Carbon prices and forest preservation over time and space in the Brazilian Amazon

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BIS annual meetings 2024
June 2024

Based on work with Juliano Assunção (Climate Policy Initiative and PUC-Rio), Lars P. Hansen (University of Chicago), and Todd Munson (Argonne National Laboratories)

Motivation I

- 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.
- Area the size of Texas has been deforested in Brazilian Amazon.
- Portions of Amazon have become a source for carbon.
- 85% of deforested and not yet abandoned land dedicated to low productivity beef cattle.
- Destruction of forest has not helped alleviate poverty in Brazil
  - Income of agricultural workers in legal Amazon was 829 reais/month in 2019, only 83% of Brazilian already low minimum wage.
  - 85% informal

Motivation II

- In Amazon, trees can store 500/550 tons of CO_2 per hectare.
- Low and declining productivity has led to 20% of deforested land being abandoned and are experiencing large-scale reforestation.
- Highlights opportunity for (passive) reforestation.
- Deforestation was ecological and economic disaster, but now great opportunity.

Road map

1. Present results from Assunção et al. [2023].
2. Implementation.
3. Comparison with other CCS schemes.
4. Externalities.
5. Conclusion

Carbon prices and reforestation I

- Assunção, Hansen, Munson and S. [2023]
- Investigate the potential social gains of preservation and reforestation in the Brazilian Amazon through the lens of a a dynamic and spatial optimization model that considers the trade-off between cattle production and carbon capture.
- The model is quantitative and uses detailed spatial information from multiple data sets.
- The data document large cross-sectional variability in cattle farming productivity and in the potential absorption of carbon,
- Data document large cross-sectional variability in cattle farming productivity and in the potential absorption of carbon in the Amazon.
- To account for this variability, model considers detailed division of the Amazon into various sites.

