Deforestation in the Brazilian Amazon

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Background

- Tropical deforestation is a global environmental issue.
- Estimates attribute upto 30% of global GHG emissions to the land use and forestry sector.
- I study a particular channel of deforestation: deforestation due to expansion of pastureland for raising beef cattle.

Research question

- Question: How do *exogenous* changes in beef prices affect deforestation for pasture?
- Pasture-related clearing is the dominant reason for new deforestation in Tropical Brazil.

Price shock → Slaughter decision → Herd size → Pasture required → Deforestation

- Slaughter decision responds differently to temporary vs permanent change in prices.
- Price response depends on both of these factors

My approach

- Assemble data on land-cover and a local measure of price for a panel of Brazilian municipalities
- Document correlations between deforestation rates and prices
- Model a forward-looking rancher who
  - observes current price
  - jointly makes the slaughter and land clearing decision
  - accounting for reproduction dynamics of cattle
- Estimate parameters of this model
- Counterfactually calculate responses of deforestation to short run and long run prices

Preview of results

- Negative or almost zero correlation between contemporaneous deforestation and prices.
- Elasticity with respect to short run price are negative and small, as expected.
- Elasticity with respect to long run price are positive but very small compared to estimates in literature.
- Implication: Indirect land use change may be over-estimated.

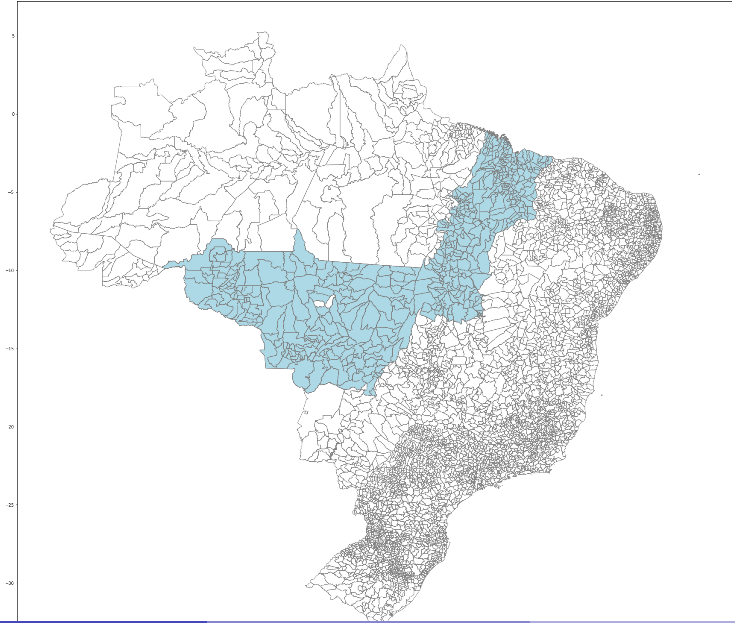
Literature

- Limited work on measuring how Amazon deforestation responds to prices (Souza-Rodrigues 2020, Assunção 2015, Barr et al 2011).
  - Dynamic approach to distinguish between long run vs short run elasticities.
- Estimates of land use elasticities are *inputs* used to calibrate CGE models (e.g. FAPRI) of policy planning e.g. biofuel policies of CARB.
  - Results can be used to calibrate these models.
- Traditional approach to estimating land use elasticities uses panel data on land cover and returns to recover unobserved switching costs between land cover types (Lubowski et al 2006, Scott 2013).
  - Same data, but incorporate endogenous unobserved state: cattle.

Data

- 533 brazilian municipalities in the 'arc of deforestation'.
- For years 2001-2011.
- Data on landcover and prices of beef/soy

