}{1-\frac{1}{1+r}} = \frac{a(1+r)}{r}$

NPV: cannot adapt, no price Δ:
$r = \sum_{t=0}^{1}(1 \cdot y_a(60) - 5000)\delta^t + \sum_{t=2}^{\infty}(1 \cdot y_a(74) - 5000)\delta^t$
$= \sum_{t=0}^{1}(1 \cdot 5400 - 5000)\delta^t + \sum_{t=2}^{\infty}(1 \cdot 5106 - 5000)\delta^t$
$= 400\sum_{t=0}^{1}\delta^t + 106\sum_{t=2}^{\infty}(1 \cdot 5106 - 5000)\delta^t$
$= 400(1+\delta) + 106\left(\frac{\delta^2}{1-\delta}\right) = 400\left(\frac{3}{2}\right) + 106\left(\frac{1}{2}\right) = 653$

* yield ↓ ⇒ profits ↓ ⇒ land value ↓

NPV: can adapt, no price Δ
$r = \sum_{t=0}^{1}(1 \cdot y_a(60) - 5000)\delta^t + \sum_{t=2}^{\infty}(1 \cdot y_a(74) - 5000)\delta^t$
$= \sum_{t=0}^{1}(1 \cdot 5400 - 5000)\delta^t + \sum_{t=2}^{\infty}(1 \cdot 5476 - 5000)\delta^t$
$= 400\sum_{t=0}^{1}\delta^t + 476\sum_{t=2}^{\infty}\delta^t$
$= 400(1+\delta) + 476\left(\frac{\delta^2}{1-\delta}\right) = 400\left(\frac{3}{2}\right) + 476\left(\frac{1}{2}\right) = 838$

* climate change is good!

NPV: adaptation w/price Δ
→ Aggregate output incr. from (5400)(100) = 540000 to (5476)(100) = 547600 w/ $\epsilon_d = \frac{1}{2}$

$\epsilon_d = \frac{\Delta Q}{\Delta P}\cdot\frac{P}{Q} = \frac{-(547600 - 540600)}{\Delta P}\cdot\frac{1}{540000}$
$= -\frac{0.014074}{\Delta P} \Rightarrow \Delta P = -\frac{0.01407}{1/2} = -0.028148$
$\Delta P = 1 - 0.028148 = 0.9718$

→ Land value:
$r = \sum_{t=0}^{1}(1 \cdot y_a(60) - 5000)\delta^t + \sum_{t=2}^{\infty}(0.9718 \cdot y_b(74) - 5000)\delta^t$
$= 400\sum_{t=0}^{1}\delta^t + 321\sum_{t=2}^{\infty}\delta^t = 600 + 161 = 761$

NPV: no adaption w/price Δ
→ Aggregate output falls from (5400)(100) = 540000 to (5106)(100) = 510600 w/ $\epsilon_d = \frac{1}{2}$

$\epsilon_d = \frac{\Delta Q}{\Delta P}\cdot\frac{P}{Q}$ (ΔP is unknown)
$= \frac{540000 - 510600}{\Delta P}\cdot\frac{1}{540000} = \frac{0.054444}{\Delta P}$
$\Delta P = 0.05444/\frac{1}{2} = 0.1088 = 1.1088$

→ Land value:
$r = \sum_{t=0}^{1}(1 \cdot y_a(60) - 5000)\delta^t + \sum_{t=2}^{\infty}(1.1088 \cdot y_a(74) - 5000)\delta^t$
$= 400\sum_{t=0}^{1}\delta^t + 661\sum_{t=2}^{\infty}\delta^t = 600 + 331 = 931$

* empirical question: cannot know impact of CC given the fact prices can Δ + people can adapt

Schlenker, Hanemann, + Fisher (2005)
→ irrigation is important for agriculture + irrigated land will respond diff. to CC than non irrigated
↳ price of water very different
→ re-estimate for non-irrigated land
↳ only find negative est.
→ study does not contradict

Mendelsohn, Nordhaus, Shaw (1994)
$value = a_1T - a_2T^2 + a_3Rain - a_4Rain^2 + \epsilon$
→ value of land as a func of temp + precip
→ compare north + south
↳ contradict; some + + some −

Deschenes + Greenstone (2007):
→ Climate could be correlated w/other unobserv. determinants of land prices (soil quality)
→ need multiple years of data to find fixed effects
↳ look @ yields so no price
→ year-to-year variation in agr. profits
↳ positive impacts = Δ is good
→ critique of hedonic method

