Uncertainty, Climate Change, and Policy Challenges
MFR & BHC

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Costs and benefits of reforestation in the Amazon
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Motivation

- The Amazon forest contains 123 ± 31 billion tons of captured carbon that can be released into the atmosphere, equivalent to the historical cumulative emissions of the United States (Malhi et al. [2006], Friedlingstein et al. [2022])
- Brazilian Amazon occupies 60% of the 2.7 million square miles that comprise the Amazon.
- An area the size of Texas has been deforested in the Brazilian Amazon.
  - 85% of land not yet abandoned used for cattle ranching.
- Portions of Amazon have become a source instead of sink for carbon.
- Destruction of forest has not help alleviate to poverty in Brazil
  - Income of agricultural workers in legal Amazon was 829 reais/month in 2019, only 83% of Brazilian minimum wage
  - 85% informal

Carbon capture potential of reforestation in tropical forests I

- Assunção et al. [2023] studies the problem of a **fictitious social planner** to provide a benchmark for *ad hoc* policy alternatives.
- Uses a rich data set on the Brazilian Amazon
- Data document large cross-sectional variability in cattle farming productivity and in the potential absorption of carbon in the Brazilian Amazon.
- To account for this variability, the dynamic model considers a detailed division of the Brazilian Amazon into various sites.
  - Planner considers trade-off between obtaining income from cattle ranching or preservation and reforesting.
  - Planer rewarded a price P^e for each ton of **net** CO_2 captured.
    - No payment simply for preservation.
  - P^e sum of planner own ("shadow price") plus transfers of \$$b$ per ton.

Carbon capture potential of reforestation in tropical forests II

  - Model accounts for dynamics of carbon accumulation
- Assunção et al. [2023] consider impact on land allocation of different values of b.
- Uses numerical methods to achieve a necessary degree of economic and environmental richness to achieve credible results.
- Estimates of crucial productivity parameters subject to non-trivial uncertainty. Paper treats parameter ambiguity from the perspective of the planner (deep uncertainty).

Agriculture area vs. carbon stock in 2017

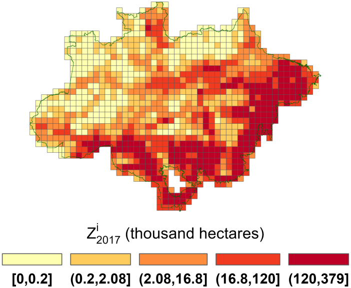


Figure: Agricultural area

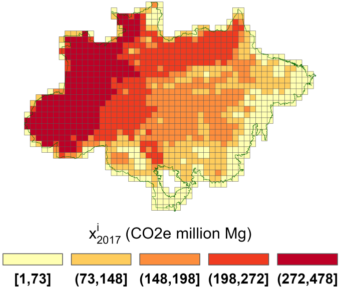


Figure: Carbon stock

Carbon sequestration capacity vs. ranching productivity

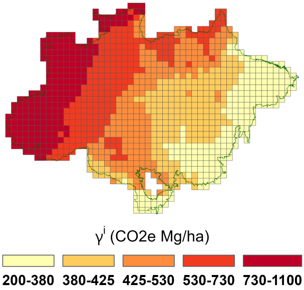


Figure: Carbon sequestration capacity

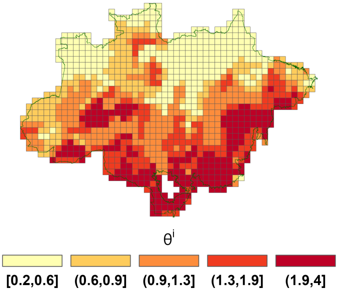


Figure: Cattle-ranching productivity

Deriving Brazilians' valuation

- Use model to elicit estimate of "shadow price" of CO_2 emissions revealed by actual deforestation in Brazilian Amazon in 1995-2008.
- Shadow price includes valuation of "forest services" provided by preserved areas
- Shadow price depends on particular version of model but coalesce around $7.
- Models that favor relatively more deforestation would generate a higher shadow price.
- Makes simulations of future optimal trajectories for a fixed transfer level b closer across models.