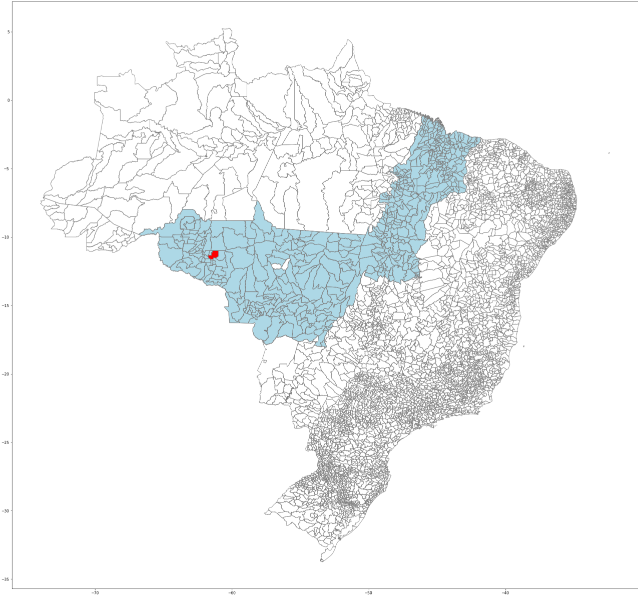
Sample of municipalities



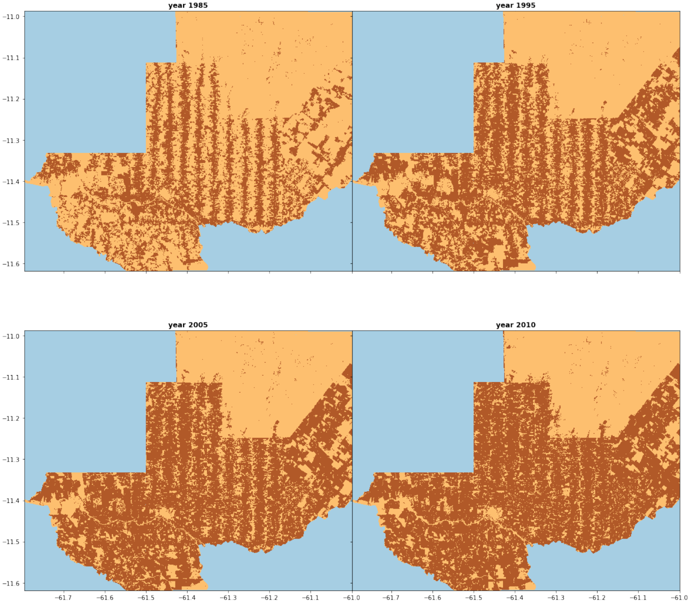
Landcover

- Landcover data from the MAPBIOMAS project
- Landsat imagery classified to several landcover types: forest, pasture, agriculture, urban etc.
  - Coarsen this classification to forest/non-forest.
- Pixel-by-pixel, find first year of deforestation
  - Non-forest is an absorbing state.
- Aggregate by municipality to calculate yearly deforestation rates.
- Change decision rules for robustness.

Landcover



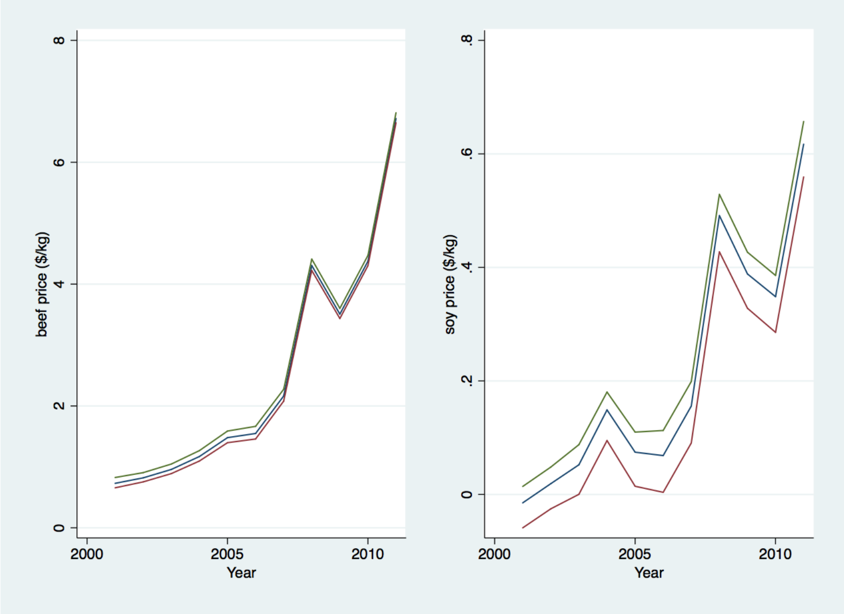
Landcover


year 1985
year 1995
year 2005
year 2010
−11.0
−11.1
−11.2
−11.3
−11.4
−11.5
−11.6
−61.7
−61.6
−61.5
−61.4
−61.3
−61.2
−61.1
−61.0

Prices

- Prices are calculated as the difference between a national price and transportation cost.
- Transportation cost calculated as the trucking cost to the least cost port.
- 95% of the variation in beef prices and 90% in soy prices is over time.