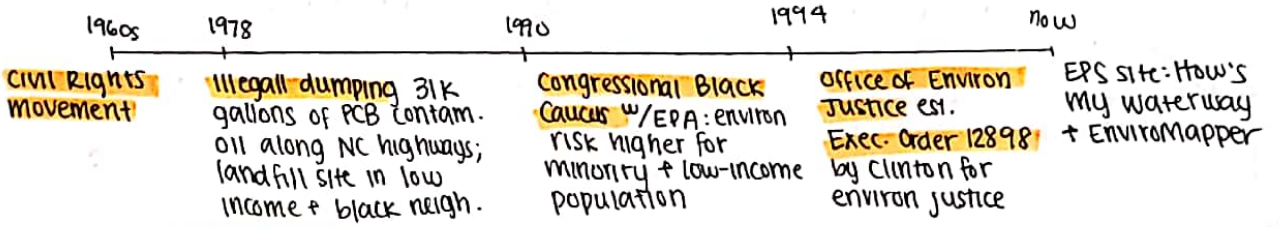
Burke + Emerick (2015)
→ Deschenes + Greenstone rely on SR Δs in weather to estim. value of climate, but this misses any adaptation
↳ need fixed effects, but also LR responses to capture "
→ not income, just crop yields
↳ longer panel + averages for endpoints
→ Compare SR + LR impacts – diff. in adaptation
↳ CC is negative (impact is small though)

Deryugina + Hsiang (2015): how county-level income per capita in US (across all sectors) respond
→ GDP decr. on hot weekdays – not weekends

Dell Jones Olken (2012): 1°C ↑ lowers GDP 1.3% in poor countries; no effect in rich countries
→ certain temp where humans are productive

Civil conflict: higher temp. implies ↑ risk of confl.
→ extreme weather events
→ climate tipping points

Environmental justice is the fair treatment + meaningful involvement of all people regardless of race, color, national origin, or income w/respect to the development, implementation, + enforcement of environ laws, regulations, + policies. This will be achieved when everyone enjoys the same degree of protection from environ + health hazards + equal access to decision-making process to have a healthy environment in which to live, learn, + work



→ may stem from **less economic alternatives** + **less aware** of risks involved (locally undesirable land uses)
→ Examples: Cancer Alley (125 comp produce ¼ petrochem products in US), pesticide exposure to Latino farmworkers, solid waste in South Africa mining, dumping waste in Ecuador by Chevron-Texaco

Do poor/minority people voluntarily sort into polluted area?
→ Tiebout model
→ challenging for LULU combat

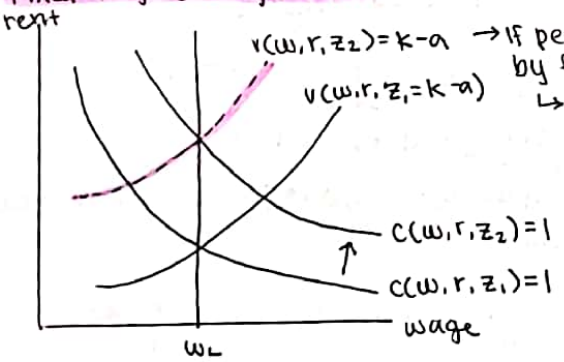
Do firms + gov't agencies deliberately locate pollution in low income neighborhoods?
→ EJ policies target this

Assumptions of Hedonic Price method
1. People are freely mobile across locations
2. People have the same preferences
3. Hence, all locations ensure the same level of utility
4. Firms are mobile + benefit from high pollution

Result: highly polluted areas have lower rents + higher wage (cost-saving of polluting) when wages are endogenous

In Reality
→ people may not be mobile
→ ppl are constrained by budget
↳ low-income may have diff. preferences from high income
→ wages may be determined by regulation (min wage) + employees do not care where you live (so no compensation)

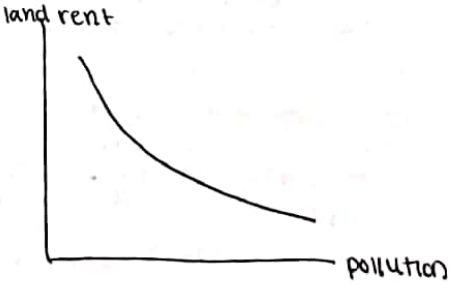
Fixed-Wage Sorting Model



→ If people are unaware of environ. risk, land rents could be determined by firms, while wages are fixed
↳ households have ↓ U in highly polluted areas

