Man Eats Forest

Impacts of Cattle Ranching on Amazon Deforestation

MEEW 2025 — Melbourne, Australia

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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)
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In this paper, we causally identify and quantify the local deforestation impacts of the production-driven cattle expansion in the Legal Amazon

Legal Amazon in 2000

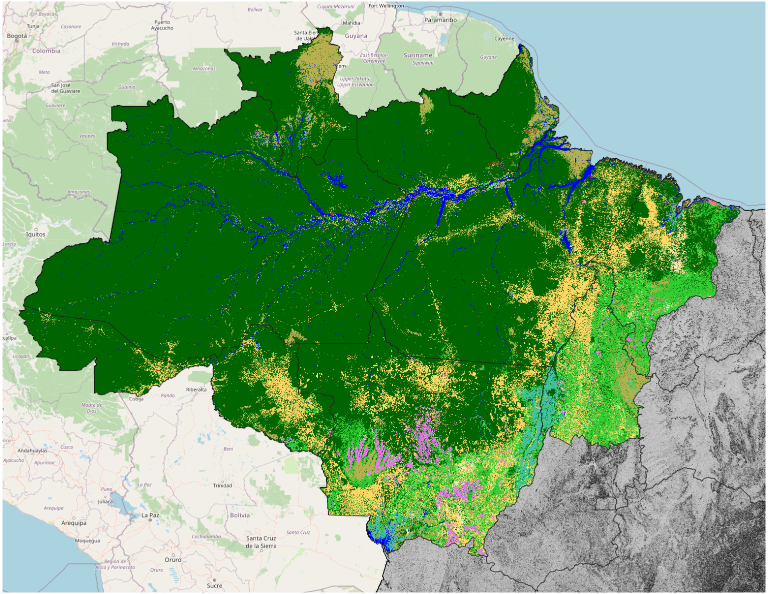
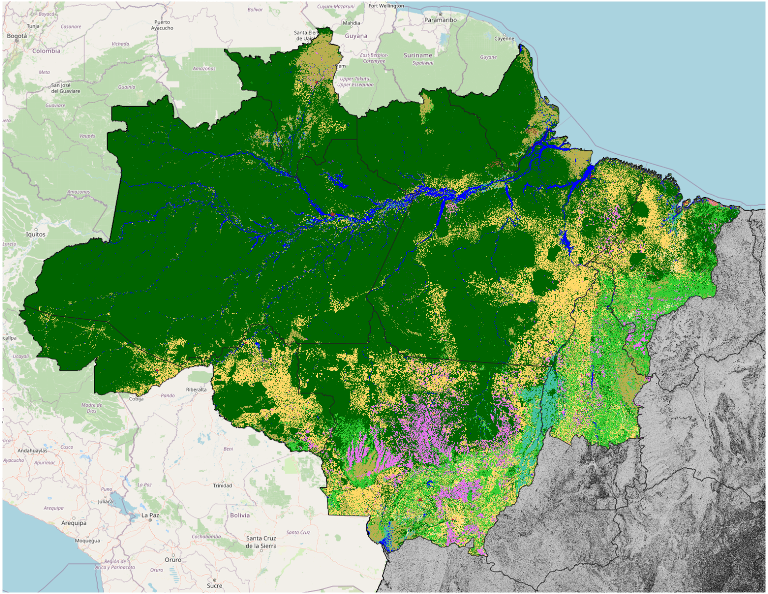


Figure: Land cover, including **forest**, **pasture**, and **croplands**, in the Legal Amazon in 2000.

Legal Amazon in 2022



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Background, Deforestation in Brazil

Reasons for high levels and resurgence include:

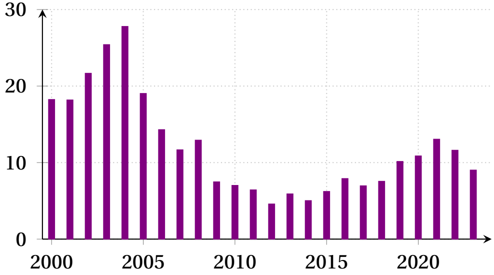

Figure: Deforestation in the Brazilian Amazon (in 1,000 km^2).

a. Cusack et al. 2021; Pendrill et al. 2022.
b. Reydon et al. 2020.
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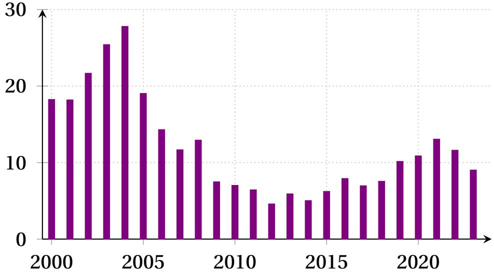
  - can be met with *intensification*, or deforestation at the *extensive margin*.



