Emission prices, biomass and biodiversity in tropical forests

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Plan

- Review results in Assunção et al. [2023a] on emission prices and biomass.
- Apply scientific literature on biodiversity on rain-forests to produce initial estimates of:
  - Impact of emission prices on future biodiversity losses.
  - Impact of past deforestation on biomass loss that was intermediated by biodiversity loss.

Motivation

- Amazon forest contains 123 ± 31 billion tons of captured carbon that can be released in atmosphere, $\sim$ historical cumulative emissions of the United States (Malhi et al. [2006], Friedlingstein et al. [2022])
- Brazilian Amazon $= 60\%$. Area size of Texas deforested.
- 85% of deforested and not abandoned land dedicated to low productivity beef cattle.
- Destruction of forest has not helped alleviate poverty in Brazil.
  - Income of agricultural workers in Amazon only 83% of Brazilian already low minimum wage. 85% informal.
- Low and declining productivity has led to 20% abandonment of deforested land, now experiencing large-scale natural reforestation.
- Highlights opportunity for (passive) reforestation.

Model I

- Since "in the long run we are all dead (fried)", need model of dynamic accumulation of biomass.
- Need measurements of carbon capturing capacity and cattle productivity to compute optimal reforestation/deforestation of the biome.
- Use rich data set on Brazilian Amazon.
  - Every parameter except discount rate and transfers from abroad is calibrated from data.
- Data reveals large cross-sectional heterogeneity.
  - Divide biome into 1043 sites (approximately 67km x 67km.)
- Absence of alternative possible productivities for land-usage, rely on models for extrapolation and interpolation.
- Need to account for "parameter uncertainty"
  - Use policy goals to assess where parameter uncertainty matters.

Model II

- For sites $i = 1, \ldots, I$, state variables X_t^i, amount of CO_2 captured in i and Z_t^i, amount of land in cattle ranching, and parameters $\bar{z}^i$ sum of forest + agricultural area, θ^i, cattle productivity and γ^i, max. carbon/ha of forest. Write φ for $(\theta^1, \gamma^1, \cdots, \theta^I, \gamma^I)$.
- Planner controls $\dot{Z}_t^i$, and

$$\dot{X}_t^i = -\gamma^i (\dot{Z}_t^i \vee 0) - \alpha \left[X_t^i - \gamma^i \left(\bar{z}^i - Z_t^i \right) \right], \tag{1}$$

- For fixed φ objective is:

$$\begin{aligned} f(d, \gamma) = \mathbb{E} \Bigg\{ \int_0^\infty e^{-\delta t} \Bigg[- P^e \left(\kappa \sum_{i=1}^I Z_t^i - \sum_{i=1}^I \dot{X}_t^i \right) \\ + P_t^a \sum_{i=1}^I \theta^i Z_t^i - [\frac{\zeta_1}{2} \left(\sum_{i=1}^I \dot{Z}_t^i \vee 0 \right)^2 + \frac{\zeta_2}{2} \left(\sum_{i=1}^I \dot{Z}_t^i \wedge 0 \right)^2] \Bigg] dt \Bigg\} \end{aligned} \tag{2}$$

subject to (1) and $0 \leq Z^i \leq \bar{z}^i$, the total area of site i.

Model III

- P^e is an exogenous price for emissions, that includes planner own valuation and transfers, κ measures CO_2 impact of cattle raising, P_t^a cattle price at t (finite-state Markov) and, ζ_j represents marginal cost of land conversion.
- d trajectory of decisions $\dot{Z}_t$, $t \in [0, \infty)$, conditional on P_t^a.
- Planner is paid for net CO_2 capture - simple preservation is not rewarded.
- Planner faces ambiguity in parameter vector φ.
- We use data and conveniently chosen prior and likelihood distributions to construct a baseline distribution π
- Planner's criteria is:

$$\max_d \min_g \int [f(d, \varphi) + \xi \log g(\varphi)] \, g(\varphi) d\pi(\varphi) \tag{3}$$

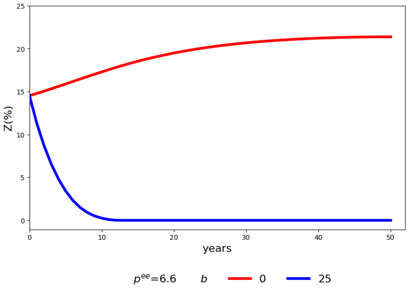
subject to $\int g(\varphi) d\pi(\varphi) = 1$.

- $\xi = \infty$ corresponds to no ambiguity-aversion.

Results: Brazilian's own valuation

- Most deforestation in Amazon has been either result of government incentives or illegal but tolerated.
- Past experience shows government is able to substantially control deforestation at low cost (Assunção et al. [2023b]).
- Current state more likely to reflect valuation of forest and alternative uses by governments than by decentralized occupiers of land.
- Using model, obtain emission price that explains current deforestation.
- P^{ee} is model dependent - If no ambiguity aversion $P^{ee} = \$6.6$, if $\xi = 5$, $P^{ee} = \$4.5$.
  - Results from more uncertainty on cattle productivity than on carbon loss.
- Add $\$b$ of transfers to P^{ee}; $b = 0$ is business-as-usual.
- P^{ee} variation makes future trajectory less dependent on model.

Land-use trajectories (no ambiguity-aversion)



- Here and Tables 1-4, use $P_t^a \equiv \bar{P}^a$, average under stationary distribution.
- Under business-as-usual biome loss exceeds 21%. Could yield "unexpected eco-system transitions".(Flores et al. [2024]).
- Deforestation lowers water recycling, affecting moisture down-wind creating cascading effects that doubles impact of initial damage (Araujo et al. [2023]).
- With transfers of $25, massive reforestation in 15 years.