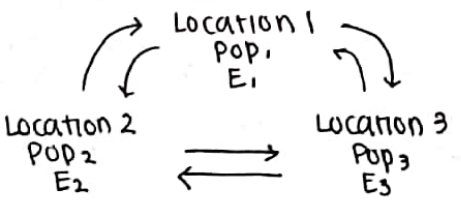
* fixed wages reduces U

→ Trade-off between rent + pollution: ↓ rent in locations of visibly high pollution levels
↳ ↑ polluting firms cannot afford to produce in stringent areas



Nuance driven residential mobility
→ US Census Bea/Bureau: >30 mil ppl move from one home to another each yr (4 living space or neighb)
↳ ppl trade off housing stock, neighborhood quality, + other (dis)amenities (schools, hospital, work)
→ fleeing the nuisance: moving away
→ coming to the nuisance: moving in

consider 3 locations ($E_1 < E_2 < E_3$) + 2 time periods (B + A)



Dynamics across location

$$\begin{pmatrix} s_{1,1} & s_{1,2} & s_{i,3} \\ s_{2,1} & s_{2,2} & s_{2,3} \\ s_{3,1} & s_{3,2} & s_{3,3} \end{pmatrix} \begin{pmatrix} pop_1^B \\ pop_2^B \\ pop_3^B \end{pmatrix}$$

$$\sum_j s_{j,k} = 1 \; \forall k = 1,2,3$$

Ex:

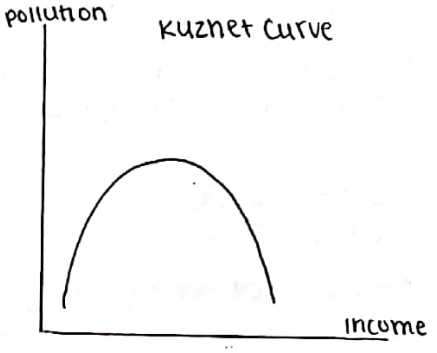
$$\begin{pmatrix} 0 & 0.6 & 0.6 \\ 0.5 & 0.25 & 0.2 \\ 0.5 & 0.15 & 0.2 \end{pmatrix} \begin{pmatrix} 3 \\ 2 \\ 1 \end{pmatrix} = \begin{pmatrix} 1.8 \\ 2.2 \\ 2 \end{pmatrix}$$

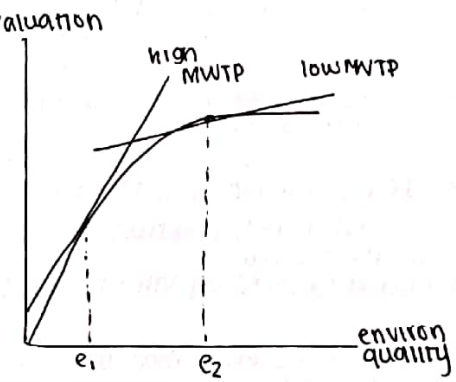
* people "come to the nuisance" regress $s_{j,k}$ on $\Delta E_{j,k}$

Depro, Timmins, + O'Neil (2014)
→ DATA: National Air Toxics Assessment (NATA)
→ Risk levels for cancer + other respiratory + neuro effects at the census tract level, based on chronic exposure to air toxics ⇒ focus on cancer risk
→ ambient conc. of emitted toxins (on vs. off road)
→ 2 groups: Hispanics + Whites in LA
→ **Results:**
1. Annual MWTP to avoid add. cancer unit is 32¢ for whites + 3¢ for Hispanics
2. But pollution may be correlated w/unobservable neighbourhood attributes (economic activity); hence, after attributing/instrumenting for NATA cancer risks, the est. are 70¢ for Hispanics + $2.30 for whites
3. Strong evidence in favor of residential mobility hypothesis as explanation for observed correlations between race + pollution (sort themselves in accordance w/WTP; contrast prev. literature)
4. Per capita income in LA 1999: whites = $35,785 while Hispanics: $11,100
   → under diminishing marginal utility of income, whites are more willing to sacrifice income
   ↳ Hispanics not indiff. to health problems; tradeoff between consumpt + pollution exposure may be rational