Evolution of agricultural area and carbon stocks

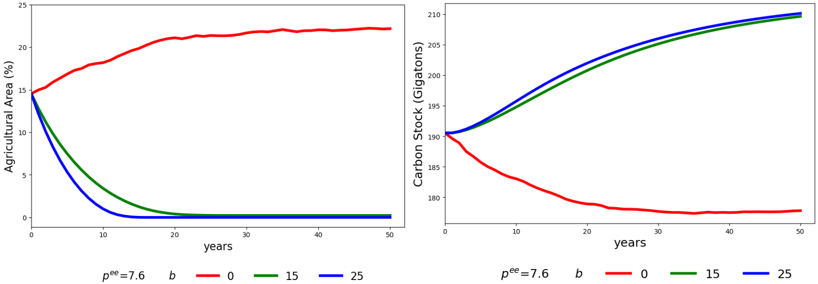


Figure: Agricultural area and carbon stock evolution.

- Business as usual ($b = 0$) increases agricultural area to more than 25%, sufficient for possible tipping of Amazon (Lovejoy and Nobre [2018])
- Predicted trajectories much different for $b = 15, 25$.

Present Value Decomposition (200 years)

b ($)	Agricultural Output Value ($ 10^{11})	Net Transfers ($ 10^{11})	Forest Services ($ 10^{11})	Adjustment Costs ($ 10^{11})	Planner Value ($ 10^{11})
0	3.73	0.00	-1.39	0.08	2.26
10	0.58	1.17	0.89	0.12	2.52
15	0.33	1.98	1.00	0.18	3.14
20	0.24	2.76	1.05	0.23	3.82
25	0.19	3.53	1.07	0.27	4.52

- $10 per ton is enough to compensate losses of agricultural output, but largest contributor to the gains is the increase in value of forest services.
- $25 per ton doubles the value for the planner - a net gain of $226 billion.

Gains from trade

- Although no reward for emissions that would have occurred without transfers, the effective impact involves these potential emissions.

Table: Transfer costs (30 years)

b (\$)	Net captured emissions (billion tons of CO2e)	Discounted net transfers (\$ 10^{11})	Discounted effective cost (\$ per ton of CO2e)
0	-17.66	0.00	NaN
10	11.67	0.86	2.93
15	13.85	1.55	4.92
20	14.62	2.21	6.85
25	15.00	2.86	8.75

- Economic efficiency requires capturing carbon at lowest possible cost.
- IRA US45Q tax credit of \$60/ton for EOR carbon capture

Agricultural area change after 30 years

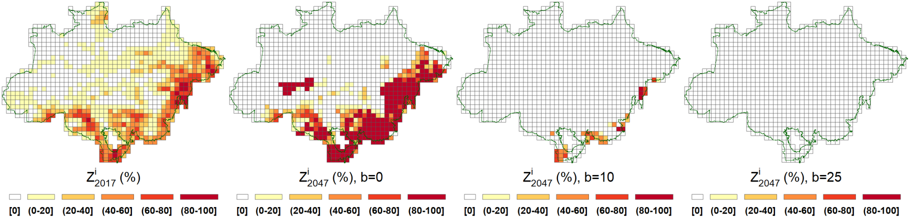


Figure: Agricultural area change after 30 years.