Prices

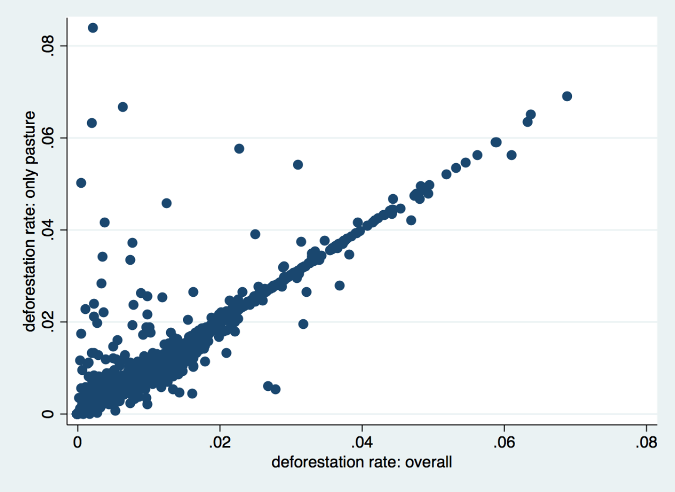


beef price ($/kg)
0
2
4
6
8
2000
2005
2010
Year
soy price ($/kg)
0
.2
.4
.6
.8
2000
2005
2010
Year

Summary Statistics

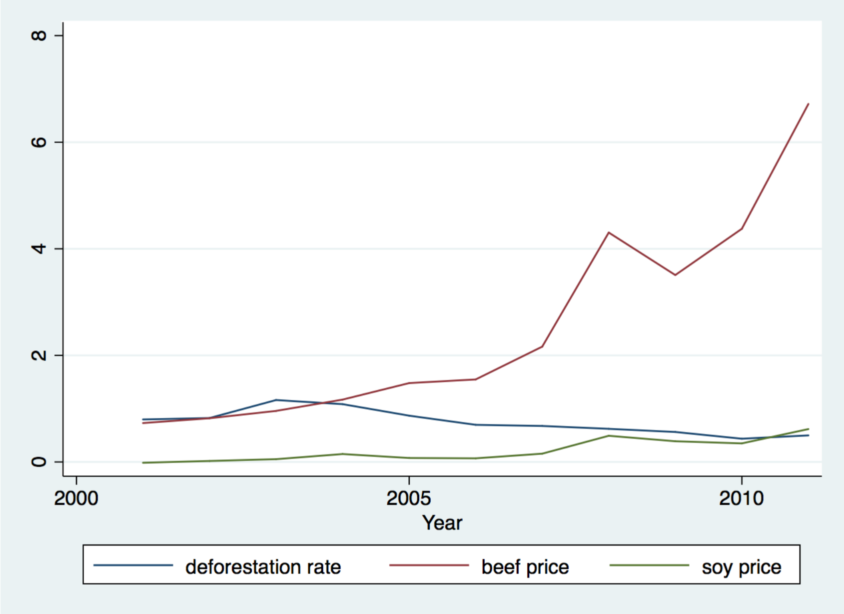
Variable	N	Mean	Std. Dev.	Min	Max
beef price ($/kg)	5,841	2.525	1.853	0.248	6.896
deforestation rate (%)	5,841	0.869	0.985	0.001	11.819

Summary Statistics



Most initial deforestation is for pasture

Summary Statistics



Levels regressions

Dependent variable: *deforestation rate*$_{it}$

	(1) FE	(2) FE	(3) FE	(4) FD	(5) FD	(6) FD
$\mathbf{p}_{\ t}$	0.083	-4.363***	-5.084***	0.559	-1.804**	-2.200**
	(0.437)	(0.450)	(0.896)	(0.692)	(0.686)	(0.697)
$\mathbf{p}_{\ t-1}$		-1.336***	-0.960*		-0.346	-0.246
		(0.202)	(0.457)		(0.350)	(0.274)
$\mathbf{p}_{\ t-2}$		-1.587***	-0.565		-1.436***	-1.026***
		(0.057)	(0.454)		(0.138)	(0.135)
$\mathbf{p}_{\ t-3}$		6.123***	4.985***		2.957**	2.615***
		(0.542)	(1.380)		(0.837)	(0.536)
N	5,841	4,248	4,248	5,310	3,717	3,717
Controls	Policy	Policy	Policy + soyprice	Policy	Policy	Policy + soyprice

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Standard errors in parantheses, clustered by year. Municipality fixed effects.

