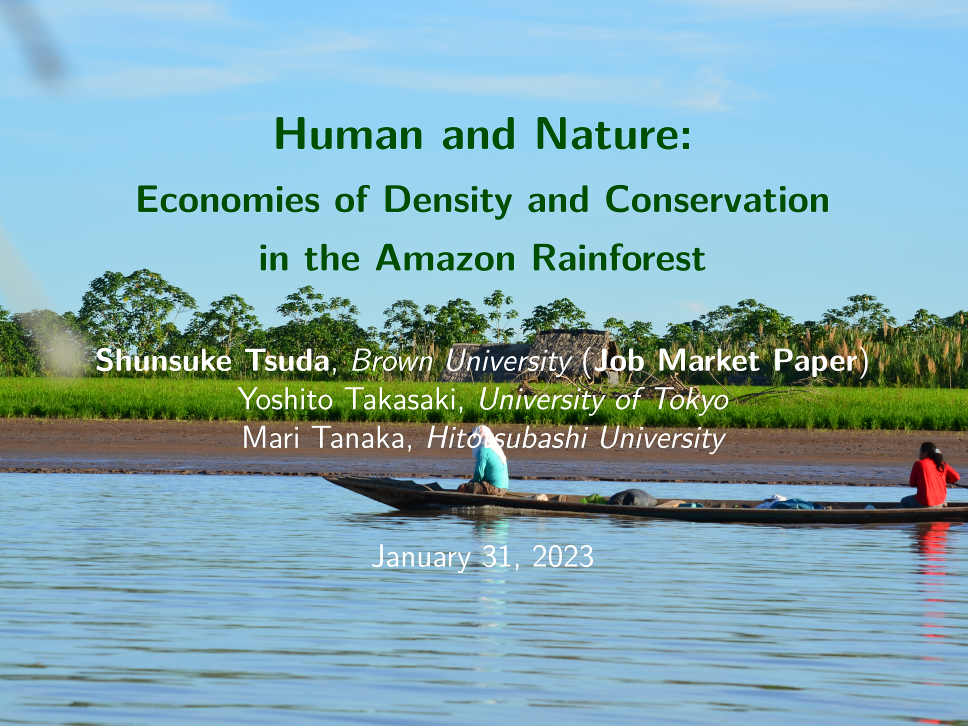


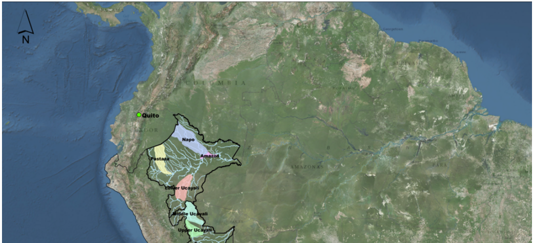
Human and Nature:
Economies of Density and Conservation in the Amazon Rainforest

Shunsuke Tsuda, *Brown University* (**Job Market Paper**)
Yoshito Takasaki, *University of Tokyo*
Mari Tanaka, *Hitotsubashi University*

January 31, 2023

Tropical Forests and Indigenous Populations

- Home to much of the world's biodiversity and natural resources
- Rapid deforestation and bio-diversity loss
- The Peruvian Amazon:
  - Traditional ways of life in remote areas without modern technology and external investments
  - Primary activities: agriculture (shifting cultivation), fishing, hunting



Human-Nature Interactions across Space in Rainforests

Policymaker's trade-offs:

- Rainforest conservation vs. Local populations' welfare:

e.g. Cost of forest clearing $\uparrow \Rightarrow$ Income from agriculture $\downarrow \Rightarrow$ Welfare loss

Human-Nature Interactions across Space in Rainforests

Policymaker's trade-offs:

- Rainforest conservation vs. Local populations' welfare:

e.g. Cost of forest clearing $\uparrow \Rightarrow$ Income from agriculture $\downarrow \Rightarrow$ Welfare loss

- Human adaptation may undermine conservation policy goals:

e.g. Sectoral reallocation: Cost of forest clearing $\uparrow \Rightarrow$ Fishing/hunting $\uparrow \Rightarrow$ Bio-diversity loss

Spatial reallocation: Protected areas $\Rightarrow$ Resource depletion in other locations $\uparrow$

Human-Nature Interactions across Space in Rainforests

Policymaker's trade-offs:

- Rainforest conservation vs. Local populations' welfare:

e.g. Cost of forest clearing ↑ ⇒ Income from agriculture ↓ ⇒ Welfare loss

- Human adaptation may undermine conservation policy goals:

e.g. Sectoral reallocation: Cost of forest clearing ↑ ⇒ Fishing/hunting ↑ ⇒ Bio-diversity loss
Spatial reallocation: Protected areas ⇒ Resource depletion in other locations ↑

Research question

Are there policies that improve both local populations' welfare and ecological conservation?

Human-Nature Interactions across Space in Rainforests

Policymaker's trade-offs:

- Rainforest conservation vs. Local populations' welfare:

e.g. Cost of forest clearing $\uparrow \Rightarrow$ Income from agriculture $\downarrow \Rightarrow$ Welfare loss

- Human adaptation may undermine conservation policy goals:

e.g. Sectoral reallocation: Cost of forest clearing $\uparrow \Rightarrow$ Fishing/hunting $\uparrow \Rightarrow$ Bio-diversity loss
Spatial reallocation: Protected areas $\Rightarrow$ Resource depletion in other locations $\uparrow$

Research question

Are there policies that improve both local populations' welfare and ecological conservation?

This paper:

1. Builds a spatial general equilibrium model with multiple rural sectors

Human-Nature Interactions across Space in Rainforests

Policymaker's trade-offs:

- Rainforest conservation vs. Local populations' welfare:

e.g. Cost of forest clearing $\uparrow \Rightarrow$ Income from agriculture $\downarrow \Rightarrow$ Welfare loss

- Human adaptation may undermine conservation policy goals:

e.g. Sectoral reallocation: Cost of forest clearing $\uparrow \Rightarrow$ Fishing/hunting $\uparrow \Rightarrow$ Bio-diversity loss
Spatial reallocation: Protected areas $\Rightarrow$ Resource depletion in other locations $\uparrow$

Research question

Are there policies that improve both local populations' welfare and ecological conservation?

This paper:

1. Builds a spatial general equilibrium model with multiple rural sectors
2. Estimates the model using data from river basins in the Peruvian Amazon
   Agglomeration: Population density $\uparrow \Rightarrow$ Productivity $\uparrow$
   Congestion: Population density $\uparrow \Rightarrow$ Productivity $\downarrow$

Human-Nature Interactions across Space in Rainforests

Policymaker's trade-offs:

- Rainforest conservation vs. Local populations' welfare:

e.g. Cost of forest clearing $\uparrow \Rightarrow$ Income from agriculture $\downarrow \Rightarrow$ Welfare loss

- Human adaptation may undermine conservation policy goals:

e.g. Sectoral reallocation: Cost of forest clearing $\uparrow \Rightarrow$ Fishing/hunting $\uparrow \Rightarrow$ Bio-diversity loss
Spatial reallocation: Protected areas $\Rightarrow$ Resource depletion in other locations $\uparrow$

Research question

Are there policies that improve both local populations' welfare and ecological conservation?

This paper:

1. Builds a spatial general equilibrium model with multiple rural sectors
2. Estimates the model using data from river basins in the Peruvian Amazon
   Agglomeration: Population density $\uparrow \Rightarrow$ Productivity $\uparrow$
   Congestion: Population density $\uparrow \Rightarrow$ Productivity $\downarrow$
3. Evaluates counterfactuals (protection policies & transport infrastructure)

A. ***Yes***

This Paper: Preview of Findings

Estimating density externalities by exploiting plausibly exogenous variation in the structure of river networks:

- **Agglomeration in agriculture** > **Congestion in access to land**

  Concentration $\Rightarrow$ Productivity $\uparrow$ & Deforestation *per farmer* $\downarrow$

- **Congestion with spatial spillovers in natural resource extraction**

This Paper: Preview of Findings

Estimating density externalities by exploiting plausibly exogenous variation in the structure of river networks:

- **Agglomeration in agriculture** > **Congestion in access to land**

  Concentration ⇒ Productivity ↑ & Deforestation *per farmer* ↓

- **Congestion with spatial spillovers in natural resource extraction**

The density externalities are quantitatively important:

e.g. Without the agglomeration ⇒ welfare ↓ 11% & Deforestation ↑ 32%

This Paper: Preview of Findings

Estimating density externalities by exploiting plausibly exogenous variation in the structure of river networks:

- **Agglomeration in agriculture** > **Congestion in access to land**

  Concentration $\Rightarrow$ Productivity $\uparrow$ & Deforestation *per farmer* $\downarrow$

- **Congestion with spatial spillovers in natural resource extraction**

The density externalities are quantitatively important:

e.g. Without the agglomeration $\Rightarrow$ welfare $\downarrow$ 11% & Deforestation $\uparrow$ 32%

Mechanisms behind the agglomeration:

- Economies of scale in transport technology and agricultural intensification

This Paper: Preview of Findings

Estimating density externalities by exploiting plausibly exogenous variation in the structure of river networks:

- **Agglomeration in agriculture** > **Congestion in access to land**

  Concentration ⇒ Productivity ↑ & Deforestation *per farmer* ↓

- **Congestion with spatial spillovers in natural resource extraction**

The density externalities are quantitatively important:

e.g. Without the agglomeration ⇒ welfare ↓ 11% & Deforestation ↑ 32%

Mechanisms behind the agglomeration:

- Economies of scale in transport technology and agricultural intensification

Counterfactuals: Well-targeted Place-based protection policies and transport infrastructure are complementary to improving human & ecological well-being

