

# Man Eats Forest

## Impacts of Cattle Ranching on Amazon Deforestation

Nikolas Kuschnig & **Lukas Vashold\***  
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# Motivation

- ▶ **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)

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- ▶ 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)

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  - ▶ footprint analyses lack causal interpretability
  - ▶ naive regressions indicate *limited impacts*

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## This paper

Uses a quasi-experimental shift-share design to **causally identify and quantify** the deforestation impacts of the **demand-driven cattle expansion** in the Legal Amazon

# Legal Amazon in 2000

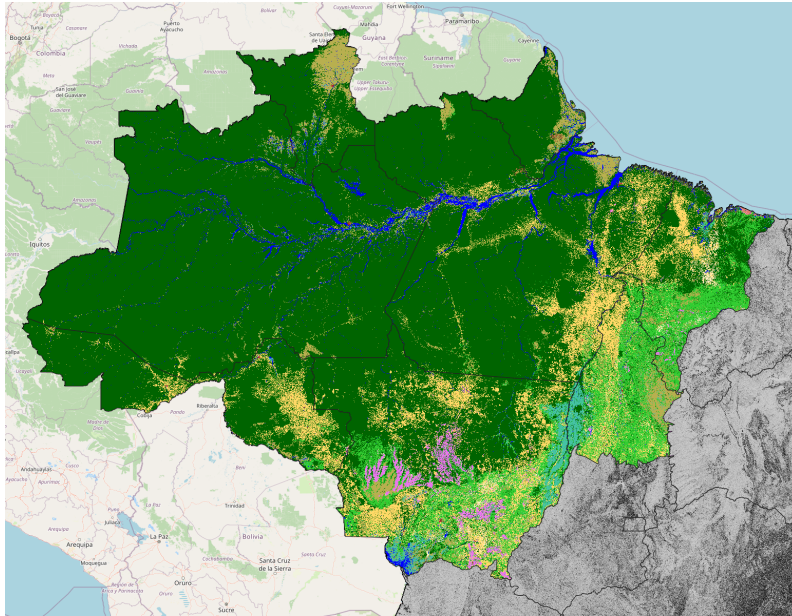


Chart: Land cover, including **forest**, **pasture**, and **croplands**, in the Legal Amazon in 2000.

# Legal Amazon in 2022

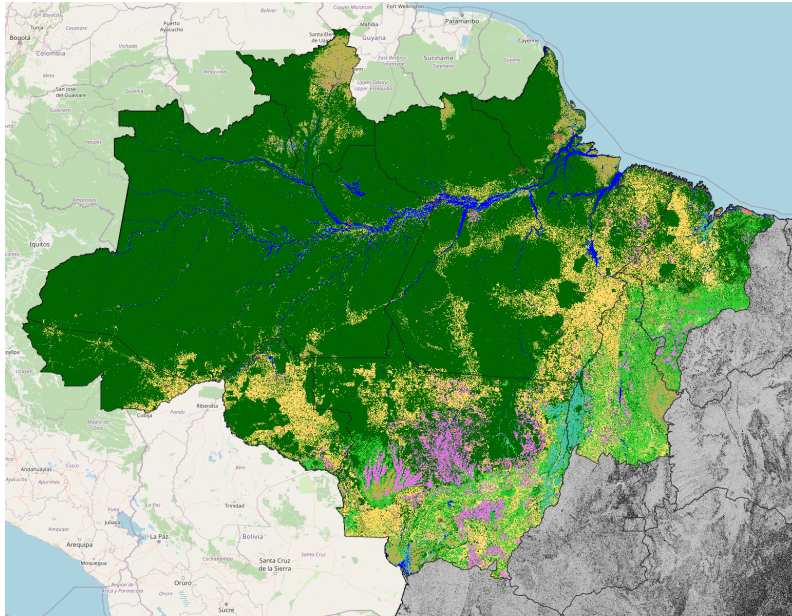
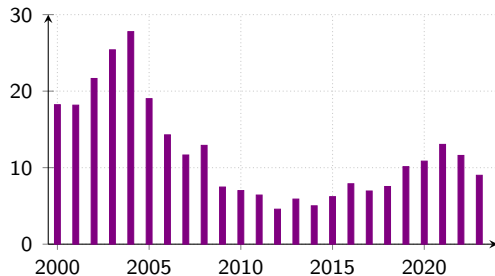