Logs regressions

Dependent variable: *log deforestation rate$_{it}$*

	(1) FE	(2) FE	(3) FE	(4) FD	(5) FD	(6) FD
p $_t$	-0.380	-0.590***	-0.541***	-0.047	-0.254	-0.211
	(0.234)	(0.128)	(0.118)	(0.417)	(0.219)	(0.157)
p $_{t-1}$		-0.022	-0.089		0.056	0.059
		(0.049)	(0.072)		(0.096)	(0.077)
p $_{t-2}$		-0.718***	-0.769***		-0.706***	-0.713***
		(0.028)	(0.047)		(0.053)	(0.043)
p $_{t-3}$		0.660***	0.746***		0.393*	0.388**
		(0.085)	(0.069)		(0.164)	(0.122)
N	5,841	4,248	4,216	5,310	3,717	3,665
Controls	Policy	Policy	Policy + soyprice	Policy	Policy	Policy + soyprice

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Standard errors in parantheses, clustered by year. Municipality fixed effects.

Model

- Model of a representative rancher.
- Starts period t with (breeding) cattle stocks of different ages and pasture land l_t.
- Each cattle head requires fixed units of land. If congestion available pasture l_t is less than this, congestion $Q(.)$ incurred.
- At the end of each period, observes p_t (exogenous, Markov state) and simultaneously chooses
    - how many "cows" to slaughter c_t,
    - how much pasture land to have next period l_{t+1}
- subject to the reproductive cycle of cattle.

Evolution of cattle stock

- Three age groups of cattle:
  - just born s_{0t},
  - one year old s_{1t},
  - two years and older s_{2t}
- Each period starts with breeding stock $b_t = s_{2t}$. Then
  - $s_{0t} = kb_t$ are born
  - Also alive: $s_{1t} = kb_{t-1}$
- During the period, δ fraction of b_t die after giving birth.
- s_{1t} become adults at the end of t and join adult stock.
- Rancher chooses c_t from adult stock.

$$b_{t+1} = (1-\delta)b_t + kb_{t-1} - c_t$$

Costs of holding cattle

- Think of pasture as soft capacity constraint.
- Land requirement

$$l_R(s_{0t}, s_{1t}, s_{2t}) = l_R(b_t, b_{t-1})$$

- With a fixed proportions assumption

$$l_R(s_{0t}, s_{1t}, s_{2t}) = \alpha_0 s_{0t} + \alpha_1 s_{1t} + s_{2t}$$

  with $\alpha_0 < \alpha_1 < 1$ for appropriately defined land units.
- Therefore

$$Q\left(b_t, b_{t-1}, l_t\right) = \begin{cases} c_q \left(l_R(b_t, b_{t-1}) - l_t\right)^\rho & \text{if } l_R(b_t, b_{t-1}) - l_t \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

  with $c_q > 0$ and $\rho > 1$.

Pasture dynamics

- Cost of clearing land

$$D(l_{t+1}, l_t) = c_l \left(l_{t+1} - l_t\right)^{\theta} \text{ if } l_{t+1} \geq l_t$$

  with $\theta > 1$ and $c_l > 0$.
- In this model, rancher never "reforests".

Rancher's problem

$$V_0 = \max_{\{c_t, b_{t+1}, l_{t+1}\}_{t=0}^{\infty}} E_0 \Sigma_{t=0}^{\infty} \beta^t \left[p_t c_t - D(l_{t+1}, l_t) \right.$$
$$\left. - Q\left(b_t, b_{t-1}, l_t\right) \right]$$

subject to

$$\begin{aligned} b_{t+1} &= (1-\delta)\, b_t + k b_{t-1} - c_t \\ c_t &\geq 0,\, b_{t+1} \geq 0 \\ l_{t+1} &\geq l_t \\ l_0, b_0, b_1 &\text{ given} \end{aligned}$$

Optimality conditions

- Euler equation for holding positive livestock

$$p_t \leq \beta E_t \Bigg[p_{t+1}(1-\delta) + \beta p_{t+2} k - \left(\frac{\partial Q(b_{t+1}, b_t, l_{t+1})}{\partial b_{t+1}} + \beta \frac{\partial Q(b_{t+2}, b_{t+1}, l_{t+2})}{\partial b_{t+1}} \right) \Bigg]$$