Human welfare ↑ Deforestation ↓ Natural resource depletion ↓

Data & Facts

2 Reasons why the Peruvian Amazon is an ideal setting

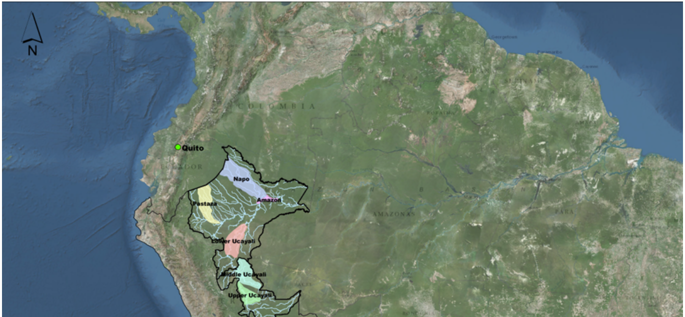
❶ Traditional ways of life in remote areas without modern technology and large-scale external investments

⟹ Attribute resource extractions to small-scale farmers and hunter-gatherers & focus on density externalities caused by them

* Small-scale deforestation recently increased in the Amazon (Kalamandeen et al. 2018)

❷ River networks almost solely constitute the transportation routes

⟹ Identify key structural parameters by exploiting exogenous river shapes



Primary Livelihoods in the Peruvian Amazon

1. **Agricultural sector**:
   - **Food crops** (manioc; farina; plantain)
   - **Cash crops** (rice; maize; beans; sugar cane; vegetables; fruits)
2. **Extractions of natural resource products**:
   - **Wild animal extractions**:
     - Fishing
     - Game meat (Hunting)
   - **Forest products**:
     - NTFP (Non-timber forest products)
     - Timber
3. Non-food manufacturing items are typically from an urban center

Primary Data

1. **Grid cells** (1km $\times$ 1km):
   - The unit of analysis in the model
   - Geographical and remote sensing information

Primary Data

1. **Grid cells** (1km $\times$ 1km):
   - The unit of analysis in the model
   - Geographical and remote sensing information
2. **Peruvian Amazon Rural Livelihoods and Poverty (PARLAP)** project:
   - Original **community census (CC, 2012-2014)** and household survey (HS, 2014-2016) from rural communities in the four major river basins

     $\rightarrow$ Sectoral populations, prices, transport modes, and many others

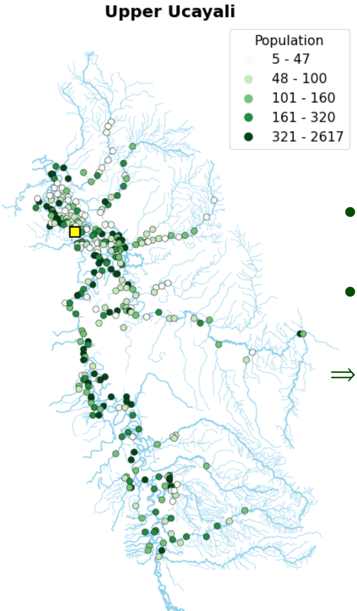
Primary Data

1. **Grid cells** (1km × 1km):
   - The unit of analysis in the model
   - Geographical and remote sensing information
2. **Peruvian Amazon Rural Livelihoods and Poverty (PARLAP)** project:
   - Original **community census (CC, 2012-2014)** and household survey (HS, 2014-2016) from rural communities in the four major river basins

     → Sectoral populations, prices, transport modes, and many others
3. **National censuses** by National Institute of Statistics and Informatics (INEI):
   - Peru Population and Housing Census (1993, 2007, 2017)

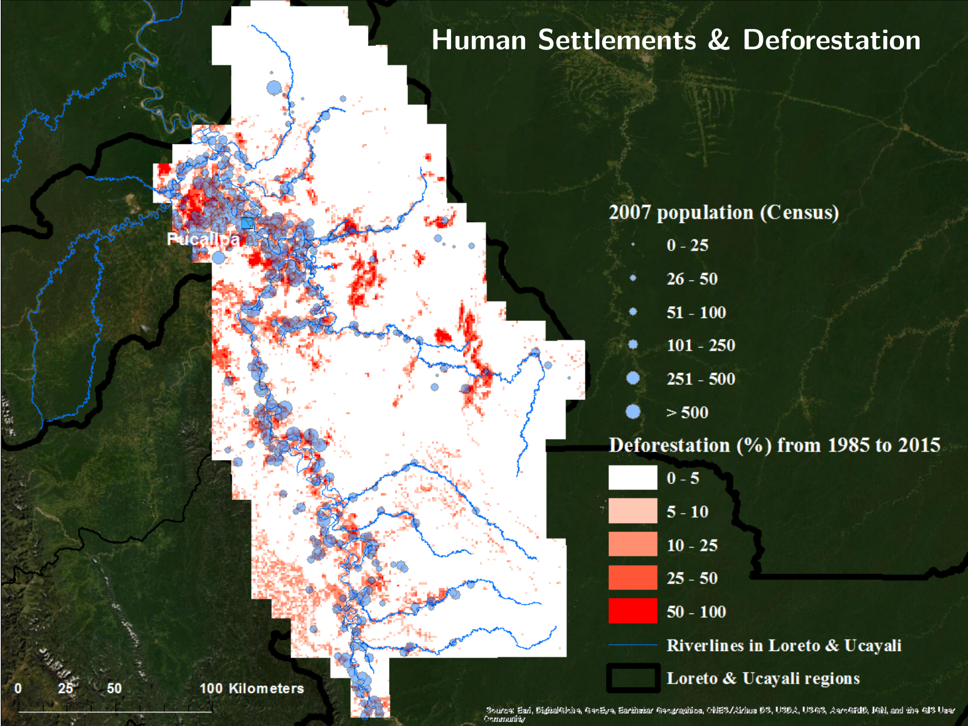
     → Complement population information (esp. urban populations)
   - Peruvian Agricultural Census (2012) → Technology use by all producers

Spatial Concentration and Dispersion of Communities and Populations

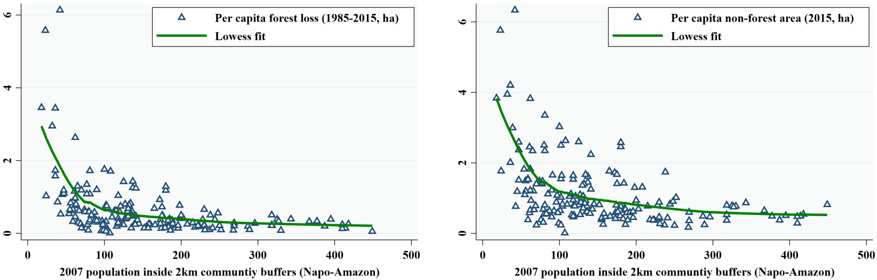


- The legend is based on quantiles (throughout the presentation)
- More than 80% of the rural communities have populations smaller than 320

$\Rightarrow$ Suggestive of *agglomeration and congestion forces of economic activities*


Human Settlements & Deforestation
Pucallpa
2007 population (Census)
0 - 25
26 - 50
51 - 100
101 - 250
251 - 500
> 500
Deforestation (%) from 1985 to 2015
0 - 5
5 - 10
10 - 25
25 - 50
50 - 100
Riverlines in Loreto & Ucayali
Loreto & Ucayali regions
0 25 50 100 Kilometers
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

The Negative and Convex Relationship between Population & Per Capita Land Footprint



Suppose, for simplicity, take this as structural, then it implies:

- Congestion force in forest clearing (even without the land market)
- A mean preserving reduction in the variance of settlement size can decrease total deforestation

Model

Spatial Model of Rainforest Communities: Intuition

- The balance between concentration and dispersion forces determines the spatial distribution of economic activities

Spatial Model of Rainforest Communities: Intuition

- The balance between concentration and dispersion forces determines the spatial distribution of economic activities
- Concentration forces:
  - Agglomeration in agriculture
  - Higher market access
  - Proximity to an urban center

Spatial Model of Rainforest Communities: Intuition

- The balance between concentration and dispersion forces determines the spatial distribution of economic activities
- Concentration forces:
  - Agglomeration in agriculture
  - Higher market access
  - Proximity to an urban center
- Dispersion forces:
  - Congestion in forest clearing
  - Congestion in natural resource extraction

Spatial Model of Rainforest Communities: Setup

GE in a river basin, consisting of locations (1km^2 cells) $o, d \in \mathcal{I} = \mathcal{R} \bigcup u$:

- $\mathcal{R}$: the set of multiple **rural** locations
- u: the urban center

Spatial Model of Rainforest Communities: Setup

GE in a river basin, consisting of locations (1km^2 cells) $o, d \in \mathcal{I} = \mathcal{R} \bigcup u$:

- $\mathcal{R}$: the set of multiple **rural** locations
- u: the urban center

3 Sectors:

- **Agriculture** (Ag): produced in **rural** locations
- **Natural resource extraction** (Nr): produced in **rural** locations
- Urban good (M): produced in the urban center

Spatial Model of Rainforest Communities: Setup

GE in a river basin, consisting of locations (1km^2 cells) $o, d \in \mathcal{I} = \mathcal{R} \bigcup u$:

- $\mathcal{R}$: the set of multiple **rural** locations
- u: the urban center

3 Sectors:

- **Agriculture** (Ag): produced in **rural** locations
- **Natural resource extraction** (Nr): produced in **rural** locations
- Urban good (M): produced in the urban center

Population:

- Each consumer inelastically supplies one unit of labor and gets wage (w_o)
- Perfectly mobile across locations while total population in the basin is fixed

Spatial Model of Rainforest Communities: Setup

GE in a river basin, consisting of locations (1km^2 cells) $o, d \in \mathcal{I} = \mathcal{R} \bigcup u$:

- $\mathcal{R}$: the set of multiple **rural** locations
- u: the urban center

3 Sectors:

- **Agriculture** (Ag): produced in **rural** locations
- **Natural resource extraction** (Nr): produced in **rural** locations
- Urban good (M): produced in the urban center

Population:

- Each consumer inelastically supplies one unit of labor and gets wage (w_o)
- Perfectly mobile across locations while total population in the basin is fixed

Trade: **Asymmetric trade costs** due to river orientations

Agriculture with Agglomeration & Congestion Externalities

$$\textbf{Land access by forest clearing}: \quad L_o(j) = \underbrace{A_{o,L} N_{o,Ag}^{-\mu_L}}_{\text{productivity}} \cdot N_{o,L}(j)$$

$$\textbf{Final output}: \quad Q_{o,Ag}(j) = \underbrace{z_{o,Ag}(j) N_{o,Ag}^{\mu_{Ag}}}_{\text{productivity}} \cdot N_{o,C}(j)^{\gamma} L_o(j)^{(1-\gamma)}$$