→ Residential mobility model: est WTP to ave ↓ exposure to toxics for whites
↳ control: housing stock, school quality, incidence of violent crimes, presence of act. w/air toxics (TRI facilities), individ moving costs ($100-$500 for 37 years + discount rate of 2.5%)
↳ two periods: 2000, 2007
↳ complicated sorting model: underst. why some stay + others move

Environmental quality is both important + bad in developing countries

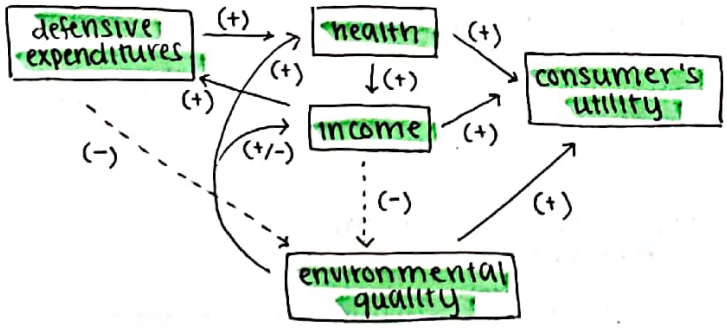




→ Places w/low environ quality should have high MWTP
↳ see opposite in developing countries
↳ VSL in Kenya v. US
→ $860 v. $8.6 mill

← typical graph

Greenstone: How environment impacts economic agents.



→ environment affects utility directly (aesthetic preferences, existence value) like income + health
→ environment affects U indirectly via health (i.e. clean air)
→ e affects U directly via tourism revenues or agricultural income
↳ positive: better yields
↳ negative: abatement cost (manuf)
→ e affects ↓ indirectly via health (productiv)
→ guard health via self-protective exp.
↳ consumption + self-protective exp impact the environ

Utility: $U(c, e; h(s, e))$

consumption, environment — direct effect
health (depends on self-protection exp. + e) — indirect

Constraints:

→ Budget: $Y = c + P_e \Delta e + P_s S$
- $P_e \Delta e$: direct purch. of environ. quality
- $P_s S$: self-protective expenditures

→ Effective income: $y = y_0 + \Delta y(e, h(s, e))$
- y_0: inital income
- Δy: incremental Δ in income due to environ + health

→ Environment: $e = e_0 + \Delta e + a(c, s)$
- e_0: inital quality
- $a(c, s)$: actions that impact the environment

Equilibrium: $\mathcal{L} = U(c, e; h(s, e)) + \lambda_y [y - c - P_e \Delta e - P_s S]$

λ_y: marginal utility of income

*y + e depend on other variables

FOC: $\frac{\partial \mathcal{L}}{\partial \Delta e} = 0 \Rightarrow \frac{\partial U}{\partial e} + \frac{\partial U}{\partial h} \cdot \frac{\partial h}{\partial e} = \lambda_y \left[P_e - \frac{\partial \Delta y}{\partial e} - \frac{\partial \Delta y}{\partial h} \cdot \frac{\partial h}{\partial e} \right]$

- $\frac{\partial U}{\partial e} + \frac{\partial U}{\partial h} \cdot \frac{\partial h}{\partial e}$: ΔU from marginal Δ in e
- $\lambda_y \left[P_e - \frac{\partial \Delta y}{\partial e} - \frac{\partial \Delta y}{\partial h} \cdot \frac{\partial h}{\partial e} \right]$: Δ in income from marginal Δ in e

Marginal WTP for Environment: $\frac{1}{\lambda y}\left[\frac{\partial u}{\partial e}+\frac{\partial u}{\partial h}\cdot\frac{\partial h}{\partial e}\right]+\frac{\partial \Delta y}{\partial e}+\frac{\partial \Delta y}{\partial h}\cdot\frac{\partial h}{\partial e}=p_e$

- when marginal U of income is ↑ then MWTPe is ↓
- aesthetic benefits + health benefits from better environ
- direct impact on income
- indirect impact on income via health
- but these impacts are big DC; hence why is the MWTP so low?

Why is MWTPe so low in developing countries?