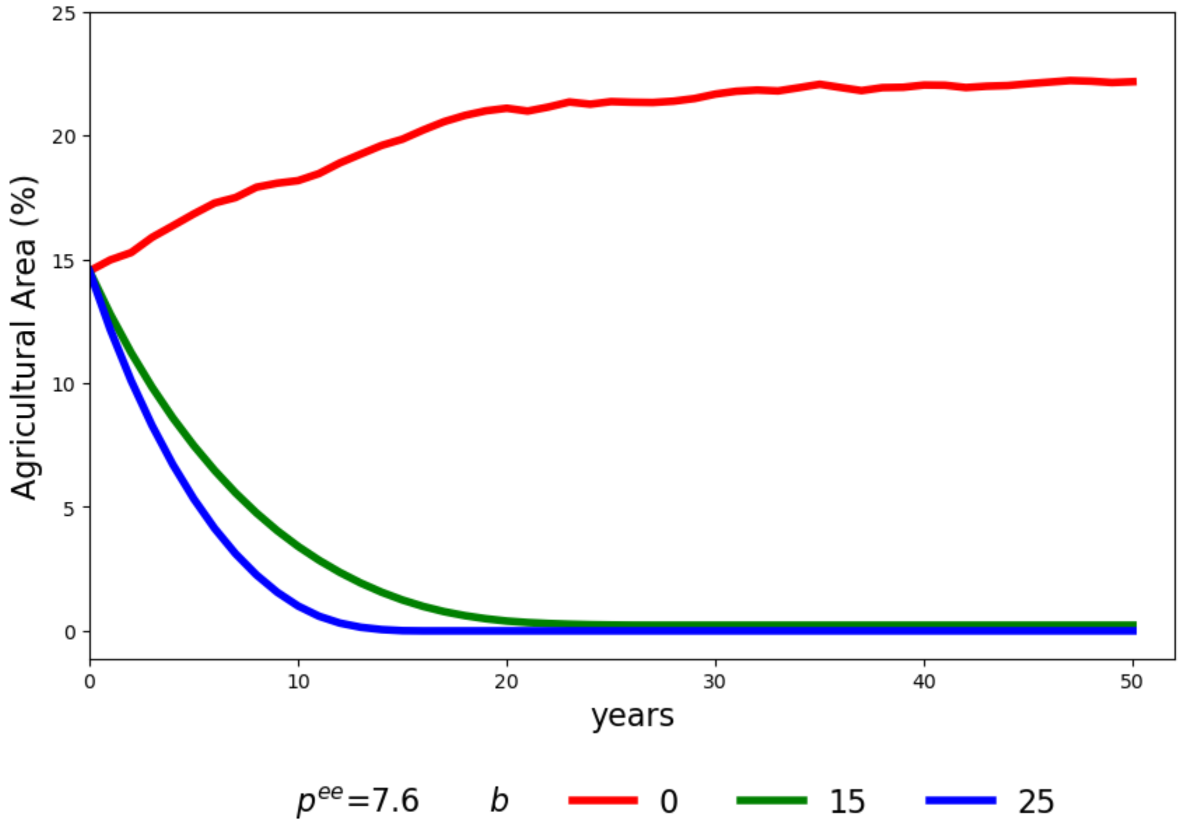
Carbon prices and reforestation II

- In paper model accounts for uncertainty in crucial parameters (sometimes referred to as deep uncertainty)
- Bottom line: With modest prices for CO_2, Brazilian Amazon would produce noticeable CO_2 capture.

Brazilian shadow price

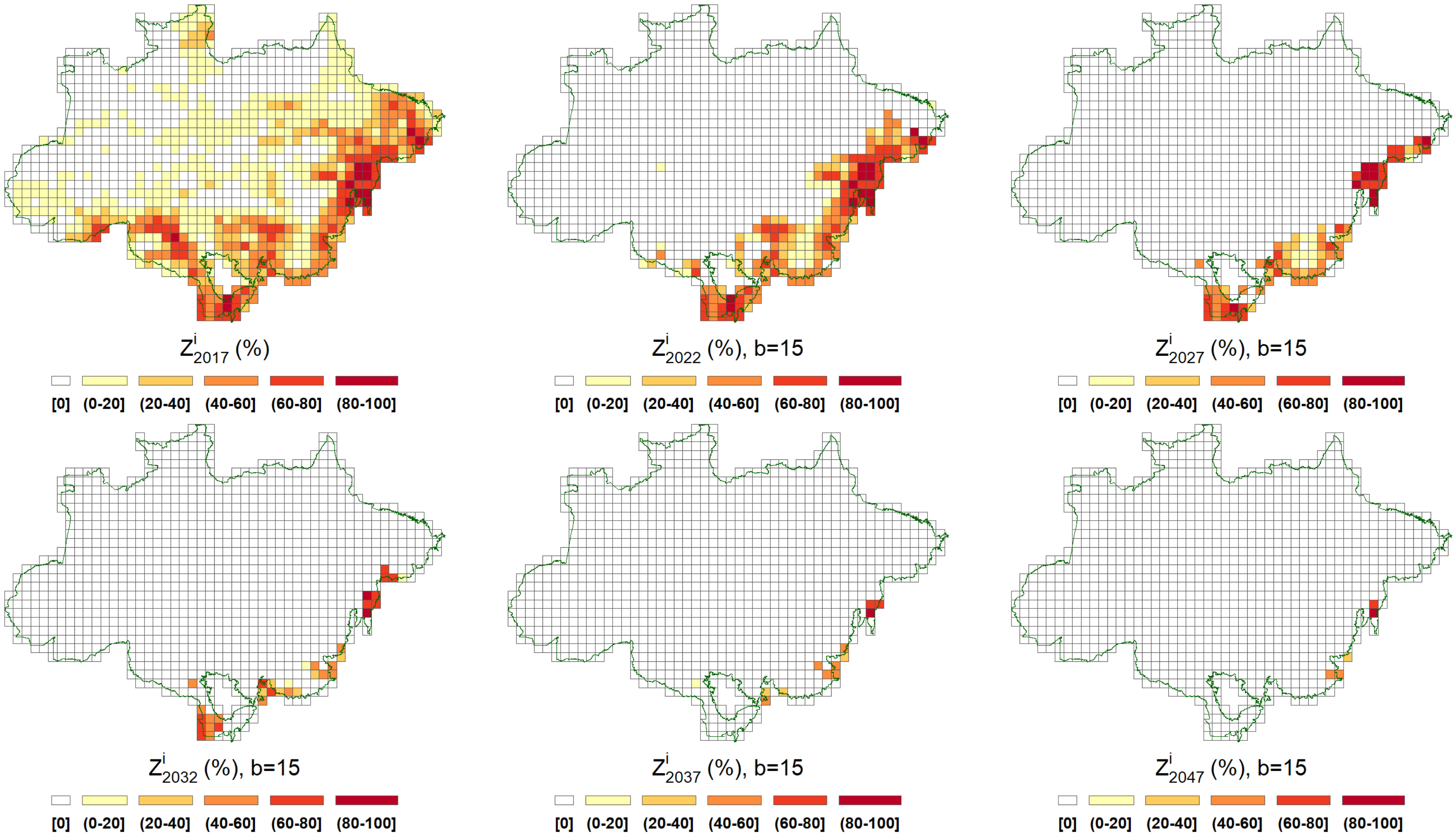
- First use model to elicit an estimate of the “shadow price” of CO_2 emissions revealed by the deforestation that actually occurred in 1995-2008.
  - “Revealed preference”
  - Shadow price also reflects value of forest services.
- Shadow price varies with version of model used but coalesce around \$7.
- Use this shadow price to predict *business-as-usual* trajectory.
- Then consider the effect of adding payments of $\$b$ per **net** ton of CO_2 captured, $b = 10, 15, 25...$
  - No payment for simply preserving.