- Euler equation for deforestation

$$\frac{\partial D\left(l_{t+1}, l_t\right)}{\partial l_{t+1}} = \beta E_t \left[-\frac{\partial D\left(l_{t+2}, l_{t+1}\right)}{\partial l_{t+1}} - \frac{\partial Q(b_{t+1}, b_t, l_{t+1})}{\partial l_{t+1}} \right]$$

Optimality conditions

- Under the fixed-proportions assumption,

$$\frac{\partial Q(b_{t+1}, b_t, l_{t+1})}{\partial l_{t+1}} = -\tilde{\alpha}_j \times \frac{\partial Q(b_{t+1}, b_t, l_{t+1})}{\partial b_j}$$

- This allows me to combine the two FOCs and eliminate all cattle stock terms b_j

$$\begin{aligned} 0 = -p_t + \beta(1-\delta)E_t[p_{t+1}] + \beta^2 k E_t[p_{t+2}] \\ -c_l \theta d_t^{\theta-1} + (\alpha_1 - \beta\alpha_0)\, c_l \theta E_t d_{t+1}^{\theta-1} \\ +\beta\alpha_0 c_l \theta E_t d_{t+2}^{\theta-1} \end{aligned}$$

Taking model to the data

- Under Rational Expectations,

$$
\begin{aligned}
-p_t + \beta(1-\delta)p_{t+1} + \beta^2 k p_{t+2} \\
-c_l\theta d_t^{\theta-1} + (\alpha_1 - \beta\alpha_0)\, c_l\theta d_{t+1}^{\theta-1} \\
+\beta\alpha_0 c_l\theta d_{t+2}^{\theta-1} &= \epsilon_t
\end{aligned}
$$

  where ϵ_t is the expectational error.

- Assuming interior solutions, the Euler equation GMM moment conditions:

$$E\left[\epsilon_t Z_t\right] = 0$$

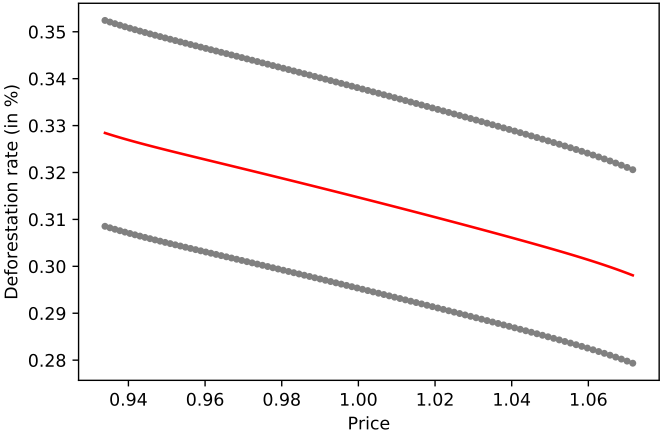
Taking the model to data

- Calibrate lifecycle parameters and capacity requirements using agronomic data and $\beta = 0.9$.
- 4 basic instruments for GMM: 1 lag of price, 2 lags of deforestation and 1 lag of total deforested area.
- RE moment conditions identify deforestation cost parameters, θ and c_l.
- In the baseline, c_l is a "fixed effect" to reflect different policy regimes.

Estimates

- Estimates of θ are quite precise and lie between 2.5 and 4.
- The level parameters c_l are imprecisely estimated but matter less for the policy function.
- RE does not place any restrictions on the price process.
- I estimate an AR(1) in logs specification for prices and use that to solve the model.

Results: Policy function



Results

Statistic	Estimate	SE
A: Next period deforestation		
1% temporary price increase	-0.0023	0.0004
10% permanent price increase	0.0012	0.0003
B: Time to complete forest clearing		
Baseline	379 years	66 years
1% temporary price increase	0.05	0.004
10% temporary price increase	0.5	0.03
1% permanent price increase	-1.5	0.05
10% permanent price increase	-14.5	4.9

Conclusion

- Estimate elasticity of deforestation with respect to beef prices.
- Estimated elasticities are small - even for permanent price changes.
- Lower bound - no leakage or spillovers
- Implication:
  - Indirect land use concerns probably overstated
  - Limited role for interventions that affect prices