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Reasons for high levels and resurgence include:



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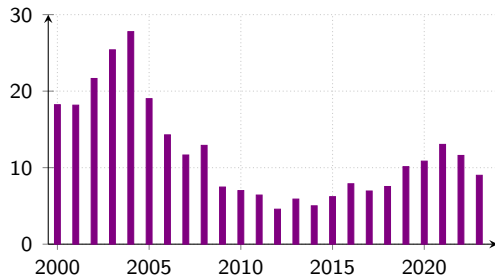
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Reasons for high levels and resurgence include:

- ▶ strong and rising **demand for agricultural products**, especially **beef products**<sup>a</sup>
  - ▶ can be met with *intensification*, or deforestation at the *extensive margin*.



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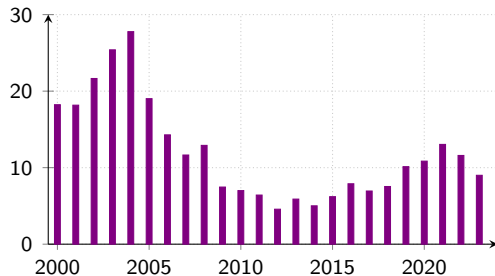
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- ▶ weak *land governance* enabling speculative **land appropriation**<sup>b</sup>
  - ▶ forest is cut, agricultural activities are feigned, and ownership is claimed.



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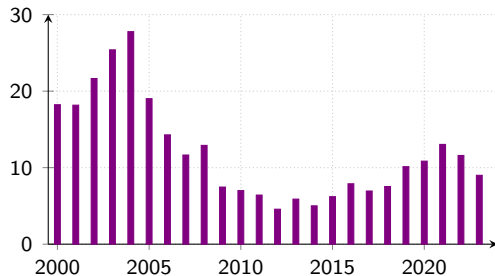
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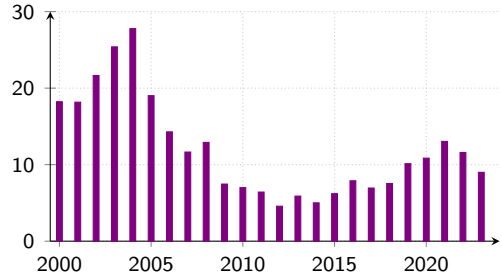
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- ▶ ...is moving deeper into the Amazon (Vale et al. 2022) and is the **proximate cause of ~90-95% of deforestation** there (Haddad et al. 2024),
- ▶ ...is linked to deforestation that accounts for a **fifth of global land use emissions** from the tropics, ~500MT per year (Pendrill et al. 2019),

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- ▶ ...is linked to deforestation that accounts for a **fifth of global land use emissions** from the tropics, ~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

# Empirical Specification I

We depart from a simple (first-difference) panel regression specification:

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

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),

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- ▶  $\mathbf{X}_{i,t-s}$  holds (suitably lagged) control variables,
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## Entangled effects

However,  $\beta$  is not *identified*, i.e. as  $c_{i,t}$  captures multiple drivers of the cattle expansion

## Empirical Specification II

To *identify the causal effect* of cattle expansion, we use a shift-share instrument:<sup>1</sup>

$$\begin{aligned}y_{i,t} &= \beta \hat{c}_{i,t} + \mathbf{X}'_{i,t-s} \gamma + \mu_t + u_{i,t} \\ c_{i,t} &= \mathbf{X}_{i,t-s} \alpha + \omega B_{i,t} + \mu_t^b + \varepsilon_{i,t}\end{aligned}$$

1. Also called ‘Bartik’; see Borusyak, Hull, and Jaravel 2022, for more details.

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- We instrument the measure of cattle expansion  $c_{i,t}$  with

$$B_{i,t} = \sum_m z_{i,m,t=0} g_{m,t},$$

- constructed as interaction of **shifts**  $g_{m,t}$  with **shares**  $z_{i,m,t=0}$  for export market  $m$