- $N_{o,L}$ & $N_{o,C}$: Employment for forest clearing & cropping
- $N_{o,Ag} = N_{o,L} + N_{o,C}$: Total employment for agriculture
- μ_L: Parameter governing **congestion force in forest clearing** ▸ Why?
  (consistent with the stylized fact)
- μ_{Ag}: Parameter governing **agglomeration force in agricultural production and marketing**
- $z_{o,Ag}(j)$: Fréchet shock of variety j productivity
  (θ: comparative advantage; $A_{o,Ag}$: absolute advantage)

Natural Resources with Congestion Externality across Space

$$Q_o^{Nr}(j) = \underbrace{z_{o,Nr}(j)\Big[\sum_{d\in\mathcal{R}} D_{od}^{-\nu} N_{d,Nr}\Big]^{-\mu_{Nr}}}_{\text{productivity}} \cdot N_{o,Nr}(j)$$

- $N_{o,Nr}$: Total employment for natural resource extraction in o
- $z_{o,Nr}(j)$: Fréchet shock of variety j productivity
- D_{od}: River-equivalent distance between cells o & d in the shortest path
- μ_{Nr}: Parameter governing **congestion force from surrounding populations in common pool natural resource extraction**
- ν: Parameter governing **spatial decay in accessing natural resources**
- Implicit assumption: People travel longer distances for natural resource extractions (than for agriculture)

Spatial Equilibrium Conditions

1. Sectoral labor markets (Ag, Nr, M) clear
2. The overall labor market clears (given the fixed total population in each basin)
3. Utility is equalized across populated locations (due to free labor mobility)
4. The total deforested area does not exceed the available land area

Estimation

Estimating the Model in a Sequential Procedure

Parameter	Description	Estimation strategy
δ_K	Elasticity of trade cost $(K = Ag, Nr, M)$	Commodity prices from the CC
λ_{up}, λ_{land}	Relative costs in terms of downstream river	Travel time and transport costs survey
σ	Within-sector elasticity of substitution	Expenditure information from ENAHO
$\bar{\sigma}$	Across-sector elasticity of substitution	Expenditure information from ENAHO
γ	Labor share in agricultural production	From the literature
θ	Trade elasticity	From the literature
μ_L	**Congestion in forest clearing**	Linear IV using the community-level data
μ_{Ag}	**Agglomeration in agricultural production**	Model inversion and linear IV
μ_{Nr}	**Congestion in natural resource extraction**	Model inversion and non-linear GMM
ν	**Spatial decay in natural resource access**	Model inversion and non-linear GMM
$\{A_{o,K}\}$	Absolute advantages $(K = Ag, Nr)$	Calibration
A_M	Absolute advantages in the urban sector	Calibration

Estimating the Model in a Sequential Procedure

Parameter	Description	Estimation strategy
δ_K	Elasticity of trade cost $(K = Ag, Nr, M)$	Commodity prices from the CC
λ_{up}, λ_{land}	Relative costs in terms of downstream river	Travel time and transport costs survey
σ	Within-sector elasticity of substitution	Expenditure information from ENAHO
$\bar{\sigma}$	Across-sector elasticity of substitution	Expenditure information from ENAHO
γ	Labor share in agricultural production	From the literature
θ	Trade elasticity	From the literature
μ_L	**Congestion in forest clearing**	Linear IV using the community-level data
μ_{Ag}	**Agglomeration in agricultural production**	Model inversion and linear IV
μ_{Nr}	**Congestion in natural resource extraction**	Model inversion and non-linear GMM
ν	**Spatial decay in natural resource access**	Model inversion and non-linear GMM
$\{A_{o,K}\}$	Absolute advantages $(K = Ag, Nr)$	Calibration
A_M	Absolute advantages in the urban sector	Calibration

1. Obtain some parameters without solving the model ▸ Detail

Estimating the Model in a Sequential Procedure

Parameter	Description	Estimation strategy
δ_K	Elasticity of trade cost $(K = Ag, Nr, M)$	Commodity prices from the CC
λ_{up}, λ_{land}	Relative costs in terms of downstream river	Travel time and transport costs survey
σ	Within-sector elasticity of substitution	Expenditure information from ENAHO
$\bar{\sigma}$	Across-sector elasticity of substitution	Expenditure information from ENAHO
γ	Labor share in agricultural production	From the literature
θ	Trade elasticity	From the literature
μ_L	**Congestion in forest clearing**	Linear IV using the community-level data
μ_{Ag}	**Agglomeration in agricultural production**	Model inversion and linear IV
μ_{Nr}	**Congestion in natural resource extraction**	Model inversion and non-linear GMM
ν	**Spatial decay in natural resource access**	Model inversion and non-linear GMM
$\{A_{o,K}\}$	Absolute advantages $(K = Ag, Nr)$	Calibration
A_M	Absolute advantages in the urban sector	Calibration

1. Obtain some parameters without solving the model ▸ Detail
2. Given the parameters obtained in the previous steps, invert the model to recover wages and productivities that rationalize the observable sectoral populations as a spatial equilibrium ▸ Detail

Estimating the Model in a Sequential Procedure

Parameter	Description	Estimation strategy
δ_K	Elasticity of trade cost $(K = Ag, Nr, M)$	Commodity prices from the CC
λ_{up}, λ_{land}	Relative costs in terms of downstream river	Travel time and transport costs survey
σ	Within-sector elasticity of substitution	Expenditure information from ENAHO
$\bar{\sigma}$	Across-sector elasticity of substitution	Expenditure information from ENAHO
γ	Labor share in agricultural production	From the literature
θ	Trade elasticity	From the literature
μ_L	**Congestion in forest clearing**	Linear IV using the community-level data
μ_{Ag}	**Agglomeration in agricultural production**	Model inversion and linear IV
μ_{Nr}	**Congestion in natural resource extraction**	Model inversion and non-linear GMM
ν	**Spatial decay in natural resource access**	Model inversion and non-linear GMM
$\{A_{o,K}\}$	Absolute advantages $(K = Ag, Nr)$	Calibration
A_M	Absolute advantages in the urban sector	Calibration

1. Obtain some parameters without solving the model ▸ Detail
2. Given the parameters obtained in the previous steps, invert the model to recover wages and productivities that rationalize the observable sectoral populations as a spatial equilibrium ▸ Detail
3. Employ GMM to estimate parameters governing the density externalities in productivities obtained in the previous step

Step 3. Density Externalities in Agriculture

- Inverted productivity composites of agriculture:

$$\tilde{A}_{o,Ag} \equiv \underbrace{A_{o,Ag} A_{o,L}^{(1-\gamma)\theta} \kappa_1^{\theta}}_{\text{fundamentals}} \cdot \underbrace{N_{o,Ag}^{\tilde{\mu}_{Ag}\theta}}_{\text{externalities}} \quad \text{where } \tilde{\mu}_{Ag} \equiv \mu_{Ag} - (1-\gamma)\mu_L$$

- Procedure:
  1. Estimate $\tilde{\mu}_{Ag}$
  2. Estimate μ_L
  3. Back out μ_{Ag}

Step 3. Agglomeration Externality in Agriculture via Linear IV

- Inverted composite productivities of agriculture:

$$\tilde{A}_{o,Ag} \equiv \underbrace{A_{o,Ag}\kappa_1^{\theta}}_{\text{fundamentals}} \cdot \underbrace{N_{o,Ag}^{\tilde{\mu}_{Ag}\theta}}_{\text{externalities}} \quad \text{where } \tilde{\mu}_{Ag} \equiv \mu_{Ag} - (1-\gamma)\mu_L$$

- Empirical specification:

$$\ln \tilde{A}_{o,Ag} = \beta_0 + \tilde{\mu}_{Ag}\theta \ln N_{o,Ag} + \mathbf{b}X_o + \phi_B + \epsilon_{o,Ag}$$

- Endogenous: $\ln N_{o,Ag}$
- $RNA_o \equiv \sum_{d \in RC} (\tilde{\tau}_{od})^{-\theta}$: "River Network Access" as an IV
  (RC: grid cells with rivers)
- Identifying assumption ▸ Intuition:

  After controlling for ▸ geographic characteristics of the own location, productivity fundamentals are uncorrelated with accessibility to other locations
- A similar strategy for estimating μ_L using the community-level information of non-forest areas ▸ Detail

▸ Historical IV ▸ First stage ▸ Randomness

3. Congestion in Natural Resource Extraction with Spatial Spillover via Non-Linear GMM

- Inverted productivity composites of natural resource extraction:

$$\tilde{A}_{o,Nr} \equiv \underbrace{A_{o,Nr}}_{\text{fundamentals}} \cdot \underbrace{[\sum_d D_{od}^{-\nu} N_{d,Nr}]^{-\mu_{Nr}\theta}}_{\text{externalities}}$$

- Moment conditions:

$$\mathbb{E}[\epsilon_{o,Nr} \ln RNA_o] = 0 \quad \text{and} \quad \mathbb{E}[\epsilon_{o,Nr} \ln(\sum_{d|D_{o,d} \leq x} RNA_d)] = 0, \; x \in \mathcal{X}$$

  - $\epsilon_{o,Nr}$: the residual variation in $\ln A_{o,Nr}$ (productivity fundamentals)
  - $\mathcal{X} = \{2, 5, 10, 25, 50, 75, 100\,(\text{km})\}$
  - Similar to the identification strategy by Ahlfeldt et al. (2015)

- Estimate ν & μ_{Nr} by the two-step nonlinear GMM

3. Density Externalities in Agriculture and Natural Resource Extraction

Parameter	Point estimate	Standard errror	Description
(A) Agriculture			
$\tilde{\mu}_{Ag}$	0.064	0.010	$= \mu_{Ag} - (1-\gamma)\mu_L$
	J test p-value = 0.648		
μ_L	0.522	0.094	Congestion in forest clearing
μ_{Ag}	0.273		Agglomeration in agricultural production
(B) Natural resource extraction			
μ_{Nr}	0.335	0.042	Congestion in natural resource extraction
ν	0.593	0.075	Spatial decay of congestion externality
	J test p-value = 0.821		

Notes: Estimates of density externalities in agriculture (panel A) are based on the linear specification using $\ln RNA_o$ and the initial community existence in 1940 as instruments. Estimates of parameters governing congestion externality in natural resource extraction (panel B) are based on the non-linear GMM using $\ln RNA_o$ and $\{\ln \sum_{d|D_{o,d} \leq x} RNA_d\}$ for $x \in \mathcal{X} = \{2, 5, 10, 25, 50, 75, 100\}$ as instruments.