Effect of transfers



- Business-as-usual causes deforestation sufficient for hydrological cycle of Amazon becoming unable to support rain forest in certain areas. (Flores et al. [2024])
- In contrast, even $b = 15$ produces substantial reforestation.

Evolution of occupation by agriculture, $b = 15$



Planner Value Decomposition (200 years)

Table: Deterministic case

b ($)	Agricultural Output Value ($ billion)	Net Transfers ($ billion)	Forest Services ($ billion)	Adjustment Costs ($ billion)	Planner Value ($ billion)
0	372.86	0.00	-139.75	7.69	225.42
5	133.26	30.43	46.26	5.64	204.31
10	57.72	116.05	88.20	11.73	250.24
15	33.29	197.21	99.92	17.63	312.78
20	23.60	274.68	104.38	22.49	380.16
25	18.69	350.92	106.68	26.63	449.67

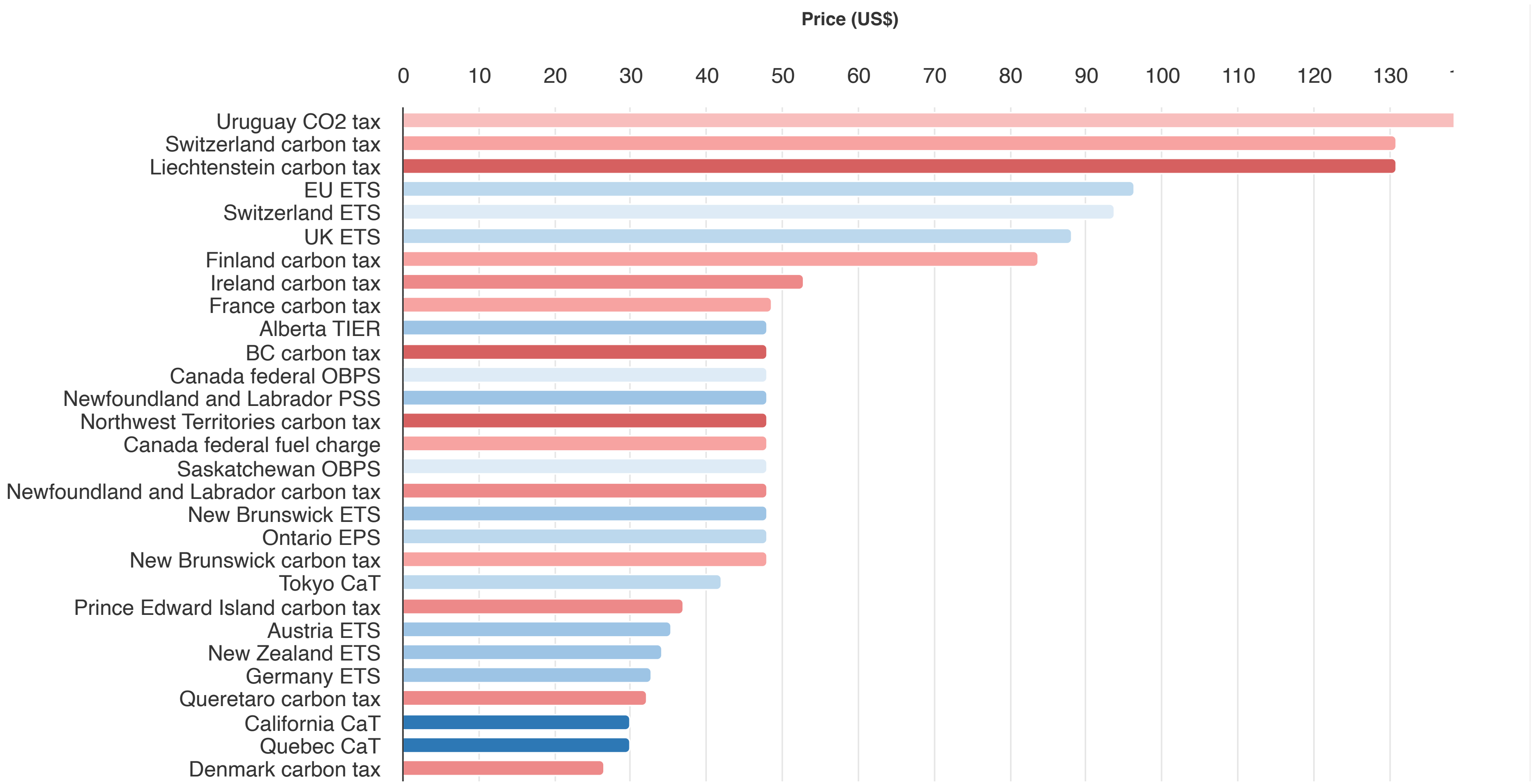
Notes: Forest services are calculated using baseline shadow price ($b = 0$)