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### Identification

We rely on *exogeneity of the shifts* for identification, and exploit *shares for relevance*

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## Construction of the instrument [▸ Details](#)

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

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- ▶ Distance to slaughterhouse locations, interacted with municipality  $i$ 's initial cattle stocks as **share**  $z_{i,m,t=0}$  to measure exposure to beef industry
  - ▶ Transport costs are crucial factor for the profitability of agriculture (Souza-Rodrigues 2019), and slaughterhouses are an intermediate destination (Vale et al. 2022)

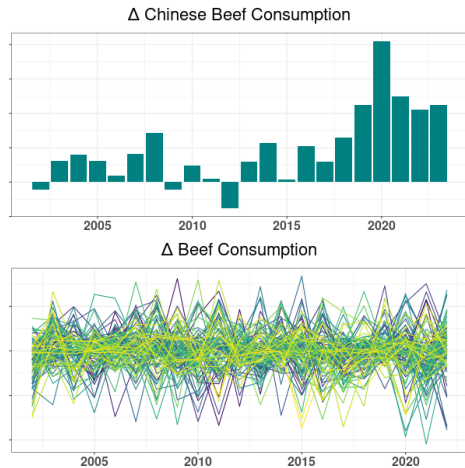
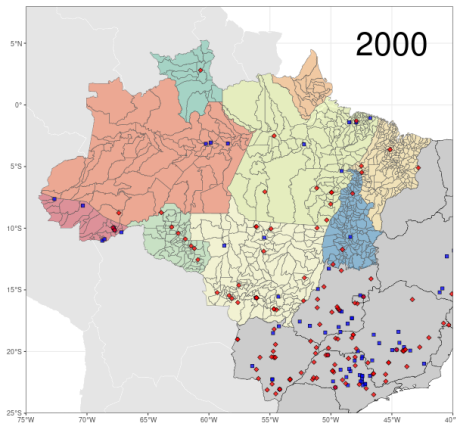
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  - ▶ Transport costs are crucial factor for the profitability of agriculture (Souza-Rodrigues 2019), and slaughterhouses are an intermediate destination (Vale et al. 2022)
- ▶ Changes in international beef consumption as **shifts**  $g_{m,t}$ , where we consider
  - (i) changes in **all export destinations** weighted by exports at the municipality level
  - (ii) changes in **Chinese beef consumption** for periods lacking export information

# Shift-Share Instrument Components



**Chart:** Slaughterhouse locations in 2000 and changes in aggregate beef consumption.

Sources: Vale et al. 2022; FAO 2023

## Data & Sources

Main sample covers 808 municipalities in the 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)
- ▶ Municipality-level beef exports (Ermgassen et al. 2020)
- ▶ International beef consumption (FAO 2023)

## Results

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	2003–2022	2011–2022
Forest~	OLS	OLS
Cattle	<b>-0.103</b> (0.03)	<b>-0.109</b> (0.03)
Pasture	<b>-0.895</b> (0.03)	<b>-0.832</b> (0.04)
Covariates	Full	
Year FEs	Yes	
$N \times T$	16,160	9,696
$F$ stat (Cattle)		
$F$ stat (Pasture)		

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

## Results

	2003–2022		2011–2022
Forest~	OLS	IV-CHN	OLS
Cattle	<b>-0.103</b> (0.03)	<b>-0.429</b> (0.14)	<b>-0.109</b> (0.03)
Pasture	<b>-0.895</b> (0.03)	<b>-0.971</b> (0.03)	<b>-0.832</b> (0.04)
Covariates	Full	...	
Year FEs	Yes	...	
$N \times T$	16,160	16,160	9,696
$F$ stat (Cattle)		301.6	
$F$ stat (Pasture)		796.1	