3. Density Externalities in Agriculture and Natural Resource Extraction

Parameter	Point estimate	Standard errror	Description
(A) Agriculture			
$\tilde{\mu}_{Ag}$	0.064	0.010	$= \mu_{Ag} - (1-\gamma)\mu_L$
	J test p-value $= 0.648$		
μ_L	0.522	0.094	Congestion in forest clearing
μ_{Ag}	0.273		Agglomeration in agricultural production
(B) Natural resource extraction			
μ_{Nr}	0.335	0.042	Congestion in natural resource extraction
ν	0.593	0.075	Spatial decay of congestion externality
	J test p-value $= 0.821$		

Notes: Estimates of density externalities in agriculture (panel A) are based on the linear specification using $\ln RNA_o$ and the initial community existence in 1940 as instruments. Estimates of parameters governing congestion externality in natural resource extraction (panel B) are based on the non-linear GMM using $\ln RNA_o$ and $\{\ln \sum_{d|D_{o,d} \leq x} RNA_d\}$ for $x \in \mathcal{X} = \{2, 5, 10, 25, 50, 75, 100\}$ as instruments.

- Robust to different IVs and samples ▸ Table
- Robust to different controls ▸ Table
- How important are these parameter values quantitatively? (next)

Quantitatively large effects of the agglomeration externality on

- **improving human welfare & reducing deforestation**
- **at the expense of natural resource depletion**

Counterfactual Outcomes **without the Agglomeration Externality**

Basin	Welfare	Deforestation	Natural resource depletion
Napo	-12.2%	+59.9%	-0.9%
Pastaza	-9.8%	+26.2%	-0.8%
LowerUcayali	-14%	+22.6%	-3.2%
UpperUcayali	-7.8%	+19.2%	-1.3%

- $\mu_{Ag} \rightarrow 0$

Quantitatively large effects of the agglomeration externality on

- **improving human welfare & reducing deforestation**
- **at the expense of natural resource depletion**

Counterfactual Outcomes **without the Agglomeration Externality**

Basin	Welfare	Deforestation	Natural resource depletion
Napo	-12.2%	+59.9%	-0.9%
Pastaza	-9.8%	+26.2%	-0.8%
LowerUcayali	-14%	+22.6%	-3.2%
UpperUcayali	-7.8%	+19.2%	-1.3%

- $\mu_{Ag} \to 0$
- Spatial reallocation of agriculture: from concentration into dispersion because the congestion externality in forest clearing dominates
- Sectoral reallocation: more agricultural employment to feed the population given that consumption demands across Ag & Nr goods are complementary

Maps

Mechanisms behind the Agglomeration Externality in Agriculture

1. Economies of scale in transport technology ▸ Detail
    - Endogenous transport modes (different types of boats available)
    - Endogenous transaction costs
    - Trade costs decrease with origin populations
    - Isomorphic to the original model
2. Economies of scale in agricultural intensification ▸ Detail

Counterfactuals

Counterfactual Experiments: Overview

The aim is to design a “win-win” policy that simultaneously achieves:

- Local populations’ welfare ↑
- Deforestation ↓
- Natural resource depletion ↓

Counterfactual experiments:

1. Resettlement and protection policies ▸ Detail
2. Improvement of transport infrastructure
3. Combination of them

Improving River Transport Infrastructure: Overview

- **High trade costs**:
  - Asymmetric transport costs due to river orientations
  - Seasonality of transport costs due to water level fluctuations
  - Slow speed of river boats
- **Transport infrastructure investments**:
  - Better quality boats
  - River dredging

    Amazon Waterway Project: Government scheme with Chinese investment to deepen and widen the central parts of rivers to allow larger ships to travel

Improving River Transport Infrastructure: Overview

- **High trade costs**:
  - Asymmetric transport costs due to river orientations
  - Seasonality of transport costs due to water level fluctuations
  - Slow speed of river boats
- **Transport infrastructure investments**:
  - Better quality boats
  - River dredging

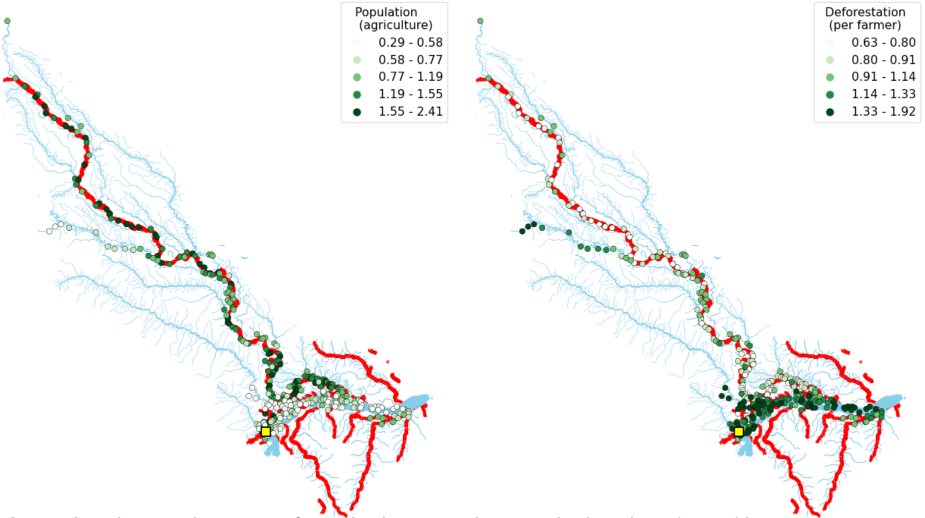
    Amazon Waterway Project: Government scheme with Chinese investment to deepen and widen the central parts of rivers to allow larger ships to travel
- Replace the **downstream-river-equivalent distance** with:

$$D_{od} = D_{od,initial,down} + \lambda_{up} D_{od,initial,up} + \lambda_{land} D_{od,land} + \lambda_{upgraded} D_{od,upgraded}$$

where $\lambda_{upgraded} = 0.8$ & symmetric transport cost in the "upgraded" part

Connecting Hinterlands to the Central Area of Basin ⇒

- **Spatial reallocation of farmers toward remote areas**
- **Deforestation per farmer ↓ in remote areas**



Legend: values in the counterfactual relative to those in the benchmark equilibrium
Red lines: transport infrastructure improvement

Connecting Hinterlands to the Central Area of Basin ⇒

- **Welfare ↑**
- **Deforestation ↓**
- **Natural resource depletion (↓)?**

Basin	Welfare	Deforestation	Natural resource depletion
Napo	+1.8%	**-1.6%**	-0.3%
Pastaza	+1.3%	**-2.8%**	-0.6%
LowerUcayali	+2.5%	**-2.8%**	-2.9%
UpperUcayali	+1.2%	**-1.5%**	**+0.3%**

- Total deforestation decreases by reducing the variance of the settlement size in the river basin, given the structure of congestion forces in access to land (negative and convex relationship between population and per-farmer deforestation)
- **The agglomeration benefits spread more evenly across the basin with more moderate-sized settlements**

Connecting Hinterlands to the Central Area of Basin ⇒

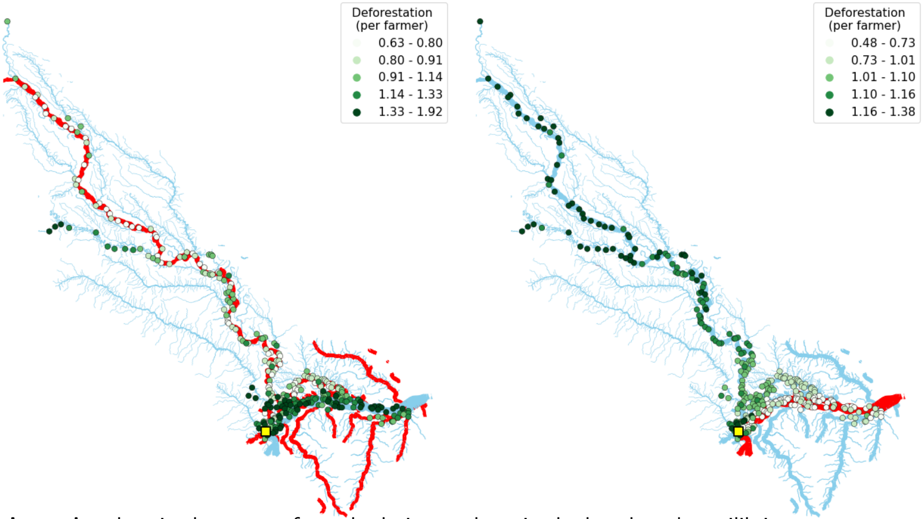
- **Welfare ↑**
- **Deforestation ↓**
- **Natural resource depletion (↓)?**

Basin	Welfare	Deforestation	Natural resource depletion
Napo	+1.8%	**-1.6%**	-0.3%
Pastaza	+1.3%	**-2.8%**	-0.6%
LowerUcayali	+2.5%	**-2.8%**	-2.9%
UpperUcayali	+1.2%	**-1.5%**	**+0.3%**

- Total deforestation decreases by reducing the variance of the settlement size in the river basin, given the structure of congestion forces in access to land (negative and convex relationship between population and per-farmer deforestation)
- **The agglomeration benefits spread more evenly across the basin with more moderate-sized settlements**

* Close to the win-win policy, but not perfect (see Upper Ucayali)

Connecting Hinterlands to the Central Area of Basin (left) vs. Concentrating the Infrastructure Investment in the Center (right)



Legend: values in the counterfactual relative to those in the benchmark equilibrium
Red lines: transport infrastructure improvement

The direction of deforestation impact depends on where in the spatial structure of river networks the improvement takes place