Transfer cost (30 years)

b ($)	Net captured emissions (billion tons of CO2e)	Discounted net transfers ($ billion)	Discounted effective cost ($ per ton of CO2e)
0	-17.75	0.00	–
5	5.95	21.53	0.91
10	11.59	85.52	2.91
15	13.77	154.38	4.90
20	14.53	219.90	6.81
25	14.92	284.48	8.71

- Gains from trade
- Emissions Δ of 32.6 Gigatons when b changes from 0 to 25.
- 2/3 of change in first 15 years
- Compare with current 1.5º budget $\sim$ 250 Gigatons (Lamboll et al. [2023])

Carbon prices above $25 (World Bank)

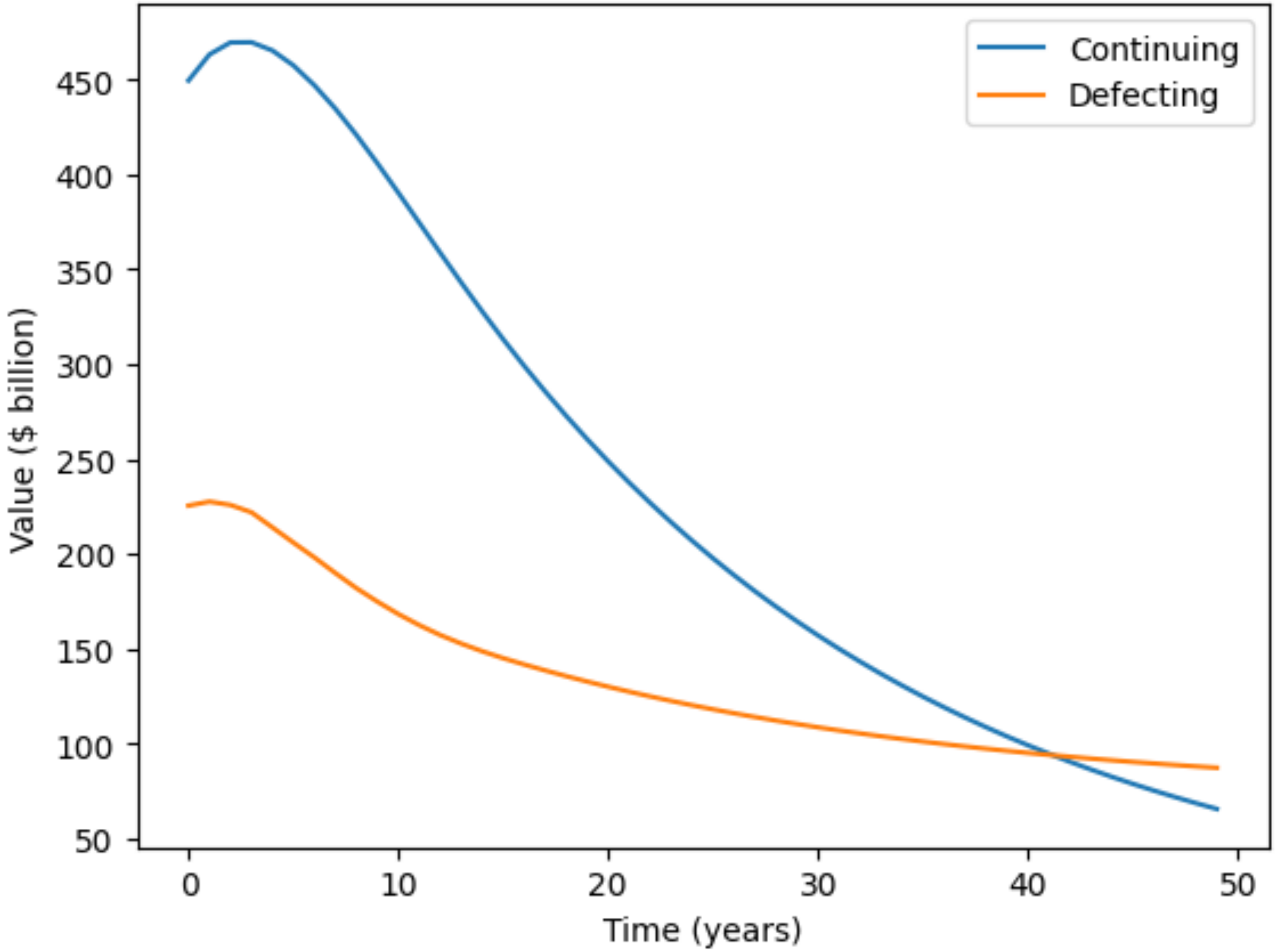


- Economic efficiency implies all carbon prices should be the same.
  - Rationale behind ETS

Implementation

- Implementation should be done in scale.
  - Minimize edge effects caused by contact of preserved areas with human activity.
    - No large natural fires in Amazon.
  - Experience in Brazil shows that using satellite data allows for deterrence at low cost (Assunção et al. [2022]).
- Values table shows that Brazil would sign an agreement to receive (pay) $b = 25$ dollars for each ton of CO_2 captured (emitted) in the Brazilian Amazon.
- However since mature forests reach an equilibrium, the value of transfers eventually converge to zero.
- Possibility: At t, Brazil defects and opts to follow optimal trajectory when $b = 0$, starting from (z_t, x_t). Let V_t be the value as of t of continuing to obey agreement and W_t the value as of t of defecting.
- Defection will occur if $W_t > V_t$.

Value of continuing versus defecting



Avoiding defection

- Max present value of $W_t - V_t$ for $t \leq 50$ is less than \$8.2 billion.
- Deflection can be avoided with carrot or stick.
- Carrot: Set fund of \$8.2 billion payable at $t = 50$ if no (substantial) deviation in z_t, for $t \leq 50$. Effective cost less than 25 cents per ton.
- Stick: Brazil issues bond with initial value of \$8.2 billion that only becomes due if (substantial) deviation in z_t, for $t \leq 50$ is observed.
  - Boycotting agriculture produced in Amazon
- Many Carbon capture and sequestration (CCS) projects are private, with no clear liability horizon. Limited liability implies that indemnification for loss is limited by value of firm's assets (Gollier [2005]). Long term liability for leaks often transferred to governments.
  - Australian Commonwealth and Western Australia state agreed to take over liability of Gorgon CCS project from Chevron and partners that include Shell and ExxonMobil after closing of project.

