

Deforestation and Conservation

MIT Lecture Notes — Day 6

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Outline

- 1 Deforestation: Drivers and solutions
- 2 Models of deforestation
- 3 Models of conservation (contracts)
- 4 Dynamics of conservation
- 5 Open research questions

Conservation: Tropical Forests

- Deforestation in the tropics has contributed to 30% of man-made CO₂ emissions, and it contributes to 10-20% of annual greenhouse gas emissions.
- Only in 2000-2012, tropical rainforest in South America was reduced by 4.2%, in Asia by 12.5%, and in Africa by 2.8%.
- Negative externalities \$2-4.5 trillion a year (the Economist, 2010)
- Deforestation could be halved at a cost of \$21–35 billion per year.

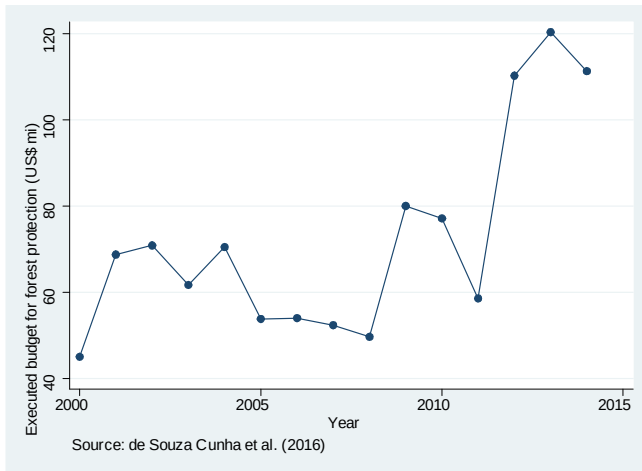
Deforestation: Causes

- Causes of deforestation: Profit, illegal logging, weak property rights, costly monitoring (Alston and Andersson, 2011; Angelsen, 2010; Damette and Delacote, 2012)
- "Deforestation in Indonesia is largely driven by the expansion of **profitable and legally sanctioned** oil palm and timber plantations and logging operations" (Burgess et al, 2013)
- Each percentage point of palm-driven **poverty reduction** corresponds to a 1.5–3 percentage point loss of forest area in Indonesia (Edwards '18).
- In **Himalaya**: "**the Forest Department was poorly staffed and thus unable** to implement and enforce the national policies" (Shyamsundar and Ghate, 2014)

Illegal Deforestation

Country\Year	Forest Cover 2000 (1000 ha)	Deforestation 2000-2010	Illegal logging in 2013
Brazil	545943	5%	> 50%
Cameroon	22116	10%	65%
Ghana	6094	19%	70%
Indonesia	99409	5%	60%
Laos	16433	6%	80%
Malaysia	21591	5%	35%
Papua New Guinea	30133	5%	70%
Rep. Congo	22556	1%	70%

Enforcement Expenditures



Deforestation: Solutions

- Before 2005: rapid deforestation in the Brazilian Amazon was a consequence of lax enforcement of laws prior to the mid-2000s.
- Then, with stronger legal fees, deforestation fell (Burgess, Costa, Olken '18)
- Deforestation observed from 2007 through 2011 was 75% smaller than it would have been in the absence of fines (Assuncao et al. '13)
- Payments for Ecosystem Services (PES) necessary to internalize externalities
- Uganda: Benefit is 2.4 times as large as the program costs (Jayachandran et al., '17)

Conservation Contracts

- **Contracts Exists:** The United Nations, the World Bank, and the Norwegian government are offering financial incentives to countries successful in reducing deforestation.
- Contracts are signed with a set of individual countries: Brazil, Indonesia, Guyana, Ethiopia, Vietnam, Mexico, Tanzania, Congo.
- **Simple contracts:** Rate is uniform and constant: 5 USD/ton avoided CO₂, for every unit of deforestation less than some (negotiated) benchmark
- **No districts** (within countries) are offered such contracts
- **Limited success** so far / Too early to judge

Conservation Contracts: General Motivation

- Many environmental problems are linked to resource extraction
- Traditional environmental policy regulates (end-of-pipe) emission
- Regulating supply can be a better alternative
- Even for a climate coalition, the possibly most efficient policy is to target the fossil fuel deposits in nonparticipating countries.
- **But what is the best conservation contract?**

Models of Conservation

- Let x_i be deforestation level in district $i \in N \equiv \{1, \dots, n\}$.
- Demand is $p = \bar{p} - a \sum_i x_i$.