Basin	Welfare	Deforestation	Natural resource depletion
(A) Transport infrastructure improved by connecting hinterlands to the center			
Napo	+1.8%	**-1.6%**	-0.3%
(B) Transport infrastructure improved by concentrating investments in the center			
Napo	+1%	**+7%**	-0.4%

The direction of deforestation impact depends on where in the spatial structure of river networks the improvement takes place

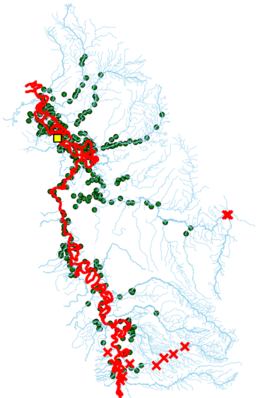
Basin	Welfare	Deforestation	Natural resource depletion
(A) Transport infrastructure improved by connecting hinterlands to the center			
Napo	+1.8%	**-1.6%**	-0.3%
(B) Transport infrastructure improved by concentrating investments in the center			
Napo	+1%	**+7%**	-0.4%

Improving the infrastructure only in densely populated areas ⇒ Deforestation ↑

- The population is more concentrated in the central area of the basin
- On the flip side, **much smaller communities with much higher deforestation *per farmer* in hinterlands**, which is dominating here

(A) Protecting the rural frontier &
(B) Transport infrastructure that connects hinterlands to the center

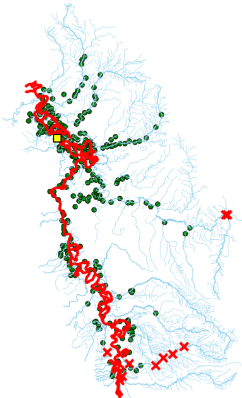
Basin	Welfare	Deforestation	Natural resource depletion
Napo	+1.6%	-7%	-0.6%
Pastaza	+1.1%	-5%	-0.4%
LowerUcayali	+2.3%	-4.9%	-3.1%
UpperUcayali	+1.1%	-3.5%	-0.5%



- **The trade-offs are resolved:**
  - Welfare ↑
  - Deforestation ↓
  - Natural resource extraction ↓

(A) Protecting the rural frontier &
(B) Transport infrastructure that connects hinterlands to the center

Basin	Welfare	Deforestation	Natural resource depletion
Napo	+1.6%	-7%	-0.6%
Pastaza	+1.1%	-5%	-0.4%
LowerUcayali	+2.3%	-4.9%	-3.1%
UpperUcayali	+1.1%	-3.5%	-0.5%



- **The trade-offs are resolved:**
  - Welfare ↑
  - Deforestation ↓
  - Natural resource extraction ↓

(A) More compact basin for human settlements

⇒ Overall scope of natural resource extraction activities is narrowed & congestion ↑

(B) Integrated between the center and hinterlands

⇒ Agglomeration benefits spread more evenly

Well-targeted protection policies and transport infrastructure are complementary to improving human and ecological well-being

Counterfactuals	**Welfare**	**Deforestation**	**Natural resource depletion**
(A) Protection policies			
i. Protecting the rural frontier	–	–	–
ii. Targeting the smallest communities	–	–	+
(B) Transport infrastructure			
i. Connecting hinterlands to the center	+	–	?
ii. Concentrating in the center	+	+	?
(A) i. + (B) i.	**+**	**−**	**−**

Conclusions

This paper:

- Applies a multi-sector spatial GE model to rainforest communities
- Estimates density externalities (agglomeration & congestion)

Conclusions

This paper:

- Applies a multi-sector spatial GE model to rainforest communities
- Estimates density externalities (agglomeration & congestion)

RQ. ***Are there policies that improve both local populations' welfare and ecological conservation?***

Conclusions

This paper:

- Applies a multi-sector spatial GE model to rainforest communities
- Estimates density externalities (agglomeration & congestion)

RQ. ***Are there policies that improve both local populations' welfare and ecological conservation?***

A. ***Yes***

* Combination of a protection policy and transport infrastructure investments
* Spatial targeting matters for both

Conclusions

This paper:

- Applies a multi-sector spatial GE model to rainforest communities
- Estimates density externalities (agglomeration & congestion)

RQ. ***Are there policies that improve both local populations' welfare and ecological conservation?***

A. ***Yes***

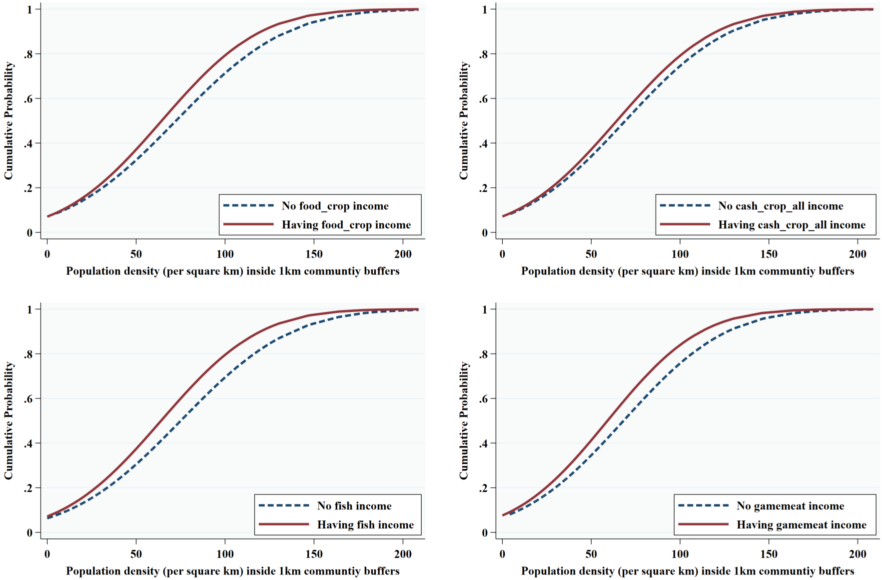
* Combination of a protection policy and transport infrastructure investments
* Spatial targeting matters for both

Future research:

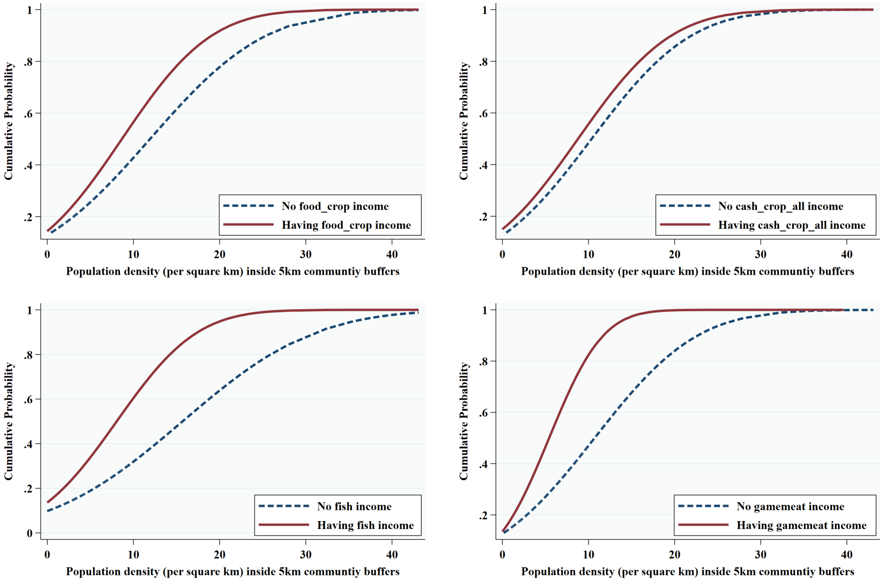
- Dynamics: community formation, resource depletion, external investments
- Across-sector externalities
- Indigenous populations' values of their traditional ways of life

Appendix

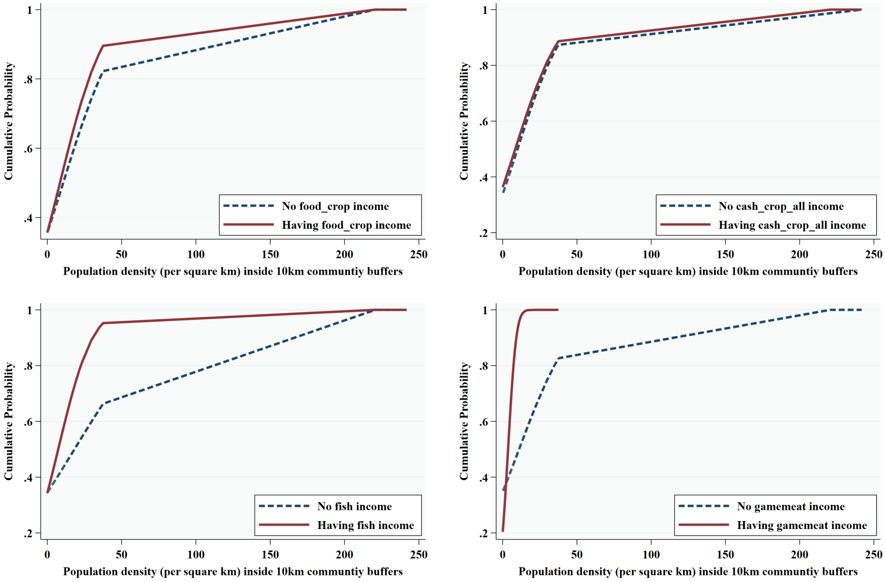
Population Density (*1km* buffer) & Activity/Occupation: Agricultural Sector vs. Wild Animal Extractions



Population Density (*5km* buffer) & Activity/Occupation: Agricultural Sector vs. Wild Animal Extractions



Population Density (*10km* buffer) & Activity/Occupation: Agricultural Sector vs. Wild Animal Extractions



Spatial Distribution of Agriculture and Natural Resource Extraction

- Population density in a smaller buffer of a community becomes close to the population density of that community itself
- A smaller population density in a large buffer of a community implies more sparseness of communities and less competition over natural resources
- **Spatial distributions of natural resource extractions become more contrastable from agricultural activities as the buffer size enlarges** ($x = 5km, 10km$ compared to $x = 1km, 2km$)