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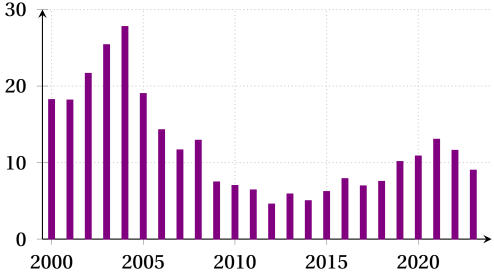
  - forest is cut, agricultural activities are feigned, and ownership is claimed.



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- *policy interventions* being **not resilient** with respect to political influence[c]

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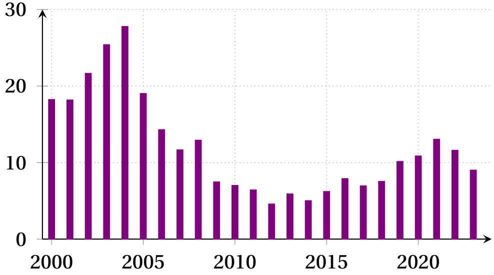

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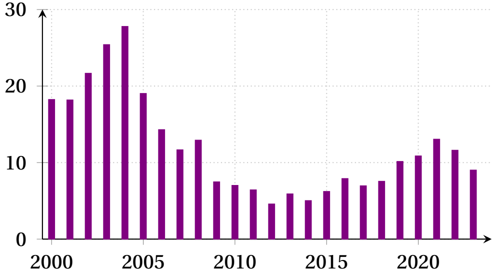

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- ...is moving deeper into the Amazon (Vale et al. 2022) and is the **proximate cause of ∼90-95% of deforestation** there (Haddad et al. 2024),
- ...is linked to deforestation that accounts for a **fifth of global land use emissions** from the tropics,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

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

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

  - $\Delta y_{i,t}$ denotes **forest change** in municipality i at time t,
  - $\Delta c_{i,t}$ is a measure of **cattle expansion** (e.g. change in cattle head),
  - $\mathbf{X}_{i,t-s}$ holds various control variables, and μ_t are time-fixed effects.

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

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  - $\mathbf{X}_{i,t-s}$ holds various control variables, and μ_t are time-fixed effects.

- Use the instrument $B_{i,t}$ to *causally identify* the effect of interest, β, as
  - as, inter alia, $c_{i,t}$ captures multiple drivers of the cattle expansion,
  - and naive regressions capture distorted global effects away from the frontier.

- and isolate the local impacts of the **production-driven cattle expansion**.

Construction of the instrument ▸ Details

We construct the shift-share (or 'Bartik')[1] instrument $B_{i,t}$ as

$$B_{i,t} = \sum_m \frac{\text{exports}_{i,m,t=0}}{\text{exports}_{i,t=0}} z_{i,t=0}\, g_{m,t}$$

1. See Borusyak et al. 2022, for more details.

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- Distance to slaughterhouse locations, interacted with municipality i's initial cattle stocks as **share** $z_{i,t=0}$ to measure exposure to beef industry

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- 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

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Rely on *shift exogeneity for identification*, and exploit *shares for relevance*

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Shift-Share Instrument Components