- ① In a **sales-driven** model, profit is:

$$u_i = px_i.$$

- ② In an **illegal** logging model, enforcement is preventive at unit j if there is a large expected penalty:

$$\theta_j \geq p.$$

- With stock X_i , protection cost c , marginal opportunity value v_i :

$$u_i = -c \sum_{j \in i} \theta_j - \sum_{j \in i} (v_j \mid \theta_j < p) = -cp(X_i - x_i) - v_i x_i.$$

- ③ By **combining** the two models, we get:

$$u_i = bpx_i - cp(X_i - x_i) - v_i x_i.$$

Alternative Interpretations

Forests	Coal
Weak property rights c large	Strong property rights b large

- While c may be high for forests, c is small for fossil fuels
- All extraction could be illegal, and b could be the *probability* that i captures the cutter('s revenue) in the region that is not highly protected.
- Parameter b could be the government's *weight* on the utility/profit of the extractor (whether legal or illegal)

The Market Equilibrium

- District i cuts more if
 - large stock X_i or small value v_i ,
 - price likely to be high, i.e. if neighbors are likely to cut less,
 - small stock X_j or large value v_j , $j \neq i$:

$$x_i = \frac{cX_i}{b+c} + \frac{(b+c)\bar{p} - acX - v_i(n+1) + nv}{a(b+c)(n+1)}.$$

- Total extraction increases if
 - large total stock $X \equiv \sum_i X_i$ or small $v \equiv \sum_i v_i/n$

$$\begin{aligned}x &= \frac{n}{n+1} \left(\frac{\bar{p}}{a} - \frac{v}{b+c} \right) + \frac{cX}{(b+c)(n+1)}, \\p &= \frac{\bar{p}}{n+1} - \frac{acX - anv}{(b+c)(n+1)},\end{aligned}$$

Externalities are Key

Proposition

- If j conserves, i benefits IFF property rights are **strong** (large b/c):

$$\frac{\partial u_i}{\partial (-x_j)} = \frac{e_i}{n+1} \equiv \frac{(b+c)\bar{p} - acX - v_i(n+1) + nv}{n+1}$$

- Large districts conserve relatively more IFF $e > 0$:

$$\frac{x_i}{X_i} - \frac{x_j}{X_j} = \left(\frac{e_i}{X_i} - \frac{e_j}{X_j} \right) \frac{1}{a(b+c)}$$

- Centralization leads to more conservation IFF $e_i > 0$.

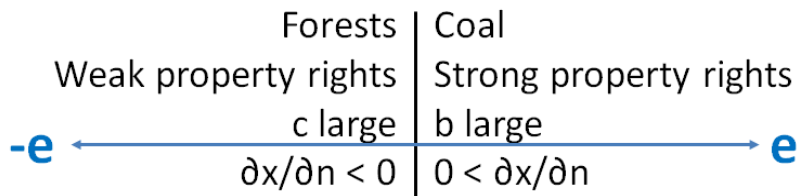
Corollary

- **Decentralization** *increases extraction IFF districts are strong* :

$$\text{sign} \frac{\partial x}{\partial n} = \text{sign } e, \text{ where } e \equiv \sum_i e_i / n$$

- **Decentralizing** power contributed to deforestation in Indonesia (Burgess et al, 2013)
- **The opposite** happened in Himalaya (Somanathan et al, 2008; Baland et al, 2010)

(De)Centralization: Takeaways



Contracts under Centralization

- Consider a "donor" D who has payoff $u_D = -dx$ (minus transfers).
- Suppose D selects t_C and $\bar{x}_C$, and offers $t_C \cdot \max\{0, \bar{x}_C - x\}$ to C, in order to maximize

$$u_D = -dx - t_C \cdot \max\{0, \bar{x}_C - x\}.$$

- Since C's problem is nonconcave, we must ensure that $u_C(t_C) \geq u_C(0)$. This requires

$$u_C^0(x) + t_C \cdot (\bar{x}_C - x) \geq u_C^0(\hat{x}) \quad \forall \hat{x} > \bar{x}_C. \quad (\text{IC})$$

- Given this constraint, the solution to D's problem is

$$t_C = d, \bar{x}_C = \frac{e + 2qX}{2a(b+c)} - \frac{d}{4a(b+c)}.$$

- This (Pigou) subsidy implements the **first best**.