1. **High marginal utility of consumption** *no market failure
   - → consumers tend to be poor (think of Depro et al)
   - → if U is concaved in income, ↑ MU of consumption + ↓ MWTPe
   - → if income ↑, then maybe MWTPe will as well
     - ↳ Jalan + Somanathan (2008): Indian households w/more assets spend more on water quality
     - ↳ Kremer (2011): Kenyan households w/more assets are more willing to walk to access clean water
     - ↳ Ashraf (2010) + Berry (2011): no correlation
   - → higher income may contribute to more degradation
     - ↳ Alix-Garcia (2013): conditional cash transfer program ↑ deforestation in Mexico (↑ beef consump)
2. **High marginal costs of improving environment**
   - → too expensive to clean up (assumption that politicians may care about people)
   - → weak enforcement + institutions
     - ↳ Greenstone + Hanna (2014): even w/strict laws, developing countries have difficulty enforcing
     - ↳ Besley + Persson (2013): difficult to collect taxes in " "
   - → badly designed policies: lack of expertise, ↓ accountability → poorly chosen policy obj. or misdirected reg.
     - ↳ Field, Glennerster, + Hussam (2011): info campaign of arsenic in Bangladesh leads to worse outcome via incr. consump. of polluted surface water
   - → unanticipated consequences
     - ↳ Davis (2008): driving reg. based on license plates in Mexico → ↑ second-hand cars
   - → Decentralized problem: pollution levels higher at boundaries w/other countries
   - → complementaries between infrastructure + policy
     - ↳ Ryan (2014): poor infras. can hurt consumers by limiting comp. (↑er cost of project suppliers)
3. **Political Economy + Rent-Seeking**
   - → Politicians + gov't may be corrupt + do not seek to max welfare = distort policies
     - ↳ Oliva (2010): 9.6% old car owners in Mexico bribe to circumvent reg.
     - ↳ Burgess (2012): natural resources viewed as source of rent; corrup. ↑ deforestation in Indonesia
     - ↳ Duflo (2013): own auditors in India = emission intensity ↑ but not reported
   - → Firms can respond to distorted policies in unexp. ways
     - ↳ McRae (2009): gov't subsidies for public service undermine incentive to impr. infra. in CO
     - ↳ Hseieh + Klenow (2009): political favors remove resources from efficient firms
4. **Market Failures**: public good + externality
   - → Trade-off between consump. + environ exp.
     - ↳ Free ride public goods: benefit if others contribute = ↓ social optimum
     - ↳ Defensive exp. (rich) v. improving environ. for everyone
   - → Trade-off between environ. policy + defensive exp.
     - ↳ rich people can defend themselves so will not ask politicians which harm the poor
   - → Observed MWTP may not be true (energy efficiency gap ex)
     - ↳ **Imperfect info**: people ignore impact of pollution on health + productivity
       - → Jalan + Somanthan (2008): provide info on quality of tap water to Delhi = Δ in exp. after treat.
       - → Ashraf (2013): Zambia urban consumer more price sensitive to water tech w/ info
       - → Benneat (2012): complicated info about well contam = suboptimal outcome
         - ↳ method of info delivery could matter
     - ↳ **Credit constraint**: missing capital markets may ↓ incentives for investment w/LR payoffs
       - → Gulteras (2014): positive relationship between WTP + credit availability for water
         - ↳ credit markets must work well!
       - → can prohibit investment in environ-damaging production + consump.
     - ↳ **Land/Property rights**: often insecure in developing countries = suboptimal invest.
       - → Ali (2011): secure land titling program = ↑ invest. in environ. quality
     - ↳ **Risk**
     - ↳ **Behavioral Implications**
       - → reference anchor: consistently exp. poor environ quality — hard to adjust
         - ↳ ex: automatic bill payments
         - ↳ Devoto (2012): admin barriers have large impact on take-up of connection to municipal water system

*Counter: MAC lower for developing countries

Application: Tropical Forests

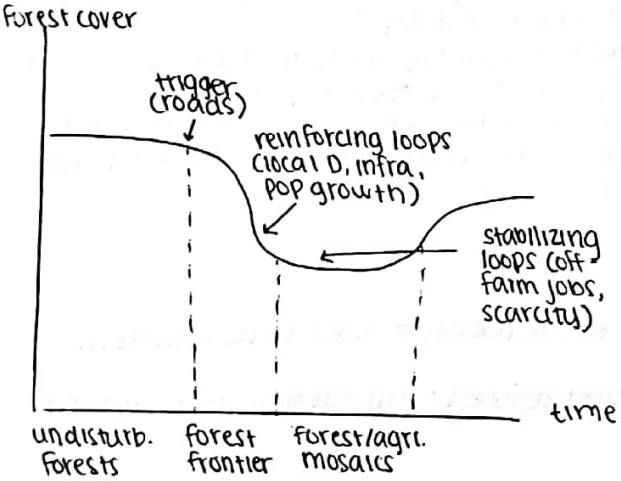
→ Why save tropical forests?
1. Preserve Biodiversity (~50% terrestrial species)
2. Preserve a stock of carbon
3. Reduce GHG emissions

