Man Eats Forest
Impacts of Cattle Ranching on Amazon Deforestation

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Motivation I

- Amazon **deforestation** continues to be an issue, threatening
  - local *biodiversity* and *livelihoods* (Gibson et al. 2011; Villén-Pérez et al. 2022)
  - regional and global *climates* (Leite-Filho et al. 2021; Araujo et al. 2023)
- In Brazil, **demand for land** primarily stems from *agriculture*,
  - with *cattle* and soy being the predominant factors (Rajão et al. 2020)
  - mining and other agricultural products play a limited role (Garrett et al. 2021)
- But no framework for **causal interpretation** of its deforestation impacts,
  - footprint analyses lack causal interpretability.
  - naive regressions indicate *limited impacts*.

This paper

Uses a quasi-experimental research design to **causally identify** the deforestation impacts of the *agricultural expansion* in Brazil, with a focus on the cattle industry

Motivation II

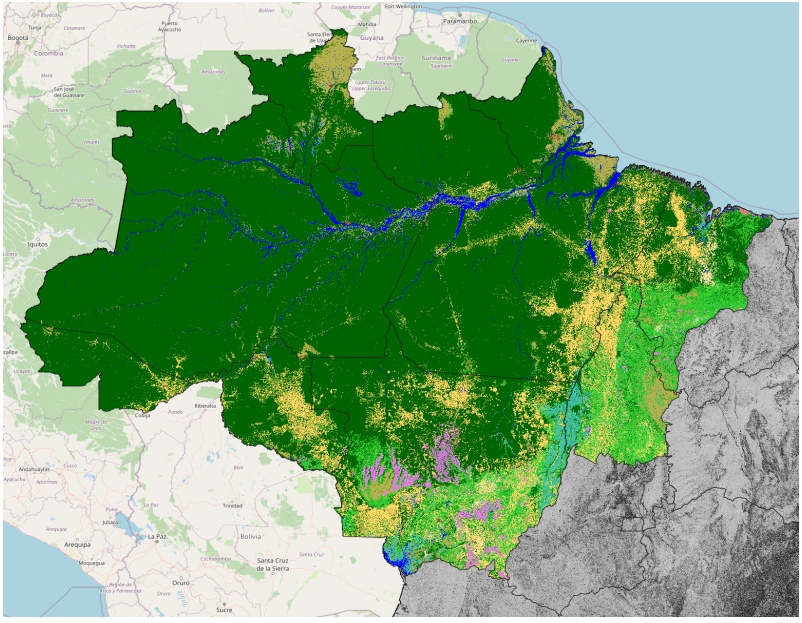

Chart: Land cover, including **forest**, **pasture**, and **croplands**, in the Legal Amazon in 2000.

Motivation III

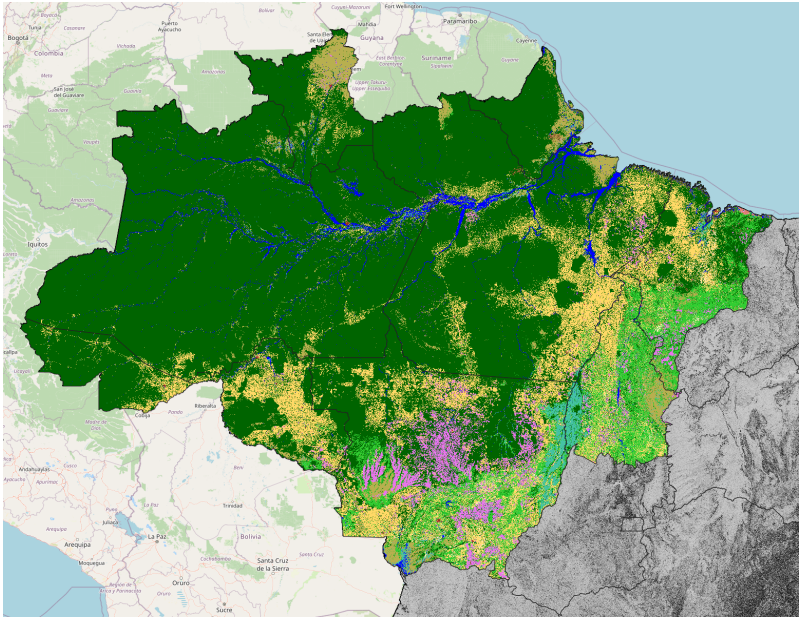

Chart: Land cover, including **forest**, **pasture**, and **croplands**, in the Legal Amazon in 2022.