Contracts under Decentralization

- Suppose D offers $t_i \cdot \max \{0, \bar{x}_i - x_i\}$ to $m \in \{1, \dots, n\}$ independent districts.
- D's problem is to select the $\bar{x}_i$'s and $\mathbf{t} = (t_1, \dots, t_m)$ to maximize:

$$u_D = -dx(\mathbf{t}) - \sum_{i \in \{1, \dots, m\}} t_i \cdot \max \{0, \bar{x}_i - x_i(\mathbf{t})\}$$

- ...subject to the constraint that $x_i(\mathbf{t})$ is a best reply for every i :

$$u_i^0(\mathbf{x}(\mathbf{t})) + t_i \cdot (\bar{x}_i - x_i) \geq u_i^0(\hat{x}_i, x_{-i}(\mathbf{t})) \quad \forall \hat{x}_i > \bar{x}_i. \quad (\text{IC}_i)$$

- **Leakage:** Conservation in one district makes $n - 1$ other districts want to extract more.

Contracts: Equilibrium

Proposition

- The *equilibrium* contract is:

$$t = \frac{2}{n+1}d \text{ and } \bar{x}_i = x_i(\mathbf{0}) - \frac{3(n+1) - 4m}{4a(b+c)(n+1)}t$$

- Decentralization $\Rightarrow$ more extraction IFF property rights strong:

$$\frac{e}{d} > -2 \left(\frac{m-l+1}{n-l+2} + \frac{m}{n+1} - 1 \right)$$

- D prefers centralization IFF property rights are strong:

$$\frac{e}{d} > - \left(\frac{m-l+1}{n-l+2} + \frac{m}{n+1} - 1 \right).$$

- If $m = n = 2$, conditions are $e/d > -1/3$ and $e/d > -1/6$.

Contracts: Example with two districts

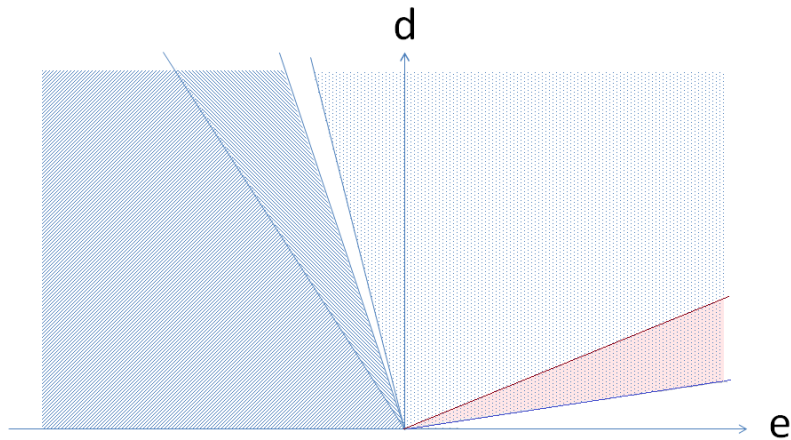
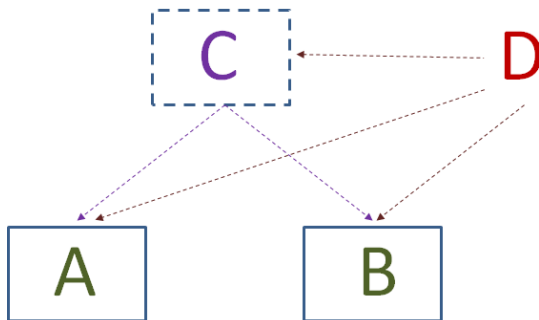


Figure: If $m = n = 2$, centralization is first best, but D prefers decentralization to the left, while C prefers decentralization to the right. In the red area, D's presence reduce conservation.