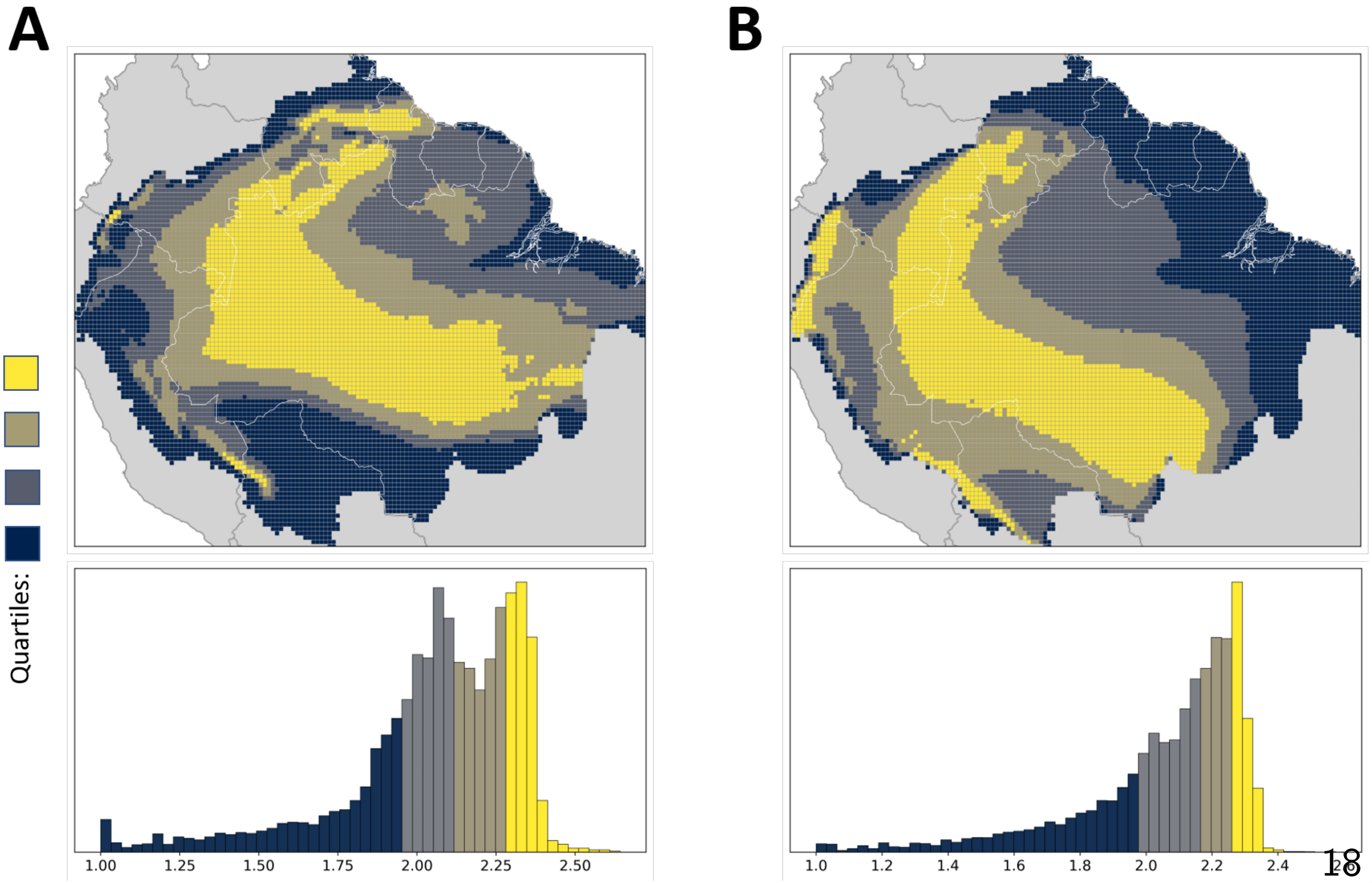
Comparison with other carbon sequestration schemes

- US IRC Section 45Q, states that secure geological storage includes "storage at oil and gas reservoirs".
- According to CBO, almost all CCS facilities in the US use captured CO_2 for enhanced oil recovery (EOR)to force more oil out of aging oil fields.
  - Occidental Petroleum, which is developing large carbon removal projects in Texas, uses EOR to sell what it calls"net-zero oil"
  - Capture carbon to release naturally captured carbon.
- As of 9/23 total US capacity for CCS amounted to 22 million tons, .4% of US current emissions.
- Under IRA, U.S. 45Q tax credit for EOR carbon capture projects pays $60/ton ($130 for direct air capture DAC)) for facilities that start construction before 2033 and pay prevailing wages during the construction phase and during the first 12 years of operation. Amounts adjusted for inflation after 2026.