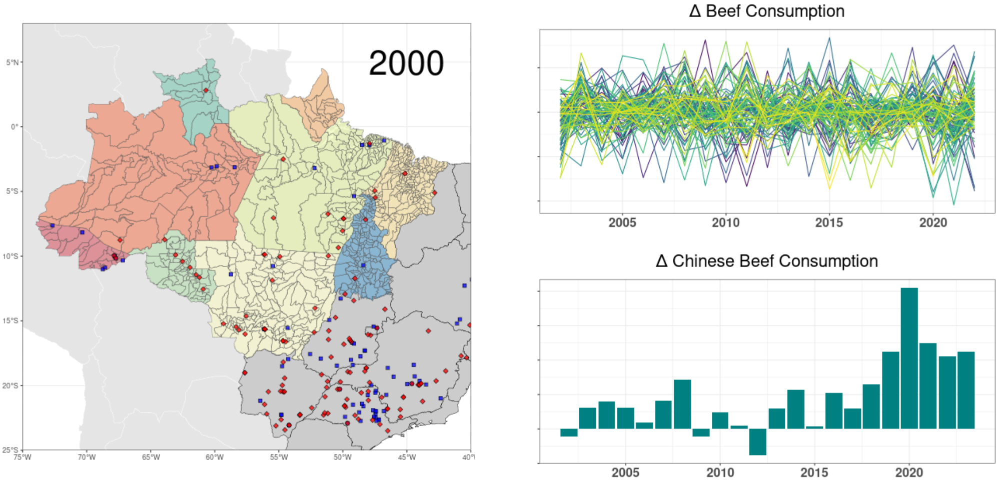

Figure: Slaughterhouse locations in 2000 (left) and changes in aggregate beef consumption (right). Sources: Vale et al. 2022; FAO 2024

Data & Sources

Main sample covers 808 municipalities in the Legal Amazon from 2003 until 2022:

- Land cover and land use change statistics (MapBiomas 2024)
- Socioeconomic and agricultural data (IBGE 2024)
- Environmental fines (IBAMA 2024)
- Protected areas (UNEP-WCMC and IUCN 2024)
- Meteorological indicators (Beguería et al. 2010)
- Slaughterhouse locations (Vale et al. 2022)
- Municipality-level beef exports (Ermgassen et al. 2020)
- International beef consumption (FAO 2024)

Results, cattle expansion

	2003–2022	2011–2022
ΔForest∼	OLS	OLS
ΔCattle	**-0.102**	**-0.108**
	(0.02)	(0.03)
Covariates	Full	
Year FEs	Yes	
$N \times T$	16,160	9,696
F stat (Cattle)		

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

▸ Pasture expansion

Results, cattle expansion

	2003–2022		2011–2022
ΔForest~	OLS	IV-CHN	OLS
ΔCattle	**-0.102**	**-0.402**	**-0.108**
	(0.02)	(0.13)	(0.03)
Covariates	Full	…	
Year FEs	Yes	…	
$N \times T$	16,160	16,160	9,696
F stat (Cattle)		318.2	

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

Pasture expansion

Results, cattle expansion

	2003–2022		2011–2022		
ΔForest~	OLS	IV-CHN	OLS	IV-CHN	IV-EXP
ΔCattle	**-0.102**	**-0.402**	**-0.108**	**-0.425**	**-0.341**
	(0.02)	(0.13)	(0.03)	(0.13)	(0.10)
Covariates	Full	…			
Year FEs	Yes	…			
$N \times T$	16,160	16,160	9,696	…	
F stat (Cattle)		318.2		427.3	57.1

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

▸ Pasture expansion

Results, effect size

- Footprint analyses imply substantial **land use needs of cattle**
  - *Stocking rates* suggest that **each cow** requires **~0.8 hectare** of grazing area[2]
  - Reported **forest-to-pasture** transition rate of **~0.66 hectare** per cattle[3]

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- Naive estimates suggest almost **decoupling** of cattle and land

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Results, effect size

- Footprint analyses imply substantial **land use needs of cattle**
  - *Stocking rates* suggest that **each cow** requires ∼**0.8 hectare** of grazing area[2]
  - Reported **forest-to-pasture** transition rate of ∼**0.66 hectare** per cattle[3]
- Naive estimates suggest almost **decoupling** of cattle and land
- **Instrumented estimates** closer to those suggested by footprint analyses
  - but still amount to only **56–70%** of them
  - large share of observed deforestation **unexplained**

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  - but still amount to only **56–70%** of them
  - large share of observed deforestation **unexplained**
- Substantial **aggregate effects** of production-driven cattle expansion
  - Cattle herds in Legal Amazon grew by ≈40 million in 2003–2022
  - Amounts to **≈16 million hectares of forest lost** due beef production
  - Using conservative conversion rates, this implies **4.8 gigatons of CO_2 emissions**