Back

Congestion Forces in Land Access ▸ Back

- Farmers clear forests to obtain agricultural land only nearby their residential locations in the absence of the land market and property rights and with a high monitoring cost (mean land footprint depth from river $\approx$ 1 km)
- The monitoring cost and the negotiation cost for allocating land areas to farmers increase as the agricultural population increases
- Therefore, deforested areas cannot increase proportionally to the increase in the population size in a community

- The effect of the cooperative nature of forest clearing may be large among small communities: consistent with the convexity

Step 1. Obtaining Parameters without Solving the Model

Parameter	Description	Estimation strategy	Value
δ_{Ag}	Elasticity of trade cost	Commodity prices from the CC	0.178
δ_{Nr}	Elasticity of trade cost	Commodity prices from the CC	0.137
δ_{M}	Elasticity of trade cost	Commodity prices from the CC	0.098
λ_{up}	Relative upstream-river travel cost	Travel time and transport costs survey	1.282
λ_{land}	Relative land travel cost	Travel time and transport costs survey	36.767
σ	Within-sector elasticity of substitution	Expenditure information from ENAHO	2.401
$\bar{\sigma}$	Across-sector elasticity of substitution	Expenditure information from ENAHO	0.752
γ	Labor share in agricultural production	From the literature	0.6
θ	Trade elasticity	From the literature	7.8

Back

Step 2. Model Inversion

- Observable data: sectoral populations ($\{N_{o,Ag}\}$, $\{N_{o,Nr}\}$, $\{N_{u,M}\}$)
- Use the $2|\mathcal{R}| + 1 + |\mathcal{I}|$ equations from the spatial equilibrium conditions (sectoral labor market clearing + utility equalization across space)

  with the observables

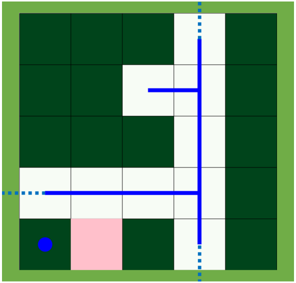
  to solve for $2|\mathcal{R}| + 1 + |\mathcal{I}|$ unknowns (productivity composites + wages): $\{\tilde{A}_{o,Ag}\}$, $\{\tilde{A}_{o,Nr}\}$, $A_{u,M}$, $\{w_o\}$

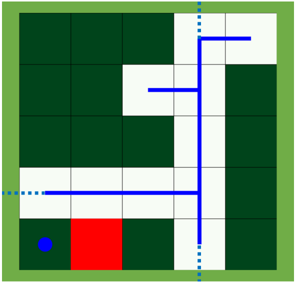
  → Use the inverted productivity composites as data in the next step

Back

Intuition of Identifying the Density Externalities

$RNA_o \equiv \sum_{d \in RC} (\tilde{\tau}_{od})^{-\theta}$: River Network Access ($RC$: white cells)

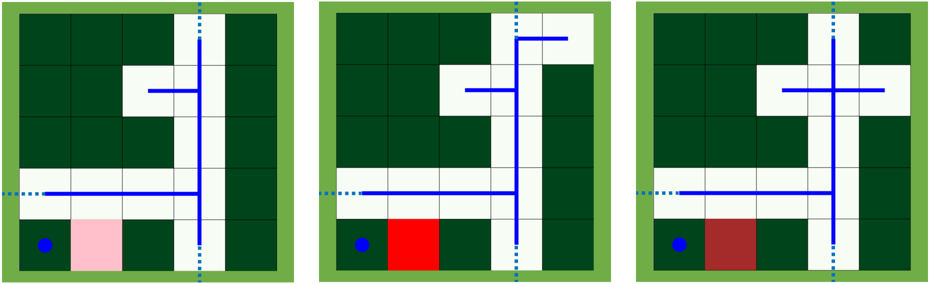




RNA **at the pink cell** < RNA **at the red cell**

Intuition of Identifying the Density Externalities

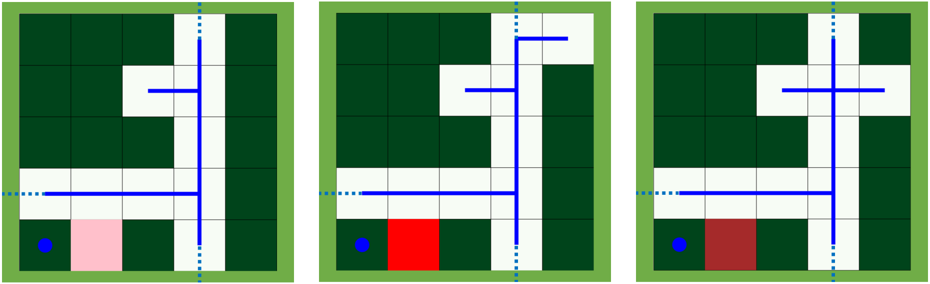
$RNA_o \equiv \sum_{d \in RC} (\tilde{\tau}_{od})^{-\theta}$: River Network Access ($RC$: white cells)



RNA **at the pink cell** $<$ RNA **at the red cell** $<$ RNA **at the brown cell**

Intuition of Identifying the Density Externalities

$RNA_o \equiv \sum_{d \in RC} (\tilde{\tau}_{od})^{-\theta}$: River Network Access ($RC$: white cells)



RNA **at the pink cell** $<$ RNA **at the red cell** $<$ RNA **at the brown cell**

- **Independence**: Given the same observable agricultural conditions (river proximity, water areas, soil conditions, etc), unobservable productivity fundamentals are uncorrelated with the variation in RNA *that stems from exogenous river shapes in locations far away from the own location*
- **Exclusion**: RNA (as a market potential shifter) affects productivity only through its effect on employment and thus through externalities that arise

Back

Geographic Controls

- River cell dummy
- Distance to the river point and its square
- Interaction between the above two
- River confluences
- Elevation
- Flood experience
- Geology measures
- Water (main and non-main) areas
- Distance to the urban center

Back

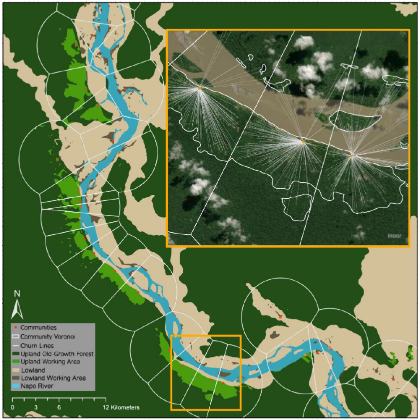
Historical IV

IV: Community existence in its current location by 1940

- The primary reason for early settlement was the opportunity to extract natural resource products
- The Amazon Rubber Boom:
  - Began the late 19th century, but collapsed around 1940
  - Significantly impacted initial settlements (Barham et al. 1996; Coomes 1995)

⇒ The locations of communities established before 1940 were likely to be determined primarily by natural resource endowments, not by advantages in agricultural productivity

Back



Voronoi Polygons and Land Footprint around the Census Communities

Notes: To proxy community boundaries for agricultural land use, we partition land in the study area into voronoi polygons. We define community boundaries as being up to 5 km from the centroid of the communities in the CC data. Within each community voronoi polygon, we detect all patches of agricultural fields and secondary forests through satellite images. We then sum them up to calculate the working area (land footprint) of each community. See Coomes et al. (2021) for more details. This community-level land footprint information is used for estimating the congestion externality in forest clearing.

Back

Table: River Networks, Initial Communities, and Current Populations

	$\log(N_{o,Ag})$			Community existence (1940)	
	(1)	(2)	(3)	(4)	(5)
$\log(RNA_o)$	0.758***		0.711***	-0.0145	0.0699
	(0.223)		(0.218)	(0.0254)	(0.0726)
Community existence (1940)		0.740***	0.730***		
		(0.0983)	(0.0980)		
Basin FE	Yes	Yes	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes	No	Yes
Mean (Dep. var.)	4.322	4.322	4.322	0.194	0.194
SD (Dep. var.)	1.192	1.192	1.192	0.395	0.395
R^2	0.154	0.195	0.206	0.094	0.117
Observations	893	893	893	904	899

Notes: Robust standard errors in parentheses. The sample includes 1 square km grid cells that have positive populations. Geographical controls include a dummy of high river orders (4 and 5), distance to the urban center, distance to the river, squared distance to the river, interaction terms of these two variables with a river cell dummy, elevation, river confluences, flood vulnerability, geology measures, and open water access measures.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

▸ Back

(A) River Network Access

	(1) Water share: non-main channel	(2) River confluence: 1st×2nd or 2nd×3rd	(3) River confluence: 3rd×4th	(4) Flood vulnerability	(5) Pleistocene soil share	(6) Tertiary soil share
$\log(RNA_o)$	0.00751	0.0470	-0.0743	-0.217	-0.0444	-0.0498
	(0.0161)	(0.0470)	(0.0618)	(0.307)	(0.0362)	(0.0474)
Mean (Dep. var.)	0.030	0.077	0.083	1.606	0.021	0.211
SD (Dep. var.)	0.087	0.266	0.277	1.606	0.115	0.344
R^2	0.068	0.095	0.137	0.130	0.057	0.735
Observations	899	899	899	899	899	899

(B) Early human settlements

	(1) Water share: main channel	(2) Water share: non-main channel	(3) Flood vulnerability	(4) Floodplain soil share	(5) Pleistocene soil share	(6) Tertiary soil share
Community existence (1940)	0.0263	-0.00352	0.218	0.00191	0.00777	-0.0108
	(0.0193)	(0.00698)	(0.142)	(0.0268)	(0.0122)	(0.0257)
Mean (Dep. var.)	0.109	0.030	1.606	0.584	0.021	0.211
SD (Dep. var.)	0.203	0.087	1.606	0.359	0.115	0.344
R^2	0.162	0.038	0.116	0.250	0.030	0.243
Observations	899	899	899	899	899	899
Basin FE	Yes	Yes	Yes	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors in parentheses. The sample includes 1 square km grid cells that have positive populations. In panel (A), geographical controls include a dummy of high river orders (4 and 5), distance to the urban center, distance to the river, squared distance to the river, interaction terms of these two variables with a river cell dummy, elevation, water share of main channel rivers, and floodplain soil share. In panel (B), geographical controls include a dummy of high river orders (4 and 5), distance to the urban center, distance to the river, squared distance to the river, interaction terms of these two variables with a river cell dummy, elevation, and river confluences.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