Motivation IV

Reasons for resurgence include:

- rising *demand for agricultural products*, especially for **beef**[a]
  - can be met with *intensification*, or deforestation at the *extensive margin*.
- weak *land governance* driving speculative **land appropriation**[b]
  - forest is cut, agricultural activities are feigned, and ownership is claimed.
- policy interventions becoming toothless through political meddling[c]

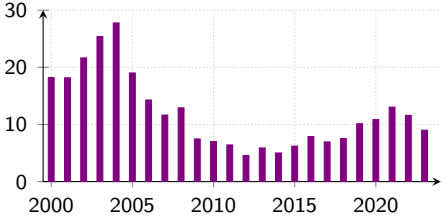

Chart: Deforestation in the Brazilian Amazon (in 1,000 km^2).

a. Cusack et al. 2021; Pendrill et al. 2022.
b. Reydon, Fernandes, and Telles 2020.
c. Kuschnig et al. 2023.

The role of the cattle industry in Brazil

The cattle and beef industry in Brazil...

- ...is important for the national economy at **8% of GDP** (CEPEA 2023), and the livelihoods of local farmers specifically (Ermgassen et al. 2020),
- ...is moving deeper into the Amazon biome (Vale et al. 2022) and is the **proximate cause of 70% of deforestation** there (MapBiomas 2023),
- ...is linked to deforestation that accounts for a **fifth of global emissions** from the tropics, at roughly 500MT per year (Pendrill et al. 2019),
- ...and, due to the mobility of cattle, acts as the **main intermediary for land appropriations** in the Amazon (Fearnside 2017).

Empirical Specification I

We depart from a naive panel regression specification:

$$y_{i,t} = \beta c_{i,t} + \boldsymbol{X}'_{i,t-s}\boldsymbol{\gamma} + \lambda_i + \mu_t + \delta_i\, t + u_{i,t},$$

where

- $y_{i,t}$ denotes **forest loss** in municipality i at time t,
- $c_{i,t}$ is a measure of **cattle expansion** (e.g. change in pasture area, cattle head),
- $\boldsymbol{X}_{i,t-s}$ holds (suitably lagged) control variables,
- λ_i and μ_t are municipality- and time-fixed effects, and
- $u_{i,t} \sim \mathcal{N}(0, \sigma_y^2)$ is the error term.

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Entangled effects

However, it does not allow for a **clear interpretation of the effect of cattle**, β, inter alia as the measure $c_{i,t}$ captures all drivers of its expansion.

Empirical Specification II

To *identify the causal effect* of cattle expansion, we use a Bartik instrument:[1]

$$y_{i,t} = \beta \hat{c}_{i,t} + \boldsymbol{X}'_{i,t-s}\boldsymbol{\gamma} + \lambda_i + \mu_t + \delta_i\, t + u_{i,t}$$
$$c_{i,t} = \boldsymbol{X}_{i,t-s}\boldsymbol{\alpha} + \omega B_{i,t} + \lambda_i + \mu_t + \delta_i\, t + \varepsilon_{i,t}$$

- The *endogenous variable* $c_{i,t}$ is instrumented with $B_{i,t} = \sum_m z_{i,m,t=0}\, g_{m,t-1}$,
  - interaction of exposure to beef production in municipality i ($z_{i,m,t=0}$) and *exogenous shocks* on changes in demand for beef products ($g_{m,t-1}$).
- Now, β reflects the effect of the demand-driven agricultural expansion.

1. Also called 'shift-share'; see Borusyak, Hull, and Jaravel 2022, for more details.

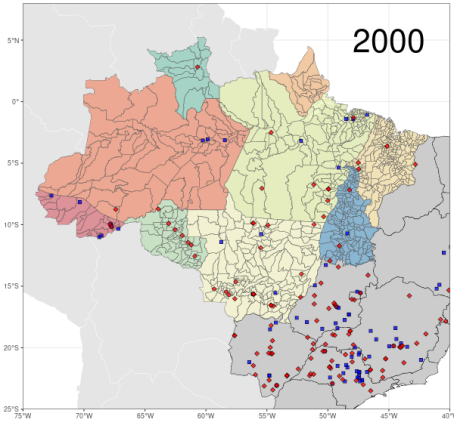
Construction of the instrument

We construct our Bartik (or *shift-share*) instrument $B_{i,t}$ using:

- Distance to slaughterhouse locations, interacted with municipality i's initial cattle stocks as **share** variable $z_{i,m,t=0}$.
  - Transport costs are crucial factor for the profitability of agriculture (Souza-Rodrigues 2019), and slaughterhouses are an intermediate destination (Vale et al. 2022)
- Changes in international beef consumption as **exogenous shift** $g_{m,t}$.
  - The demand is *relevant to* and partly satisfied with Brazilian beef,[2]
  - but is unlikely to affect Amazon deforestation in other ways.
- Baseline specification considers Chinese beef consumption changes only ($m = 1$), alternative instrument is based on municipality-specific export shares ▸ Details