Contracts: Example with two districts



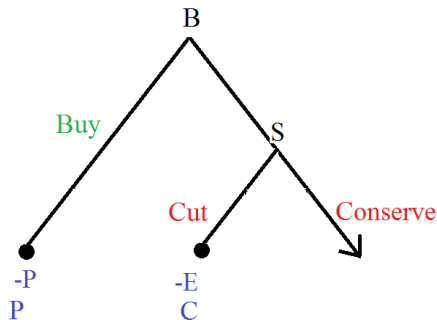
Contracts: Takeaways

Forests	Coal
Weak property rights	Strong property rights
c large	b large
$\frac{\partial x}{\partial n} < 0$	$0 < \frac{\partial x}{\partial n}$
$x < x^{FB}$	$x^{FB} < x$
D prefers decentr.	D prefers centr.
C prefers centr.	C prefers decentr.

Dynamics: With Commitments

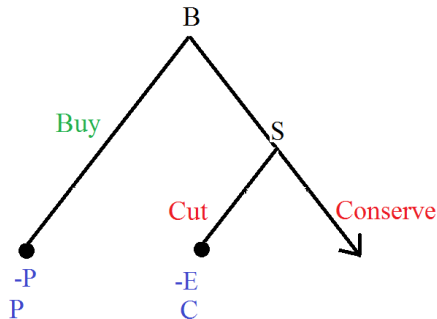
- Anticipating future contracts...
- ① If $e < 0$, extract to avoid high protection cost
 - Similar to "green paradox" (for different reasons)
 - D can take advantage of this by committing to weak contracts
 - Long-term contracts are weaker than short-term contracts
- ② If $e > 0$, conserve today to take advantage of high p
 - Opposite of "green paradox"
 - D can take advantage of this by committing to aggressive contracts
 - Long-term contracts are stronger than short-term contracts

Dynamics: Without Commitments



- Suppose the Buyer's value is $E > C$, which is the value to the Seller.
- Equilibrium in static game: "pay" ($b = c = 1$) for any $P \in (C, E)$.
- With bargaining, $P = (1 - \alpha)C + \alpha E$ for some $\alpha \in [0, 1]$.

Dynamics: Without Commitments



- For a "conservation good", S receives E also if S conserves.
- S conserves indeed, if B is expected to buy (next period).
- If S conserves, B does not need to buy.

Dynamics: The Equilibrium

If B pays with probability b , S is willing to conserve if and only if:

$$\begin{aligned} C &\leq \delta bP + \delta(1-b)C \Rightarrow \\ b &\geq \frac{C}{P-C} \left(\frac{1-\delta}{\delta} \right) \in (0,1). \end{aligned}$$

If S cuts with probability c , B is willing to pay if and only if:

$$\begin{aligned} P &\leq cE + (1-c)\delta P \Rightarrow \\ c &\leq \frac{(1-\delta)P}{E-\delta P} \in (0,1). \end{aligned}$$

Proposition

- If $P \in (C/\delta, E)$, there is a unique equilibrium:

$$b = \frac{C}{P - C} \left(\frac{1 - \delta}{\delta} \right) \in (0, 1)$$

$$c = \frac{(1 - \delta) P}{E - \delta P} \in (0, 1)$$

Dynamics: Takeaways

- There is no (good) equilibrium in pure strategies
 - If B does buy, S conserves. But if S conserves, B does *not* buy
 - This contradiction implies **cutting in equilibrium**
- The Rental market is similar
 - or *worse* if conservation value large, commercial value low, enforcement cheap
 - I.e., buy local conservation, **rent in other countries**
- With multiple buyers/sellers, the main results survive but:
 - cutting may increase
- For PES/REDD to work, it is necessary to make future payments credible.

Open Questions

- ❶ How can we measure and account for the leakage across space and time?
- ❷ How can conservation efforts (PES/REDD) be combined with development (aid)?
- ❸ What are the effects of **political economy** forces, interest groups, lobbying, elections...?
 - and how should these effects be taken into account when designing PES/REDD?
- ❹ How should conservation be credited in **climate agreements**?
 - Unresolved at the climate meeting last December
- ❺ How can conservation agreements be used also for other climate policies (conservation agreements on **coal, oil, Arctic oil**, etc...)?
- ❻ Conservation is an old-fashioned **technology**. How should it interact and be combined with other technology developments?