▸ Back

Table: Agglomeration Externality in Agriculture

	The calibrated value of $\log(\tilde{A}_{o,Ag})$							
	All locations				$N_o < 1000$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\log(N_{o,Ag})$	0.676***	0.440**	0.514***	0.501***	0.735***	0.384**	0.509***	0.464***
	(0.0207)	(0.171)	(0.0809)	(0.0790)	(0.0196)	(0.169)	(0.124)	(0.109)
Basin FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IV: RNA	No	Yes	No	Yes	No	Yes	No	Yes
IV: Historical	No	No	Yes	Yes	No	No	Yes	Yes
Mean (Dep. var.)	-0.096	-0.096	-0.096	-0.096	-0.172	-0.172	-0.172	-0.172
SD (Dep. var.)	4.578	4.578	4.578	4.578	4.614	4.614	4.614	4.614
First stage *F*-stat		11.502	56.653	31.005		15.298	35.632	22.822
Hansen's *J* test *p*-value				0.648				0.472
Observations	893	893	893	893	852	852	852	852

Notes: Robust standard errors in parentheses. The sample includes 1 square km grid cells that have positive populations. We use $\log(RNA_o)$ (IV: RNA) and the initial community existence in 1940 (IV: Historical) as instruments for $\log(N_{o,Ag})$. Geographical controls include a dummy of high river orders (4 and 5), distance to the urban center, distance to the river, squared distance to the river, interaction terms of these two variables with a river cell dummy, elevation, river confluences, flood vulnerability, geology measures, and open water access measures.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Back

Table: Agglomeration Externality in Agriculture

	The calibrated value of $\log(\tilde{A}_{o,Ag})$						
	IV						OLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\log(N_{o,Ag})$	0.434***	0.519***	0.519***	0.521***	0.509***	0.501***	0.676***
	(0.0920)	(0.0789)	(0.0788)	(0.0789)	(0.0789)	(0.0790)	(0.0207)
log (Elevation)		2.341***	2.354***	2.324***	2.360***	2.397***	2.252***
		(0.171)	(0.175)	(0.179)	(0.176)	(0.177)	(0.176)
River confluence (1st×2nd or 2nd×3rd)			0.0155	0.0186	0.0206	0.0309	0.0180
			(0.0958)	(0.0964)	(0.0982)	(0.0995)	(0.0969)
River confluence (3rd×4th)			-0.0356	-0.0339	-0.0246	-0.0266	0.0173
			(0.0724)	(0.0723)	(0.0730)	(0.0733)	(0.0618)
Flood vulnerability (1-4)				-0.0115	-0.00947	-0.0123	-0.0154
				(0.0136)	(0.0137)	(0.0137)	(0.0130)
Water share: non-main channel					0.0806	0.123	-0.00146
					(0.238)	(0.238)	(0.203)
Water share: main channel					0.161	0.185	0.189
					(0.122)	(0.121)	(0.120)
Floodplain soil share						0.127**	0.126**
						(0.0625)	(0.0575)
Pleistocene soil share						0.175	0.333
						(0.222)	(0.227)
Basin FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean (Dep. var.)	-0.094	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096
SD (Dep. var.)	4.576	4.578	4.578	4.578	4.578	4.578	4.578
First stage *F*-stat	28.030	29.419	29.974	29.634	30.770	31.005	
Observations	894	893	893	893	893	893	893

Notes: Robust standard errors in parentheses. The sample includes 1 square km grid cells that have positive populations. We use $\log(RNA_o)$ and the initial community existence in 1940 as instruments for $\log(N_{o,Ag})$. Other controls include distance to the urban center, distance to the river, squared distance to the river, and interaction terms of these two variables with a river cell dummy.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table: Density Externality in Forest Clearing

	log (per capita land footprint)					
	All locations		$N_o < 1000$		$N_o < 500$	
	(1) OLS	(2) IV	(3) OLS	(4) IV	(5) OLS	(6) IV
$\log(N_{o,Ag})$	-0.650***	-0.522***	-0.654***	-0.552***	-0.674***	-0.545***
	(0.0307)	(0.0940)	(0.0323)	(0.109)	(0.0346)	(0.123)
Basin FE	Yes	Yes	Yes	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes	Yes	Yes	Yes
Mean (Dep. var.)	0.929	0.929	0.956	0.956	0.981	0.981
SD (Dep. var.)	1.231	1.231	1.218	1.218	1.223	1.223
First stage *F*-stat		34.198		28.141		23.709
Hansen's *J* test *p*-value		0.987		0.896		0.969
Observations	895	895	878	878	847	847

Notes: Robust standard errors in parentheses. The unit of anaylysis is a community in the PARLAP Community Census (CC) in 2014. We use $\log(RNA_o)$ and the initial community existence in 1940 as instruments for $\log(N_{o,Ag})$. Geographical controls include a dummy of high river orders (4 and 5), distance to the urban center, distance to the river, squared distance to the river, interaction terms of these two variables with a river cell dummy, elevation, river confluence, flood vulnerability, geology measures, and open water access measures for a grid cell where each census community belongs.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

▸ Back

Table: Congestion Externality in Natural Resource Extraction with Spatial Spillovers

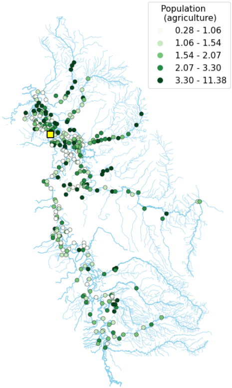
	The calibrated value of $\log(\tilde{A}_{o,Nr})$									
	IV									OLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$\log(N_{o,Nr})$	-2.127**	-1.385	-0.879	-0.581	0.0960	0.278	0.573***	0.634***	0.606***	0.950***
	(1.075)	(0.939)	(0.688)	(0.558)	(0.322)	(0.280)	(0.208)	(0.179)	(0.184)	(0.0516)
$\log(\sum_{d\|D_{o,d}\leq 2km} N_{d,Nr})$		-0.573*	-0.0343	0.0235	-0.0745	-0.0705	-0.0648	-0.0745	-0.0856	-0.0663
		(0.331)	(0.282)	(0.236)	(0.143)	(0.122)	(0.0883)	(0.0822)	(0.0838)	(0.0611)
$\log(\sum_{d\|D_{o,d}\leq 5km} N_{d,Nr})$			-0.596***	-0.286	-0.138	-0.130	-0.120*	-0.111*	-0.112*	-0.132***
			(0.189)	(0.183)	(0.106)	(0.0888)	(0.0637)	(0.0597)	(0.0613)	(0.0425)
$\log(\sum_{d\|D_{o,d}\leq 10km} N_{d,Nr})$				-0.337**	0.0345	0.0364	0.0579	0.0425	0.0322	0.0140
				(0.141)	(0.107)	(0.0885)	(0.0625)	(0.0596)	(0.0639)	(0.0378)
$\log(\sum_{d\|D_{o,d}\leq 25km} N_{d,Nr})$					-0.470***	-0.357***	-0.327***	-0.294***	-0.285***	-0.165***
					(0.0918)	(0.0837)	(0.0584)	(0.0560)	(0.0571)	(0.0283)
$\log(\sum_{d\|D_{o,d}\leq 50km} N_{d,Nr})$						-0.195***	-0.0318	-0.0548	-0.0480	-0.0619**
						(0.0610)	(0.0581)	(0.0526)	(0.0548)	(0.0242)
$\log(\sum_{d\|D_{o,d}\leq 75km} N_{d,Nr})$							-0.280***	-0.0758	-0.0407	-0.0989***
							(0.0779)	(0.125)	(0.142)	(0.0352)
$\log(\sum_{d\|D_{o,d}\leq 100km} N_{d,Nr})$								-0.258*	-0.439*	-0.263***
								(0.141)	(0.231)	(0.0498)
$\log(\sum_{d\|D_{o,d}\leq 150km} N_{d,Nr})$									0.187	0.0970*
									(0.171)	(0.0567)
Basin FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean (Dep. Var.)	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337
SD (Dep. Var.)	2.862	2.862	2.862	2.862	2.862	2.862	2.862	2.862	2.862	2.862
Observations	894	894	894	894	894	894	894	894	894	894

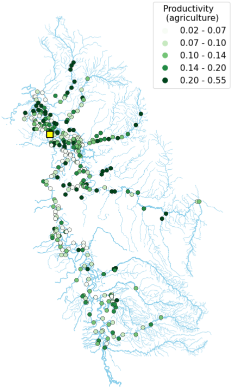
Notes: Robust standard errors in parentheses. The sample includes 1 square km grid cells that have positive populations. We use $\ln RNA_o$ and $\{\ln \sum_{d|D_{o,d}\leq x} RNA_d\}$ for $x \in \mathcal{X}$ as instruments when endogenous variables include $\log(N_{o,Nr})$ and $\{\ln \sum_{d|D_{o,d}\leq x} N_{d,Nr}\}$ for $x \in \mathcal{X}$. Geographical controls include a dummy of high river orders (4 and 5), distance to the river, squared distance to the river, interaction terms of these two variables with a river cell dummy, elevation, river confluence, flood vulnerability, geology measures, and open water access measures.