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Results, biome heterogeneity

Biome	Amazon		Cerrado	
	ΔForest∼		ΔForest∼	*incl. Savanna*∼
	OLS	IV		
Δ Cattle	**-0.107**	**-0.492**		
	(0.03)	(0.15)		
Covariates	Full	…		
Year FEs	Yes	…		
$N \times T$	10,060	…		
F stat		198.6		

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

Results, biome heterogeneity

Biome	Amazon		Cerrado		
	ΔForest~		ΔForest~		*incl. Savanna~*
	OLS	IV	OLS	IV	
Δ Cattle	**-0.107**	**-0.492**	-0.003	-0.014	
	(0.03)	(0.15)	(.002)	(0.02)	
Covariates	Full	…			
Year FEs	Yes	…			
$N \times T$	10,060	…	21,240	…	
F stat		198.6		53.2	

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Results, biome heterogeneity

Biome	Amazon		Cerrado			
	ΔForest~		ΔForest~		*incl. Savanna~*	
	OLS	IV	OLS	IV	OLS	IV
Δ Cattle	**-0.107**	**-0.492**	-0.003	-0.014	**-0.027**	**-0.388**
	(0.03)	(0.15)	(.002)	(0.02)	(.005)	(0.18)
Covariates	Full	…				
Year FEs	Yes	…				
$N \times T$	10,060	…	21,240	…		
F stat		198.6		53.2		53.2

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Results, government heterogeneity

	Lula		Rousseff		Temer		Bolsonaro	
ΔForest~	OLS	IV						
ΔCattle	**-0.097**	**-0.482**						
	(0.03)	(0.08)						
Covariates	Full	…						
Year FEs	Yes	…						
$N \times T$	6,464	6,464						
F stat		147.4						

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

Results, government heterogeneity

	Lula		Rousseff		Temer	Bolsonaro
ΔForest~	OLS	IV	OLS	IV		
ΔCattle	**-0.097**	**-0.482**	**-0.046**	-0.137		
	(0.03)	(0.08)	(0.01)	(0.07)		
Covariates	Full	…				
Year FEs	Yes	…				
$N \times T$	6,464	6,464	4,040	4,040		
F stat		147.4		36.8		

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	Lula		Rousseff		Temer		Bolsonaro
ΔForest~	OLS	IV	OLS	IV	OLS	IV	
ΔCattle	**-0.097**	**-0.482**	**-0.046**	-0.137	**-0.085**	**-0.584**	
	(0.03)	(0.08)	(0.01)	(0.07)	(0.03)	(0.16)	
Covariates	Full	...					
Year FEs	Yes	...					
$N \times T$	6,464	6,464	4,040	4,040	2,424	2,424	
F stat		147.4		36.8		62.4	

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	Lula		Rousseff		Temer		Bolsonaro	
ΔForest~	OLS	IV	OLS	IV	OLS	IV	OLS	IV
ΔCattle	**-0.097**	**-0.482**	**-0.046**	-0.137	**-0.085**	**-0.584**	**-0.158**	**-0.473**
	(0.03)	(0.08)	(0.01)	(0.07)	(0.03)	(0.16)	(0.04)	(0.13)
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		147.4		36.8		62.4		269.7

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Results, intensification

	All biomes		Legal Amazon	Amazon biome
ΔForest~	OLS	IV		
ΔCattle per pasture	**0.054**	**0.239**		
	(0.02)	(0.09)		
Covariates	Full	…		
Year FEs	Yes	…		
$N \times T$	31,480	…		
F stat		782.4		

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Results, intensification

	All biomes		Legal Amazon		Amazon biome
ΔForest~	OLS	IV	OLS	IV	
ΔCattle per pasture	**0.054**	**0.239**	**0.104**	**0.470**	
	(0.02)	(0.09)	(0.03)	(0.17)	
Covariates	Full	…			
Year FEs	Yes	…			
$N \times T$	31,480	…	16,160	…	
F stat		782.4		397.2	