→ Characteristics
1. 17% of GHG (emit CO_2 when burned)
2. Deforestation in developing + growth in developed
3. Relatively low cost of emission reduction
4. Concentrated in a few countries

→ multiple factors on why deforestation occurs (it is context dependent)
1. **Commercial Agriculture** (32%): commercial crops (20%) + cattle ranching (12%)
2. **Subsistence Activity** (48.5%)
   ↳ **shifting cultivation** (42.5%): deforest + burn biomass to provide nutrients to the soil, but this causes CO_2 emissions + is an inefficient use of land because the land is still poor (these farmers cannot afford fertilizers) so you end up w/ low yields
   ↳ fuel wood + non-timber forest products (6%)
3. **Wood extraction** (19.5%): commercial nonsustainable wood extraction (14%) + fuel wood + charcoal traded (5.5%)

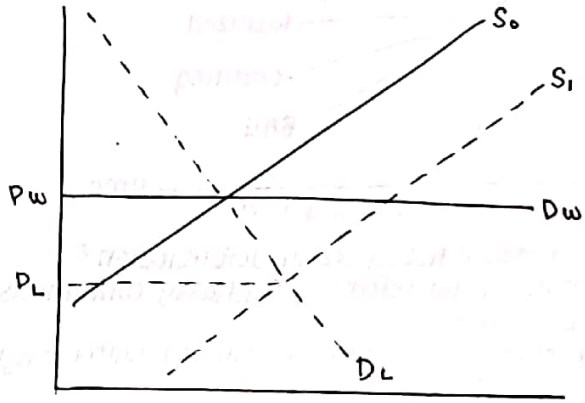
→ **Factors on Deforestation**
1. **Illegal logging + corruption** (Cambodia + China)
   ↳ many states + not private owners own land
   ↳ deforestation is a means to acquire property rights (badly secure = illegal activities)
2. **Industrial Agriculture Expansion**: deforestation is associated w/ growth
   ↳ consumers create demand → high prices → high incentives
   ↳ **Angelsen + Kaimovitz (1999)**: high correlation between ag. prices + deforest in open economies
   → Amazonia: soybean expansion
   → Indonesia + Malaysia: palm oil plantations
   > ↑ land prices = infrastr. = shift cattle ranching
3. **Cattle Ranching Expansion**
   ↳ inefficient use of land: 1 ha of newly deforested land is enough for one cow but after 6–8 years one cow will require 5 ha
   ↳ need: property rights, low maintenance cost, liquid assets

Forest Transition Theory (Angelsen, 2007)



→ Policy Q: If I stop deforestation, will it affect growth + development?

Comparative Advantage in Agr. Products



* world demand for food is perfectly elastic so an incr. in supply does not lower price

→ Policy Q: If I stop deforestation, will it affect your trade + competitiveness in the world?

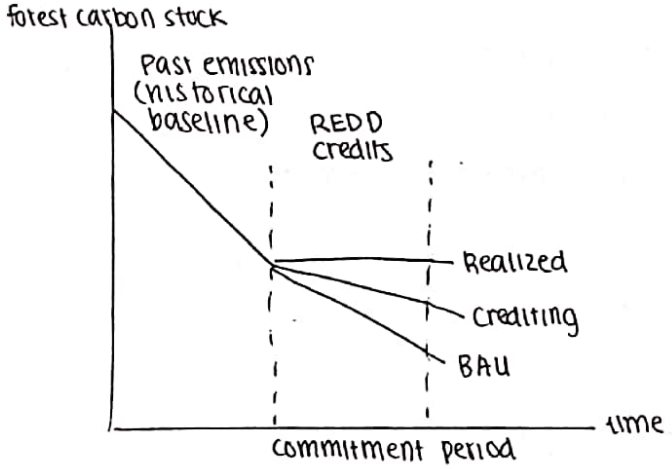
How can we reduce deforestation?
1. **Land rights reform**: deforestation is about acquiring property rights
2. **Fighting against corruption + improving institutions** so that property rights are more secure (diff)
3. **National parks**: may end of building more roads however
4. **Green labels** to promote good practices (logging)
5. **money transfers** from developed countries to developing
   → debt-for-nature swap
   → donations by companies + NGOs
   → PES or REDD