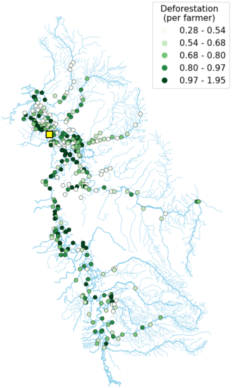
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Back

Spatial Distribution of Agriculture and Deforestation without the Agglomeration Externality







▸ Back

Economies of Scale in Transport Technology

- Consider an alternative model without the agglomeration externality in the production function but with **endogenous trade costs**:

$$\tilde{\tau}_{od,Ag} = N_{o,Ag}^{-\mu_{Ag}} \tau_{od,Ag}$$

- This model is **isomorphic to the original model**
- The trade cost can be decreasing in the origin population possibly because:
  - Large commercial boats (‘lancha’) are more likely to stop by
  - Collective investment in motor boats (‘rapido’)
  - The average transport cost charged is decreasing in the amount of products traded

Transport Modes in the Peruvian Amazon

Canue

Lancha

Peque-peque (most widely available)

Rapido (express motor boat)

Table: Community Population and Availability of Transport Modes

	Availability of Transport Modes in a Community							
	Lancha		Colectivo		Rapido		Peque-peque	
	(1) OLS	(2) IV	(3) OLS	(4) IV	(5) OLS	(6) IV	(7) OLS	(8) IV
$\log(N_{o,Ag})$	0.0469***	0.144***	0.0478***	0.0280	0.0522***	0.0566*	-0.00528	0.00418
	(0.0111)	(0.0430)	(0.0115)	(0.0383)	(0.0108)	(0.0292)	(0.00576)	(0.0156)
Basin FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean (Dep. var.)	0.492	0.492	0.386	0.386	0.110	0.110	0.972	0.972
SD (Dep. var.)	0.500	0.500	0.487	0.487	0.314	0.314	0.164	0.164
First stage F-stat		24.84462		24.84462		24.84462		24.84462
Observations	906	906	906	906	906	906	906	906

Notes: Robust standard errors in parentheses. The unit of anaylysis is a community in the PARLAP Community Census (CC) in 2014. We use $\log(RNA_o)$ and the initial community existence in 1940 as instruments for $\log(N_{o,Ag})$. Geographical controls include a dummy of high river orders (4 and 5), distance to the urban center, distance to the river, squared distance to the river, interaction terms of these two variables with a river cell dummy, elevation, river confluence, flood vulnerability, geology measures, and open water access measures for a grid cell where each census community belongs.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

- The data supports the fact that 'peque-peque' is most widely available
- Significant scale effects on the availability of 'lancha' and 'rapido'
- Consistent results for the frequency of transport modes available and other proxies of transaction costs as well

Back

Economies of Scale in Agricultural Intensification

- Test this using producer-level information from the Agricultural Census
- Modern technologies are limited: each of 24 listed modern technologies (except for boat) is used by $<10\%$ of agricultural producers
- Significant scale effects on:
  - direct inputs into land and crops (insecticides, herbicides, fungicides)
  - complementary equipment (sprayers)
  - crop processing technology to facilitate marketing (grain mill)

Table: Community Population and Modern Technology Use

(A) Basic infrastructure						
	(1) Irrigation	(2) Certified seed	(3) Crops have been certified organic	(4) Electricity for agricultural work	(5) Animals for agricultural work	(6) Tractors for agricultural work
$\log(N_{o,Ag})$	-0.00329*	-0.000857	0.0000692	-0.000688	0.00315	0.000476
	(0.00180)	(0.00430)	(0.000584)	(0.000863)	(0.00206)	(0.000811)
Mean (Dep. var.)	0.013	0.064	0.001	0.003	0.010	0.002
SD (Dep. var.)	0.112	0.245	0.037	0.054	0.098	0.044
First stage F-stat	1649.082	1649.082	1649.082	1649.082	1649.082	1649.082
Observations	25827	25827	25827	25827	25827	25827
(B) Inputs into land and crops						
	(1) Guano/manure/ compost	(2) Chemical fertilizers	(3) Insecticides	(4) Herbicides	(5) Fungicides	(6) Biologic control
$\log(N_{o,Ag})$	0.000807	0.00265**	0.0228***	0.0314***	0.0118***	-0.00239
	(0.00111)	(0.00115)	(0.00353)	(0.00371)	(0.00219)	(0.00239)
Mean (Dep. var.)	0.005	0.004	0.040	0.051	0.012	0.020
SD (Dep. var.)	0.069	0.063	0.197	0.221	0.111	0.140
First stage F-stat	1649.082	1649.082	1649.082	1649.082	1649.082	1649.082
Observations	25827	25827	25827	25827	25827	25827
(C) Animal, electrical, or mechanical energy						
	(1) Iron plow of animal traction	(2) Wooden plow of animal traction	(3) Harvester	(4) Foot plow	(5) Motorized sprayer	(6) Manual sprayer
$\log(N_{o,Ag})$	-0.000796	-0.000223	-0.000229	-0.000806	0.00197**	0.0214***
	(0.000523)	(0.000311)	(0.000282)	(0.000556)	(0.000815)	(0.00401)
Mean (Dep. var.)	0.001	0.000	0.001	0.001	0.002	0.062
SD (Dep. var.)	0.035	0.022	0.025	0.035	0.043	0.241
First stage F-stat	1649.082	1649.082	1649.082	1649.082	1649.082	1649.082
Observations	25827	25827	25827	25827	25827	25827
(D) Electrical or mechanical energy						
	(1) Grain mill	(2) Grass chopper	(3) Thresher	(4) Electric generator	(5) Wheel tractor	(6) Boat/canue/ speedboat
$\log(N_{o,Ag})$	0.00696***	0.000462	-0.00102	-0.0103***	0.000932	-0.0187**
	(0.00194)	(0.000448)	(0.000674)	(0.00323)	(0.000590)	(0.00746)
Mean (Dep. var.)	0.013	0.001	0.004	0.036	0.001	0.618
SD (Dep. var.)	0.111	0.025	0.061	0.186	0.030	0.486
First stage F-stat	1649.082	1649.082	1649.082	1649.082	1649.082	1649.082
Observations	25827	25827	25827	25827	25827	25827
Basin FE	Yes	Yes	Yes	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors in parentheses. The unit of anaylysis is a household in the 2012 Peruvian Agricultural Census. We use $\log(RNA_o)$ and the initial community existence in 1940 as instruments for $\log(N_{o,Ag})$. Geographical controls include a dummy of high river orders (4 and 5), distance to the urban center, distance to the river, squared distance to the river, interaction terms of these two variables with a river cell dummy, elevation, river confluence, flood vulnerability, geology measures, and open water access measures for a grid cell where each census community belongs.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Resettlement Policies: Overview

Q. *Is it beneficial to* ***concentrate the ecological footprint in fewer spots*** *rather than having many small communities?*

Resettlement Policies: Overview

Q. *Is it beneficial to* ***concentrate the ecological footprint in fewer spots*** *rather than having many small communities?*

(A) Protected areas that control rural frontier expansion

(B) Not allowing for small communities

Resettlement Policies: Overview

Q. *Is it beneficial to* ***concentrate the ecological footprint in fewer spots*** *rather than having many small communities?*

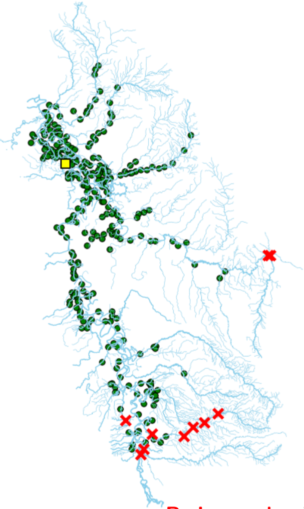
(A) Protected areas that control rural frontier expansion

(B) Not allowing for small communities

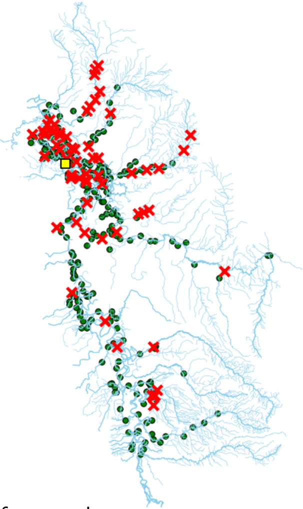
- For meaningful comparison, **each experiment directly treats an equal size of population**—2.5% of rural population in the benchmark equilibrium in each basin

E.g. (B) chooses rural locations to be treated in order, starting with the location that has the smallest population size, until the treated population reaches 2.5% of total population in each basin.

(A) Protected areas by rural frontier



(B) Small communities not allowed



Red x marks: Treated locations for resettlement

The comparison between resettlement policies illustrates the planner's ecological trade-off

Basin	Welfare	**Deforestation**	**Natural resource depletion**
(A) Protected areas: controlling rural frontier expansion			
Napo	-0.2%	**-5%**	**-0.3%**
UpperUcayali	-0.2%	**-2%**	**-0.8%**
(B) Not allowing for small communities			
Napo	-0.3%	**-12.5%**	**+0.2%**
UpperUcayali	-0.1%	**-6.9%**	**+0.5%**

(A)⇒ **natural resource depletion** ↓ but with a smaller deforestation impact

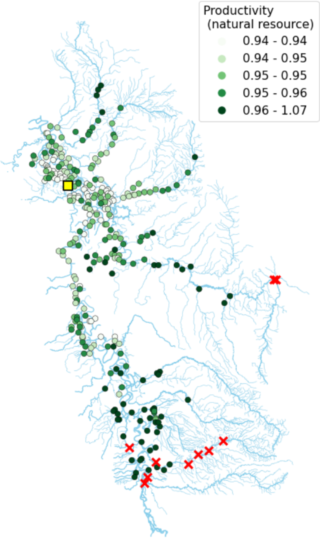
- Overall scope of natural resource extraction activities is narrowed
- Surrounding populations ↑ in most of populated areas
- Productivity ↓ due to the congestion externality with spatial spillovers

▸ Maps

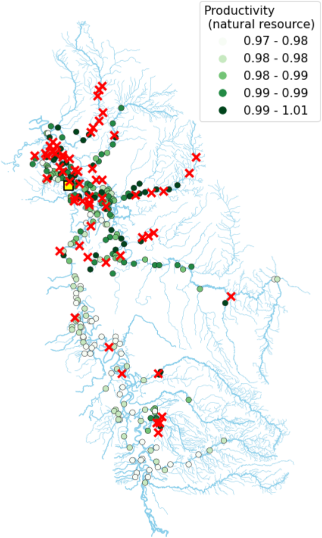
(B)⇒ **reduces deforestation the most** but **natural resource depletion** ↑

▸ Back

(A) Protected areas by rural frontier



(B) Small communities not allowed



Legend: values in the counterfactual scenario relative to those in the benchmark equilibrium

Back