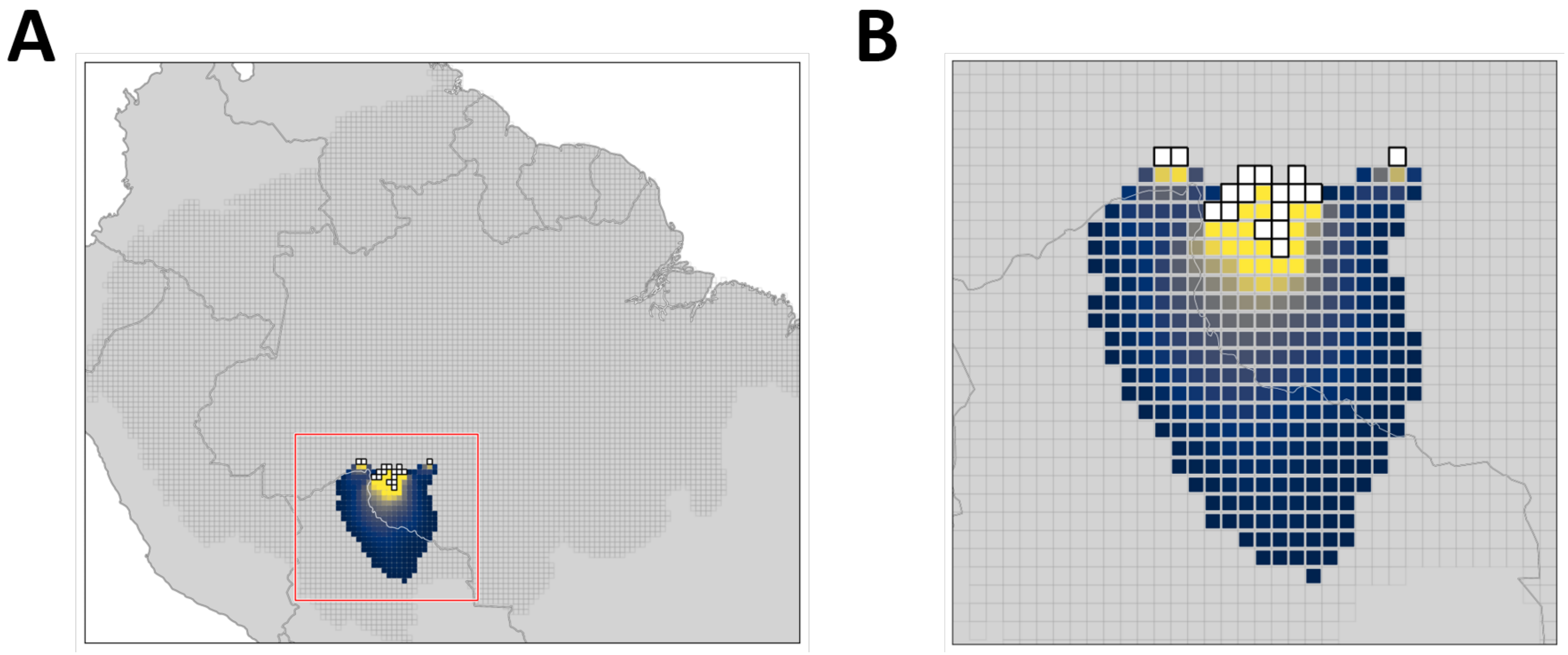
Interactions across sites

- With Araujo, Assunção and Hirota Araujo et al. [2023].
- Amazon produces large fraction of its own rainfall
- Rainfall → trees' transpiration → recharges atmospheric humidity → humidity moves downwind → rainfall.
    - Sebastião Salgado
- Degradation in a site → less atmospheric humidity → degradation downwind.
- Mapping transport of water: atmospheric trajectories at 800hPa ($\sim$ 6000 feet) from Copernicus [2017].
- Use panel data approach and variations in back trajectories to estimate impact of upwind Leaf Area Index (LAI) on downwind LAI.
- On average, degradation has a "multiplier" of 2.05.
- Additional externality

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

- With modest prices for CO_2, Brazilian Amazon would produce noticeable CO_2 capture.
  - Compared to IPCC budget
  - Compared to Griscom et al. [2017] that identify and quantify "natural climate solutions" (NCS).
- Prices are modest when compared with other CCS schemes or carbon markets
- Interactions across sites make predicted path under "business as usual" even more perilous.
- Results do not account for benefits from bio-diversity.
- Results should extend to other tropical rain-forests
  - Gains to countries would depend on extent of previous deforestation.

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