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

Results, intensification

ΔForest~	All biomes OLS	All biomes IV	Legal Amazon OLS	Legal Amazon IV	Amazon biome OLS	Amazon biome IV
ΔCattle per pasture	**0.054**	**0.239**	**0.104**	**0.470**	**0.158**	**0.746**
	(0.02)	(0.09)	(0.03)	(0.17)	(0.05)	(0.27)
Covariates	Full	…				
Year FEs	Yes	…				
$N \times T$	31,480	…	16,160	…	10,060	…
F stat		782.4		397.2		245.6

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

Implications

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

4. Haddad et al. 2024.
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- Few interventions **disincentivize** the demand for **LU-intensive food products**
  - **Domestic** taxes more targeted[4]; **Global** GHG tax affects meat products[5]
  - Marketing restrictions and **information provision**, e.g. "do pasto ao prato"

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  - **Domestic** taxes more targeted[4]; **Global** GHG tax affects meat products[5]
  - Marketing restrictions and **information provision**, e.g. "do pasto ao prato"
- **Supply-side measures** to decrease land pressures from given production
  - Targeted **credit provision** for intensification of existing pasture
  - Other measures to incentivize **restoration of pasture/forest** (similar to REDD+?)

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Summary & Conclusion

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- Our results suggest that ...
  - ... the production-driven expansion is a considerable driver of deforestation
  - ... effects are **underestimated** without proper identification
  - ... but explains only **56-70%** of observed cattle-related deforestation
  - ... intensification may alleviate land pressures.

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  - ... effects are **underestimated** without proper identification
  - ... but explains only **56-70%** of observed cattle-related deforestation
  - ... intensification may alleviate land pressures.

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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,[6]
  - but is unlikely to affect Amazon deforestation in other ways.

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

6. UN Comtrade 2024; FAO 2024.

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, pasture expansion ◂ Return

	2003–2022		2011–2022		
ΔForest~	OLS	IV-CHN	OLS	IV-CHN	IV-EXP
ΔPasture	**-0.894**	**-0.973**	**-0.832**	**-0.976**	**-0.926**
	(0.03)	(0.03)	(0.04)	(0.03)	(0.04)
Covariates	Full	...			
Year FEs	Yes	...			
$N \times T$	16,160	16,160	9,696	...	
F stat (Pasture)		732.9		711.7	86.2

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

Results, soy (preliminary)

	ΔForest~		ΔSavanna~	ΔPasture~
	OLS	IV		
ΔSoy (ha)	**-0.293**	**-0.312**		
	(0.06)	(0.07)		
ΔSoy (ton)	**-0.033**	**-0.066**		
	(0.01)	(0.02)		
Covariates	Full	…		
Year FEs	Yes	…		
$N \times T$	16,160	…		
F stat (Soy, ha)		333.2		
F stat (Soy, ton)		215.9		

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

Results, soy (preliminary)

	ΔForest~		ΔSavanna~		ΔPasture~
	OLS	IV	OLS	IV	
ΔSoy (ha)	**-0.293**	**-0.312**	**-0.069**	**-0.295**	
	(0.06)	(0.07)	(0.02)	(0.08)	
ΔSoy (ton)	**-0.033**	**-0.066**	**-0.005**	**-0.060**	
	(0.01)	(0.02)	(0.01)	(0.02)	
Covariates	Full	...			
Year FEs	Yes	...			
$N \times T$	16,160	...			
F stat (Soy, ha)		333.2		333.2	
F stat (Soy, ton)		215.9		215.9	

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

Results, soy (preliminary)

	ΔForest~		ΔSavanna~		ΔPasture~	
	OLS	IV	OLS	IV	OLS	IV
ΔSoy (ha)	**-0.293**	**-0.312**	**-0.069**	**-0.295**	**-0.202**	**-0.483**
	(0.06)	(0.07)	(0.02)	(0.08)	(0.04)	(0.10)
ΔSoy (ton)	**-0.033**	**-0.066**	**-0.005**	**-0.060**	**-0.021**	**-0.097**
	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.03)
Covariates	Full	...				
Year FEs	Yes	...				
$N \times T$	16,160	...				
F stat (Soy, ha)		333.2		333.2		333.2
F stat (Soy, ton)		215.9		215.9		215.9

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