2. UN Comtrade 2022; FAO 2023.

Bartik Instrument Components



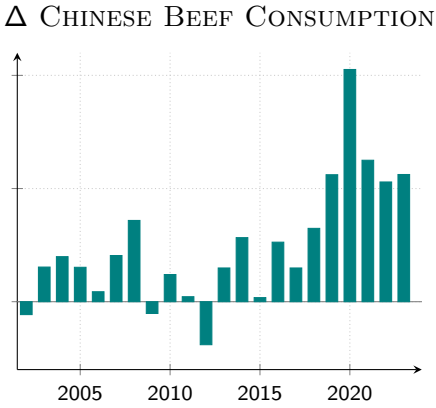


Chart: Slaughterhouse locations in 2000 and changes in aggregate Chinese beef consumption.
Source: Vale et al. 2022; FAO 2023

Data & Sources

Data cover 1574 municipalities in the Amazon, Cerrado and Pantanal biomes (∼800 in Legal Amazon) from 2003 until 2022:

- Land cover and land use change statistics (MapBiomas 2023)
- Socioeconomic and agricultural data (IBGE 2022)
- Environmental fines (IBAMA 2022)
- Protected areas (UNEP-WCMC and IUCN 2022)
- Agricultural price indices constructed in the style of Assunção, Gandour, and Rocha 2015
- Meteorological indicators (Beguería, Vicente-Serrano, and Angulo-Martínez 2010)
- Slaughterhouse locations (Vale et al. 2022)
- Beef consumption (FAO 2023)

Results

Forest∼	OLS		IV
Cattle	**-0.100**	**-0.103**	**-0.056**
	(0.02)	(0.03)	(0.02)
Pasture	**-0.831**	**-0.895**	**-0.854**
	(0.04)	(0.03)	(0.04)
Covariates	None	Full	Full
Specific trends	No	No	Yes
Fixed effects	Yes	...	
$N \times T$	16,160	...	
F stat (Cattle)			
F stat (Pasture)			

Standard errors clustered at the municipality-level. Significant ($p < 0.01$) estimates in **bold**.

▸ Export-share instrument

Results

Forest∼	OLS			IV		
Cattle	**-0.100**	**-0.103**	**-0.056**	**-0.446**	**-0.429**	**-0.548**
	(0.02)	(0.03)	(0.02)	(0.13)	(0.14)	(0.18)
Pasture	**-0.831**	**-0.895**	**-0.854**	**-1.17**	**-0.971**	**-0.884**
	(0.04)	(0.03)	(0.04)	(0.11)	(0.03)	(0.04)
Covariates	None	Full	Full	None	Full	Full
Specific trends	No	No	Yes	No	No	Yes
Fixed effects	Yes	...				
$N \times T$	16,160	...				
F stat (Cattle)				290.0	301.6	41.1
F stat (Pasture)				535.1	796.1	314.4

Standard errors clustered at the municipality-level. Significant ($p < 0.01$) estimates in **bold**.

▸ Export-share instrument

Results, biome heterogeneity

Biome	Amazon		Cerrado		Cerrado
Dependent	Forest∼		Forest∼		*Savanna*∼
	OLS	IV	OLS	IV	
Cattle	**-0.057**	**-0.698**	-0.002	-0.187	
	(0.02)	(0.23)	(.002)	(0.22)	
Covariates	Full	...			
Specific trends	Yes	...			
Fixed effects	Yes	...			
$N \times T$	10,060	...	21,240	...	

Standard errors clustered at the municipality-level. Significant ($p < 0.01$) estimates in **bold**.

Results, biome heterogeneity

Biome	Amazon		Cerrado		Cerrado	
Dependent	Forest∼		Forest∼		*Savanna*∼	
	OLS	IV	OLS	IV	OLS	IV
Cattle	**-0.057**	**-0.698**	-0.002	-0.187	**-0.009**	**-0.288**
	(0.02)	(0.23)	(.002)	(0.22)	(.002)	(0.15)
Covariates	Full	...				
Specific trends	Yes	...				
Fixed effects	Yes	...				
$N \times T$	10,060	...	21,240	...		
F stat		33.8		13.0		13.0

Standard errors clustered at the municipality-level. Significant ($p < 0.01$) estimates in **bold**.