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

## Results

Forest~	2003–2022		2011–2022		
	OLS	IV-CHN	OLS	IV-CHN	IV-EXP
Cattle	<b>-0.103</b> (0.03)	<b>-0.429</b> (0.14)	<b>-0.109</b> (0.03)	<b>-0.456</b> (0.13)	<b>-0.381</b> (0.10)
Pasture	<b>-0.895</b> (0.03)	<b>-0.971</b> (0.03)	<b>-0.832</b> (0.04)	<b>-0.971</b> (0.03)	<b>-0.914</b> (0.03)
Covariates	Full	...			
Year FEs	Yes	...			
$N \times T$	16,160	16,160	9,696	...	
$F$ stat (Cattle)		301.6		414.1	56.8
$F$ stat (Pasture)		796.1		816.4	111.9

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



## Results, biome heterogeneity

Biome	Amazon		Cerrado	
	Forest~		Forest~	<i>incl. Savanna~</i>
	OLS	IV		
Cattle	<b>-0.108</b> (0.03)	<b>-0.530</b> (0.15)		
Covariates	Full	...		
Year FEs	Yes	...		
$N \times T$	10,060	...		
		188.7		

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	Forest~		Forest~	<i>incl. Savanna~</i>
	OLS	IV	OLS	IV
Cattle	<b>-0.108</b> (0.03)	<b>-0.530</b> (0.15)	-0.003 (.002)	-0.014 (0.02)
Covariates	Full	...		
Year FEs	Yes	...		
$N \times T$	10,060	...	21,240	...
		188.7		53.3

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	Forest~		Forest~		<i>incl. Savanna~</i>	
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Cattle	<b>-0.108</b> (0.03)	<b>-0.530</b> (0.15)	-0.003 (.002)	-0.014 (0.02)	<b>-0.028</b> (.001)	<b>-0.342</b> (0.16)
Covariates	Full	...				
Year FEs	Yes	...				
$N \times T$	10,060	...	21,240	...		
$F$ stat		188.7		53.3		53.3

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

## Results, regime heterogeneity

	Lula		Rousseff	Temer	Bolsonaro
Forest~	OLS	IV			
Cattle	<b>-0.097</b> (0.03)	<b>-0.479</b> (0.08)			
Covariates	Full	...			
Year FEs	Yes	...			
$N \times T$	6,464	6,464			
$F$ stat (Cattle)		150.1			

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	Lula		Rousseff		Temer	Bolsonaro
Forest~	OLS	IV	OLS	IV		
Cattle	<b>-0.097</b> (0.03)	<b>-0.479</b> (0.08)	<b>-0.046</b> (0.01)	-0.121 (0.06)		
Covariates	Full	...				
Year FEs	Yes	...				
$N \times T$	6,464	6,464	4,040	4,040		
$F$ stat (Cattle)		150.1		38.8		

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	Lula		Rousseff		Temer		Bolsonaro
Forest~	OLS	IV	OLS	IV	OLS	IV	
Cattle	<b>-0.097</b> (0.03)	<b>-0.479</b> (0.08)	<b>-0.046</b> (0.01)	-0.121 (0.06)	<b>-0.086</b> (0.03)	<b>-0.575</b> (0.15)	
Covariates	Full	...					
Year FEs	Yes	...					
$N \times T$	6,464	6,464	4,040	4,040	2,424	2,424	
$F$ stat (Cattle)		150.1		38.8		65.7	

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Covariates	Full	...						
Year FEs	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

Forest~	All biomes		Legal Amazon	Amazon biome
	OLS	IV		
Cattle per pasture	<b>0.054</b> (0.02)	<b>0.276</b> (0.10)		
Covariates	Full	...		
Year FEs	Yes	...		
$N \times T$	31,480	...		
$F$ stat		782.6		

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



## Results, intensification

Forest~	All biomes		Legal Amazon		Amazon biome
	OLS	IV	OLS	IV	
Cattle per pasture	<b>0.054</b> (0.02)	<b>0.276</b> (0.10)	<b>0.104</b> (0.03)	<b>0.503</b> (0.18)	
Covariates	Full	...			
Year FEs	Yes	...			
$N \times T$	31,480	...	16,160	...	
$F$ stat		782.6		397.3	