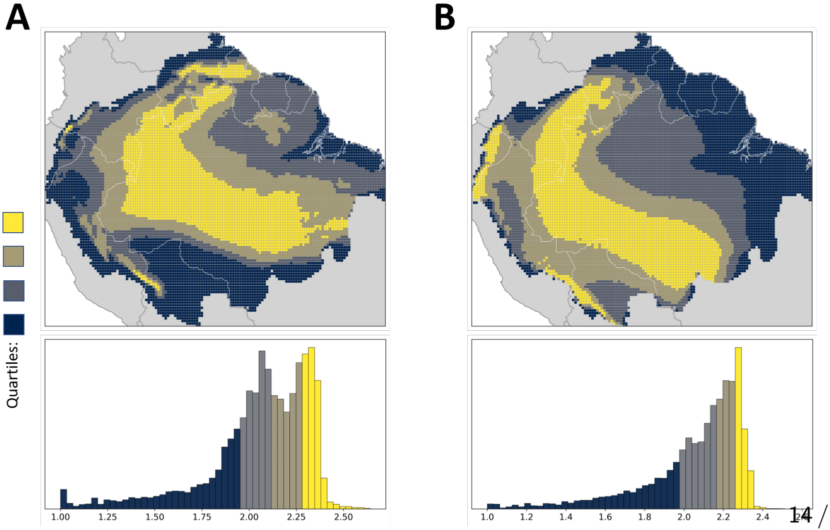
Incentives to defect

- Since mature forests reach an equilibrium, for large t, Brazil would have an incentive to abandon agreement and follow trajectory for $b = 0$
- For $t \leq 50$, and $b = 25$, maximum present value for defecting is $M =$\$5 billion. If $b = 30$, $M =$\$1.5 billion.
- Carrot: Donors deposit M in a bond payable in 50 years if no substantial deviation in planned reforestation area.
  - Cost of less than 33 cents/ ton.
- Brazil issues a bond with time zero value of M payable at t if substantial deviation in planned reforestation area is observed.

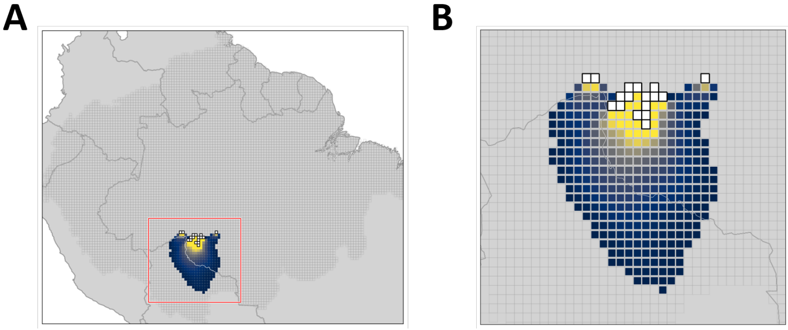
Interactions across sites

- Araujo et al. [2023].
- Amazon produces large fraction of its own rainfall
- Rainfall → trees' **transpiration** → recharges atmospheric humidity → humidity moves downwind → rainfall.
- Less trees → less water. Deforestation → degradation.
- Mapping transport of water: atmospheric trajectories at 800hPa ($\sim$ 6000 feet) from Copernicus [2017].
- Use variations in back trajectories to estimate impact of upwind Leaf Area Index (LAI) on downwind LAI.
  - LAI: Area of leaves relative to ground area.
  - Avoids attributing to interactions, human intervention in several areas simultaneously.
  - Cascading effect
- On average, deforestation has a "multiplier" of 2.05 but heterogeneous across areas.
- Additional cost (benefit) of deforestation (reforestation).

Multiplier Effect: **A: total effect of pixels; B: total effect on pixels.**



Transboundary Cascading Effects.



- Rondônia: one of the most active frontiers of deforestation
- 17 pixels (25km x 25km) in Rondônia, which are among the highest 50% deforested pixels in the biome.
- Deforestation causes degradation as far as Bolivia
- Deforestation multiplier of 1.87.

Conclusions

- Posed explicit dynamic model across heterogeneous regions in Amazon to assess potential adverse impact of deforestation.
- Rich panel data set
- Computational challenge: heterogeneity of subregions requires large number of state variables and state-constraints that bind at optimum.
  - Parameter uncertainty
- With modest prices for CO2e, Brazilian Amazon would produce noticeable CO_2 capture.
  - Compare to Griscom et al. [2017] that identify and quantify "natural climate solutions" (NCS).
  - Compare with US IRA price of $60 ton for CCS capture for enhanced oil recovery.
- Interactions across sites make predicted path under "business as usual" even more perilous.
- We did not account for losses in biodiversity in "business as usual".

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