Results, regime heterogeneity

Legal Amazon	Lula		Rousseff		Temer		Bolsonaro	
Forest∼	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Cattle	**-0.097**	**-0.479**	**-0.046**	-0.121	**-0.086**	**-0.575**	**-0.159**	**-0.517**
	(0.02)	(0.09)	(0.01)	(0.06)	(0.03)	(0.15)	(0.04)	(0.13)
Covariates	Full	...						
Specific trends	No	...						
Fixed effects	Yes	...						
$N \times T$	6,464	6,464	4,040	4,040	2,424	2,424	3,232	3,232
F stat (Cattle)		150.1		38.8		65.7		261.2

Standard errors clustered at the municipality-level. Significant ($p < 0.01$) estimates in **bold**.

Results, intensification

	All biomes		Legal Amazon		Amazon biome	
Forest∼	OLS	IV	OLS	IV	OLS	IV
Cattle per pasture	**0.052**	**0.286**	**0.102**	**0.527**	**0.158**	**0.861**
	(0.02)	(0.05)	(0.03)	(0.09)	(0.05)	(0.14)
Covariates	Full	...				
Specific trends	Yes	...				
Fixed effects	Yes	...				
$N \times T$	31,480	...	16,160	...	10,060	...
F stat		143.3		73.9		46.4

Standard errors clustered at the municipality-level. Significant ($p < 0.01$) estimates in **bold**.

Discussion

Putting our estimated effect sizes in perspective:

- *Stocking rates* suggest that **each cow** requires **roughly one+ hectares** of grazing area (see Samuel and Dines 2023).
- Reported **cattle per pasture** fall below that and naive estimates suggest **decoupling** of cattle and land.
- Our **instrumented estimates** are much closer to this **physical boundary** suggested by footprint analyses.

Potential implications:

- The beef industry is considered a **driver of economic growth**
  - Monitoring *supply chains* complicated
- **Land use externalities** lie at the heart of climate change
  - Beef has a *caloric efficiency* of 1.9%[3]
- Few interventions **disincentivize** the drivers of deforestation

3. Alexander et al. 2016.

Summary & Conclusion

- We **causally identify** the deforestation impact of the **demand-driven agricultural expansion** in Brazil with a focus on the beef industry
- Our results suggest that ...
  - ... the demand-driven expansion is a considerable causal driver of deforestation
  - ... deforestation effects are underestimated without proper identification
  - ... livestock intensification may alleviate the demand for land

For **more information**, download the slides or contact me at

- lukas.vashold@wu.ac.at

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Evolution of the beef industry in Brazil, 1966–2016

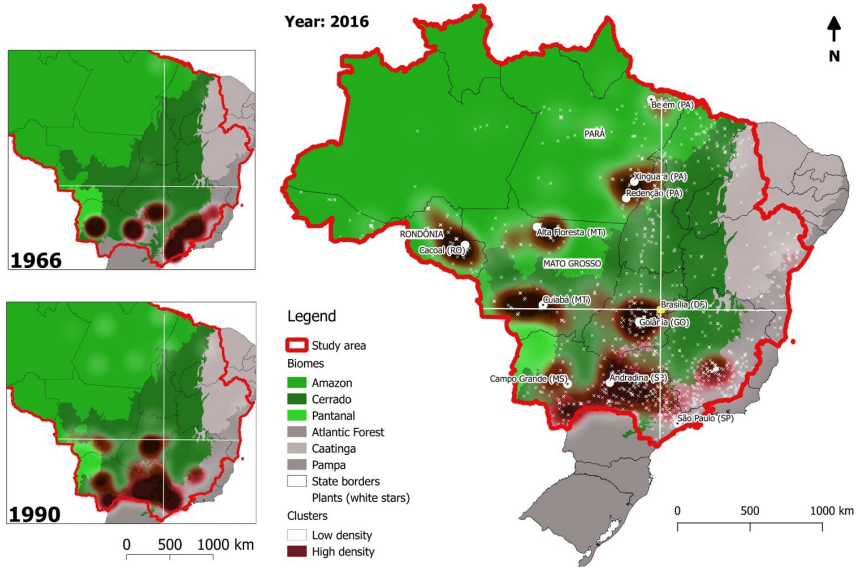

Chart: The beef industry in Brazil experienced a clear northward expansion into the Amazon biome, especially so in recent decades (taken from Vale et al. 2022).