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

## Results, intensification

Forest~	All biomes		Legal Amazon		Amazon biome	
	OLS	IV	OLS	IV	OLS	IV
Cattle per pasture	<b>0.054</b> (0.02)	<b>0.276</b> (0.10)	<b>0.104</b> (0.03)	<b>0.503</b> (0.18)	<b>0.108</b> (0.03)	<b>0.530</b> (0.29)
Covariates	Full	...				
Year FEs	Yes	...				
$N \times T$	31,480	...	16,160	...	10,060	...
$F$ stat		782.6		397.3		245.7

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

## Results, soy (preliminary)

	Forest~		Savanna~	Pasture~
	OLS	IV		
Soy (ha)	<b>-0.291</b> (0.06)	<b>-0.311</b> (0.07)		
Soy (ton)	<b>-0.033</b> (0.01)	<b>-0.064</b> (0.02)		
Covariates	Full	...		
Year FEs	Yes	...		
$N \times T$	16,160	...		
$F$ stat (Soy, ton)		169.9		

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

## Results, soy (preliminary)

	Forest~		Savanna~		Pasture~
	OLS	IV	OLS	IV	
Soy (ha)	<b>-0.291</b> (0.06)	<b>-0.311</b> (0.07)	<b>-0.066</b> (0.02)	<b>-0.295</b> (0.08)	
Soy (ton)	<b>-0.033</b> (0.01)	<b>-0.064</b> (0.02)	<b>-0.005</b> (0.01)	<b>-0.060</b> (0.02)	
Covariates	Full	...			
Year FEs	Yes	...			
$N \times T$	16,160	...			
$F$ stat (Soy, ha)		252.2		252.2	
$F$ stat (Soy, ton)		169.9		169.9	

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

## Results, soy (preliminary)

	Forest~		Savanna~		Pasture~	
	OLS	IV	OLS	IV	OLS	IV
Soy (ha)	<b>-0.291</b> (0.06)	<b>-0.311</b> (0.07)	<b>-0.066</b> (0.02)	<b>-0.295</b> (0.08)	<b>-0.198</b> (0.05)	<b>-0.493</b> (0.10)
Soy (ton)	<b>-0.033</b> (0.01)	<b>-0.064</b> (0.02)	<b>-0.005</b> (0.01)	<b>-0.060</b> (0.02)	<b>-0.020</b> (0.01)	<b>-0.098</b> (0.03)
Covariates	Full	...				
Year FEs	Yes	...				
$N \times T$	16,160	...				
$F$ stat (Soy, ha)		252.2		252.2		252.2
$F$ stat (Soy, ton)		169.9		169.9		169.9

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

# Results, robustness

We assess the **sensitivity of results** along several dimensions:

- ▶ Varying **share** definitions
  - ▶ Different computations of distance to slaughterhouses
  - ▶ Omitting slaughterhouse location information
  - ▶ Updating shares over time
- ▶ **Sample** variations
  - ▶ All municipalities in Amazon, Cerrado, and Pantanal
  - ▶ Only municipalities with deforestation and 10% initial tree cover
- ▶ **Specification** variations
  - ▶ Including municipality FEs / time trends
  - ▶ Excluding year FEs
  - ▶ Lag structure of treatment/instrument/controls

## Conclusion

## Discussion, effect size

- *Stocking rates* suggest that **each cow** requires **~0.8 hectare** of grazing area<sup>2</sup>

Pasture area per cattle head



2. Arantes et al. 2018.

3. MapBiomass 2023; IBGE 2022.



## Discussion, effect size

- ▶ *Stocking rates* suggest that **each cow** requires  $\sim 0.8$  **hectare** of grazing area<sup>2</sup>
- ▶ Reported **forest-to-pasture** transition rate of  $\sim 0.66$  **hectare** per cattle<sup>3</sup>

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- ▶ Naive estimates suggest almost **decoupling** of cattle and land
- ▶ Our **instrumented estimates** are closer to those suggested by footprint analyses
  - ▶ but still amount to only **63–75%** of them
  - ▶ large share of observed deforestation **unexplained**

Pasture area per cattle head



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## Discussion, implications

- ▶ The beef industry is considered a **driver of economic growth**
  - ▶ Monitoring *supply chains* complicated (Alix-Garcia and Gibbs 2017),
  - ▶ but recent initiatives (EUDR) could be role model for other markets