Present value decomposition (200 years)

Table 1: Present-value decomposition in 200 years

ξ	b (\$)	agricultural output value (\$ 10^9)	net transfers (\$ 10^9)	forest services (\$ 10^9)	land conversion costs (\$ 10^9)	planner value (\$ 10^9)
∞	0	364	0	-114	6	244
∞	25	15	422	111	22	526
5	0	279	0	-92	5	182
5	25	17	386	69	19	453

- In no ambiguity aversion under $b = 0$, 16 Gt of *emissions* in next 30 years. If $b = 25$ 18 GT of *capture*.
- *Effective* cost:
    - If no ambiguity-aversion, total 30 year change in emissions fr is 34 Gt; 2/3 in first 15 years.
    - Brazil paid for net capture; effective cost/ton $\sim$\$10 in next 30y.
    - If planner is ambiguity averse, 30 year difference in capture across trajectories increases; effective costs a bit lower.

Biodiversity

- No single way to measure: species count, Hill indices (account for rarity vs. abundance), functional; diversity, genetic diversity...
- No agreed scientific model that accounts for impact of bio-diversity on economic performance.
    - pricing
- Difficulty in measurement.
- Aggregation (overlap)
- Plan:
    1. Impact of prices on mean species-count per ha.
    2. Impact on implied losses of species-count for each of our 1043 sites.
    3. Multiplier effect on biomass mediated by biodiversity loss.
    4. Modeling optimal choice of biodiversity preservation.
        - In tropical forest protecting biodiversity requires protecting territory.

Emission prices and change in biodiversity/ha. in 30 years

- Estimate by Ter Steege et al. [2023] of **potential** biodiversity/ha in Amazon.
- Dynamics of biodiversity following reforestation uses estimate from Rozendaal et al. [2019] that with natural reforestation species count is 90% of potential after 32 years.

Table 2: Percentage change biodiversity per ha (1043 plots)

	mean	std	min	20%	50%	80%	max
$b = 0$	-13.65	44.21	-100.00	-0.00	0.06	2.52	290.07
$b = 25$	31.07	64.97	-0.00	0.06	1.83	46.48	515.31

- Substantial means-difference but left-skewed when $b = 0$ and right-skewed when $b = 25$.

Emission prices and change in total biodiversity in 30 years

- Biodiversity/ha cannot be scaled up to total biodiversity of plot.
  - Overlap
- Use instead the species-count area relationship, Arrhenius [1921],

$$S = cA^a, \tag{4}$$

$a = .25$ commonly used for tropical forests.

Table 3: Percentage change biodiversity (1043 plots)

	mean	std	min	20%	50%	80%	max
$b = 0$	-17.00	39.31	-100.00	0.00	0.02	0.73	45.06
$b = 25$	6.32	11.18	0.00	0.02	0.52	11.61	62.74

- Substantial mean differences but again very skewed.

Impact of biodiversity changes on biomass. I

- Weiskopf et al. [2024] estimates a relationship $p_{bm} = p_{bd}^{d}$ between percent number-of-species loss and percent biomass loss, with point estimate of .26, and a 95% CI of 0.16–0.37.
  - More species with different (functional) traits may lead to more efficient resource use.
- Biomass loss is additional to any direct biomass loss from *e.g.*, land-use change, impacts remaining biomass.
- Use estimates of maximum biomass of each our 1043 plot, dynamics of biodiversity in restored areas, and point estimate of d.

Impact of biodiversity changes on biomass. II

Table 4: % change in site biomass mediated by biodiversity (1985-2017)

	mean	min	20%	50%	80%	max
%Δ in diversity	-3.9	-31.0	-8.6	-0.2	0.0	10.1
%Δ in mass	-12.6	-77.3	-30.1	-0.9	0.0	47.0
Extra %Δ in mass	-0.5	-2.3	-1.3	-0.06	0.0	2.3

- Plots may have trivial additional loss because original loss is trivial or close to 100%.
- Aggregate additional loss induced by biodiversity = .8 Gt.
    - 15% of current annual US emissions.

Preserving biodiversity I

- Territories T_1, T_2.
- Cost of protecting a fraction λ of any territory is λ
- Budget B.
- S_C species in common and T_i has S_i ($S_2 \leq S_1$) idiosyncratic species.
- Assume equation 4 holds for each territory, and proportion of common and idiosyncratic species saved equals initial proportion.
- Optimum solves

$$\max_{\lambda}[\max\{C\lambda^a, C(B-\lambda)^a\} + S_1\lambda^a + S_2(B-\lambda)^a] \tag{5}$$

  subject to $0 \leq \lambda \leq 1$ and $0 \leq B - \lambda \leq 1$.
- Slope of species-area at origin, implies that for any B, $B - \lambda > 0$
- This positivity result generalizes to n territories.

Preserving biodiversity II

- If assume, in analogy to Weitzman [1998], constant cost per probability point of saving territory, then optima first apply full budget to territory 1.
- If interested in long-run $S_{(\cdot)}$ should be potential biodiversity.
- Flores et al. [2024] predict that by 2050, human activity and global warming would cause heterogeneous changes in state across forest.
- Some causes are human activity, but others - *e.g.,* changes in dry season mean temperature, frequency of extreme drought events - are consequence of global warming (see Figure 1 of Flores et al. [2024]).
- Potential biodiversity of sites affected by climate change.
- Regions that have lost more biodiversity overlap with regions that may move to less favorable states.
- If budgets are tight may choose to preserve less "critical" regions that have been more impacted by biodiversity loss.

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