Payment for Environmental Services (PES): "voluntary transaction in which a well-defined ES or a form of land that secures that ES is bought if + only if the provider continues to provide/supply the service (conditionality)" — Wunder, 2005

→ **Coase solution**: payment is between max WTP (value of ES) + opp cost of providers (min WTA w/ operational + transaction costs)

→ Problems of PES
1. **Lack of additionality**: programs may only work in places where opportunity cost is low or when ES is under little threat (payment not useful, does not Δ actions, land is not useful, etc); Costa Rica
2. **Fairness**: payment may be fixed per ha but opp costs are heterogeneous
3. **Carbon leakage**: project-based approach instead of national approach
4. **Non-permanence**: if transfers stop, land can be used for other activities
5. **Responsibility**: what if a fire occurs? Illegal loggers?

Reduced Emissions from Deforestation + Degradation (REDD)
→ attempt to do better than PES; nationally based; attempt to include developing countries into the negotiations on climate change
→ Why is it hard to reduce deforestation?
↳ small responsibility of developing countries in GHG emissions
↳ developing countries should be better off participating in REDD programs
→ trade-off between development + preservation
↳ for donating countries: require cost efficiency, no leakage, no additionality, + permanence
↳ Appeal of low opp. cost: cost of an activity depends on NPV of best alt. activity
→ **REDD transfers**: pay stock of carbon or deforestation
↳ Payment per ha can be determined by Q of carbon contained in biomass × value of carbon
→ Compare observed rates w/ counterfactual (baseline)
→ Ensure there was actual effort (additionality): compensate reduction of deforestation?
→ **Baseline**: what would have happened if there was no effort

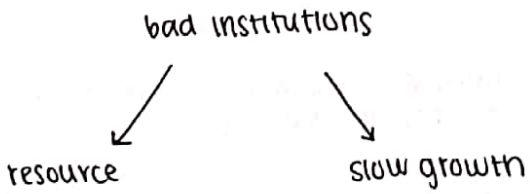


↳ **Historical baseline**: average of past deforestation rates; good for countries that had deforested in the past
↳ **Business-as-usual scenario (BAU)**: predict deforestation rates on agri. growth + productivity (but agri prices are volatile + lack robust data)
↳ **Crediting baseline**: make an agreement on a baseline that is above BAU + take into account some external factors that could reduce deforestation w/o any effort from the country

How can gov't ensure reductions in deforestation?
1. **Property rights**: land reform is politically contentious. most forests belong to states w/no enforcement; open access issues
2. **Corruption + weak institutions**: costly to monitor + fight against deforestation, satellite info on land uses, "fragile states"
3. **Conflicts over land rights**:

Does gov't represent will of the people? Is REDD in everyone's best interest?
→ why deforestation occurs (context dependent)
→ long history of failures in policies aiming at reducing deforestation
→ deforestation often creates new economic opportunities which may affect people's preferences
→ social norms may also Δ: some people (trad. leaders) may benefit more than others w/logging act.

Resource Curse Hypothesis: when the economy is highly dependent on nat resources, its growth is slower (Sachs + Warner 1995)
→ causal relationship



→ latest view: Bad institutions generate curse because corruption + rent seeking from the elite do not allow the economy to invest profits into productive sectors (Brunnschweiler + Bulte 2008) = determine growth + resource
→ **Barbier (2005)**: empirically, we can explain agri. expansion + deforestation from high corruption levels, lobbying, + high share of nat. product into exports

For individuals, is deforestation a good way to get rich?
→ Mullan (2012): poorer land = more forest (impact of colonization in Brazil)
↳ reverse causality: more assets the settlers owned before, the more they invested

Win-win situation
→ Developed countries: less deforestation implies less GHG + less biodiversity loss
→ Developing countries: foster growth that is not land dependent, offer new economic opportunities

Does it rely on developing countries?
→ How are transfers redistributed from REDD?
↳ w/corruption, they will go to the wrong places
→ Do we know which policy is effective at reducing deforestation?