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  - ▶ Beef has a *caloric efficiency* of 1.9% (Alexander et al. 2016)

Table: Land use in m<sup>2</sup> for nutritional needs.<sup>4</sup>

	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

4. Poore and Nemecek 2018.

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- ▶ Few interventions **disincentivize** the demand for **GHG-intensive products**
  - ▶ **Domestically**, recent tax restructuring could have been more targeted<sup>5</sup>
  - ▶ **Internationally**, a global uniform GHG tax would strongly affect meat products<sup>6</sup>

4. Poore and Nemecek 2018.

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## Summary & Conclusion

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

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- ▶ [www.vashold.eu](http://www.vashold.eu)



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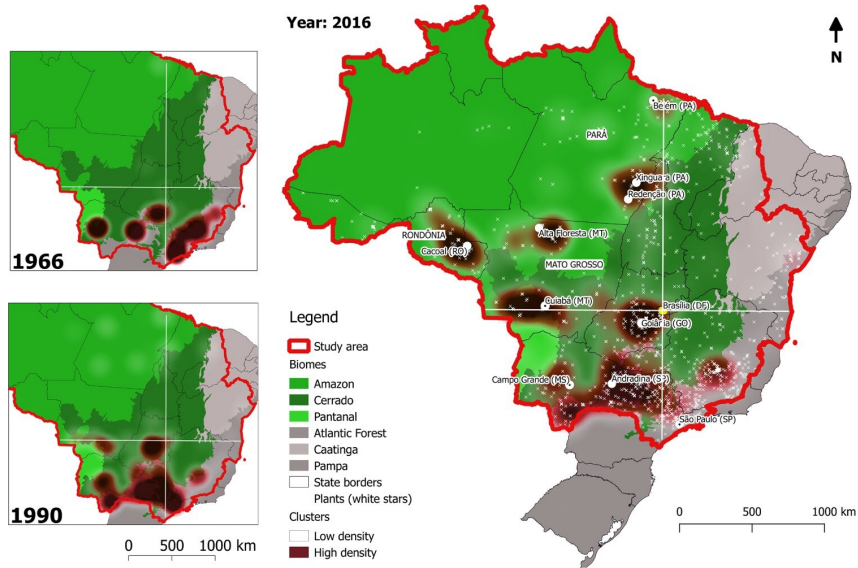


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## Appendix

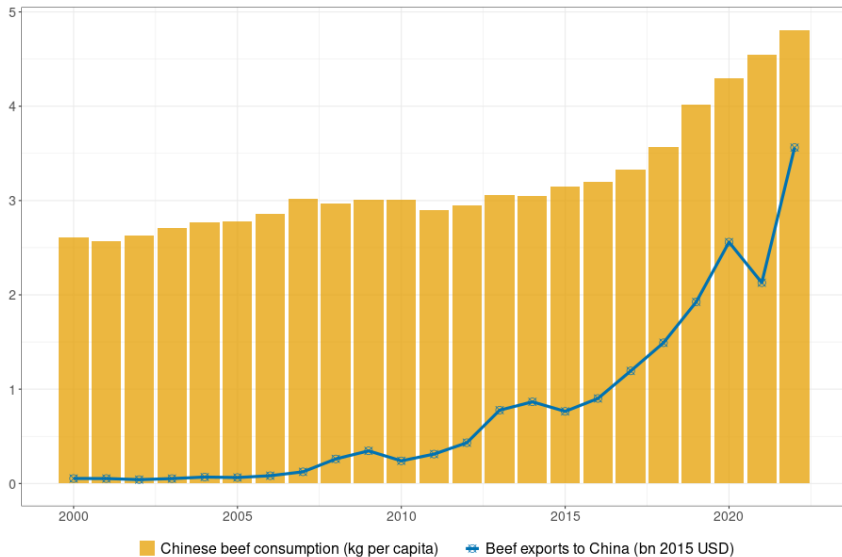


# Evolution of the beef industry in Brazil, 1966–2016



**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,<sup>7</sup>
  - ▶ but is unlikely to affect Amazon deforestation in other ways.

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

7. UN Comtrade 2022; FAO 2023.

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  $g_{m,t}$ .