China's appetite for beef is (partly) satisfied by Brazilian cattle

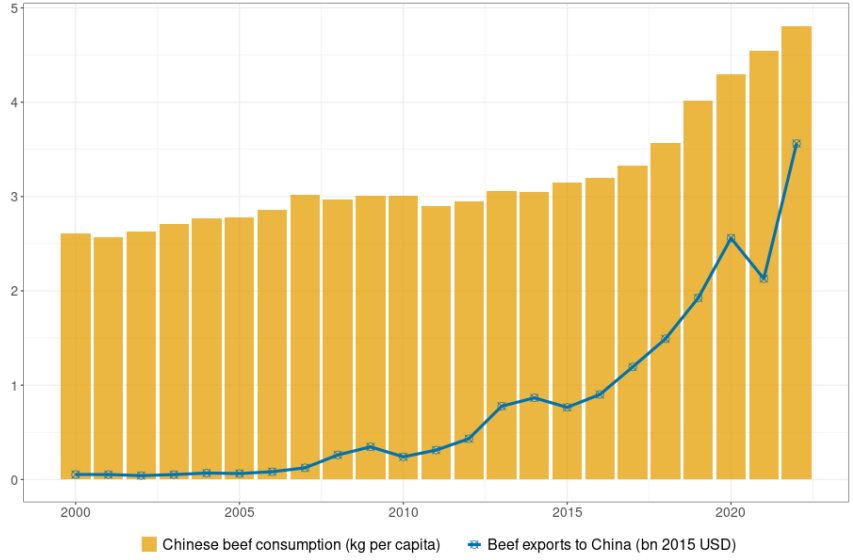

Chart: Chinese per capita beef consumption and Brazilian exports of beef products to China.
Sources: FAO 2023 & UN Comtrade 2022

Construction of the instrument

Return

We construct our Bartik (or *shift-share*) instrument $B_{i,t}$ using:

- Distance to slaughterhouse locations, interacted with municipality i's proportion on overall pasture area/cattle head as **share** variable $z_{i,t=0}$.
  - Pasture *expansion is clustered* around relevant infrastructure
  - Transport costs are crucial factor for the profitability of agriculture (Souza-Rodrigues 2019), and slaughterhouses are an intermediate destination (Vale et al. 2022)

$$z_{i,t=0} = \exp\{-d_{i,t=0}\} \times \frac{1}{C_{t=0}} \sum_{k} c_{k,t=0}\,,$$

- Changes in foreign (Chinese) beef consumption as **exogenous shift** variable g_t.
  - The demand is *relevant to* and partly satisfied with Brazilian beef,[4]
  - but is unlikely to affect Amazon deforestation in other ways.

$$g_t = \Delta \text{steak}_t^{CHN}.$$

4. UN Comtrade 2022; FAO 2023.

Construction of export-weighted instrument

Return

We construct also an instrument based on export-weighted shocks:

- Beef consumption changes in m export destinations:

$$B_{i,t} = \sum_{m} z_{i,m,t=0}\, g_{m,t-1}$$

$$z_{i,m,t=0} = z_{i,t=0} \times \frac{\text{exports}_{i,m,t=0}}{\text{exports}_{i,t=0}},$$

  - where the share $z_{i,t=0}$ from before is interacted with export shares of destinations m.
  - Export shares at the municipality level are taken from Ermgassen et al. 2020, only available for period 2010–2020.

- Growth in beef consumption of market m as **shift** variable $g_{m,t}$.

Results, export-share instrument

Return

Forest∼	OLS		China IV		Export IV	
Cattle	**-0.109**	-0.015	**-0.456**	-0.566	**-0.381**	**-0.130**
	(0.03)	(.008)	(0.13)	(.34)	(0.10)	(0.03)
Covariates	Full	...				
Specific trends	No	Yes	No	Yes	No	Yes
Fixed effects	Yes	...				
$N \times T$	9,696	...				
F stat			414.1	12.7	56.8	19.8

Standard errors clustered at the municipality-level. Significant ($p < 0.01$) estimates in **bold**.

Discussion — Implications

- *Land use externalities* lie at the heart of climate change
  - Beef has a caloric efficiency of 1.9%[a]
- A lot of consumption occurs *in Brazil*
  - Beef exports to the EU for 465 mio. USD (8,150 km^2)
  - Soy for feed at **5.6 bio. USD** (32,000 km^2)[b]

a. Alexander et al. 2016.
b. Data for 2020, obtained from trase.earth.

Discussion — Implications

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  - Soy for feed at **5.6 bio. USD** (32,000 km^2)[b]

Table: Land use in m^2 for nutritional needs[c]

	beef	cheese	eggs	nuts	**potatoes**
2,000 kcal	239.0	45.4	8.7	4.2	2.4
100g protein	163.6	39.8	5.7	7.9	5.2

a. Alexander et al. 2016.
b. Data for 2020, obtained from trase.earth.
c. Poore and Nemecek 2018.

Chart: Fritz was onto something.