

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

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# Amazon Rainforests and Populations

- Home to much of the world's bio-diversity and natural resources
- Rapid deforestation and bio-diversity loss
- Low living standards with limited modern technologies in remote areas
- Primary activities: agriculture (shifting cultivation), fishing, hunting



# **Human-Nature Interactions across Space in Rainforests**

## **Policy planner's trade-offs:**

- Rainforest conservation vs. Human welfare

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

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- ① GE framework that highlights the rainforest population's trade-off:

Richer resource endowments in sparse areas due to weak **congestion**  
vs.

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- ② Empirically examines whether **population density increases productivity (agglomeration)** or **decreases productivity (congestion)** in each sector
- ③ Evaluates counterfactual policies to answer the question

**A. Yes**

## This Paper: Empirical Findings

### A multi-sector quantitative spatial model of rainforest communities:

- Takes it to a dataset covering major river basins in the Peruvian Amazon
- Estimates density externalities, exploiting exogenous river shapes:
  - Agglomeration in agricultural production
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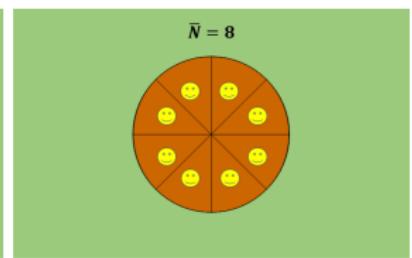
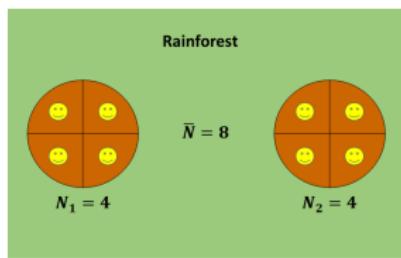
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Mechanisms behind the agglomeration externality:

- Primary: Economies of scale in transport technology
- Secondary: Economies of scale in agricultural intensification

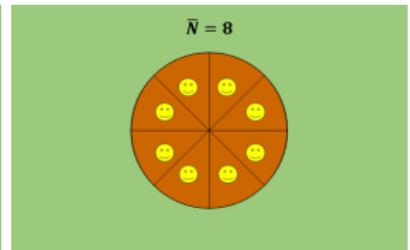
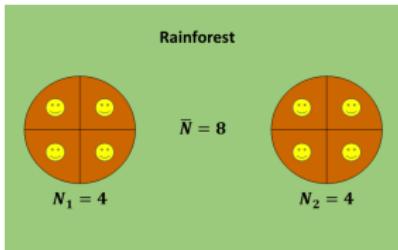
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**Q.** In the presence of externalities, is it more beneficial to **concentrate the ecological footprint in fewer spots** than having many small communities?



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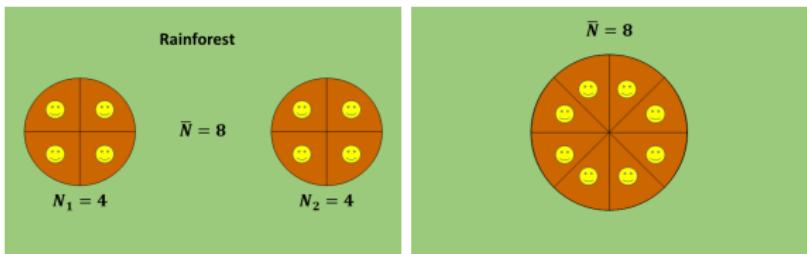
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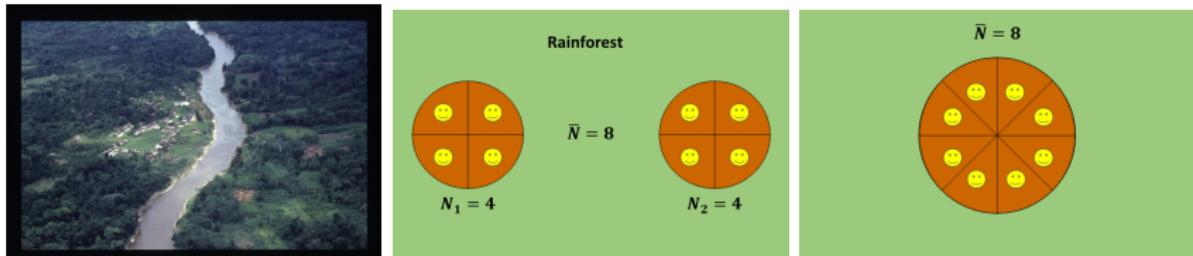
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- Protected areas and investments in transport infrastructure are complementary to eliminate the trade-offs:

Human welfare  $\uparrow$    Deforestation  $\downarrow$    Natural resource depletion  $\downarrow$

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**Agglomeration**  $\Rightarrow$  possible to achieve agricultural output  $\uparrow$  & deforestation *per farmer*  $\downarrow$

- **Protected areas and investments in transport infrastructure are complementary to eliminate the trade-offs:**
  - Human welfare  $\uparrow$    Deforestation  $\downarrow$    Natural resource depletion  $\downarrow$
- \* Place-based targeting matters for both types of interventions
- \* Policies that make the **agglomeration benefits spread more evenly across the basin** are preferable to reduce deforestation

## Literature

### 1. Trade-offs between economic development and environmental goals

- **Agriculture and deforestation:** Abman et al. (2020); Angelsen (1999JDE; 2010PNAS); Carreira et al. (2022); Foster et al. (2002); Szerman et al. (2022)
- **Policy discussion of combating deforestation:** Alix-Garcia et al. (2015AEJ); Assunção et al. (2022); Jayachandran (2022); Sousa-Rodrigues (2019REStud)
- **Commons:** Dasgupta and Mäler (1995); Hardin (1968); Ostrom (1990)

### Contributions

- Agglomeration  $\Rightarrow$  Agricultural productivity  $\uparrow$  & Deforestation  $\downarrow$
- Protection policies and transport infrastructure in a unified framework
- Competition over common pool resources in spatial general equilibrium

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## 2. Economic geography and quantitative spatial/urban models

- **Environment in spatial models:** Balboni (2020); Costinot et al. (2016JPE); Cruz & Rossi-Hansberg (2021); Hollingsworth et al. (2022); Jedwab et al. (2022)
- **Agricultural trade:** Pellegrina (2022JDE); Porteous (2019AEJ); Sotelo (2020JPE)
- **Agglomeration economies:** Ahlfeldt et al. (2015ECTA); Duranton & Puga (2020JEP)

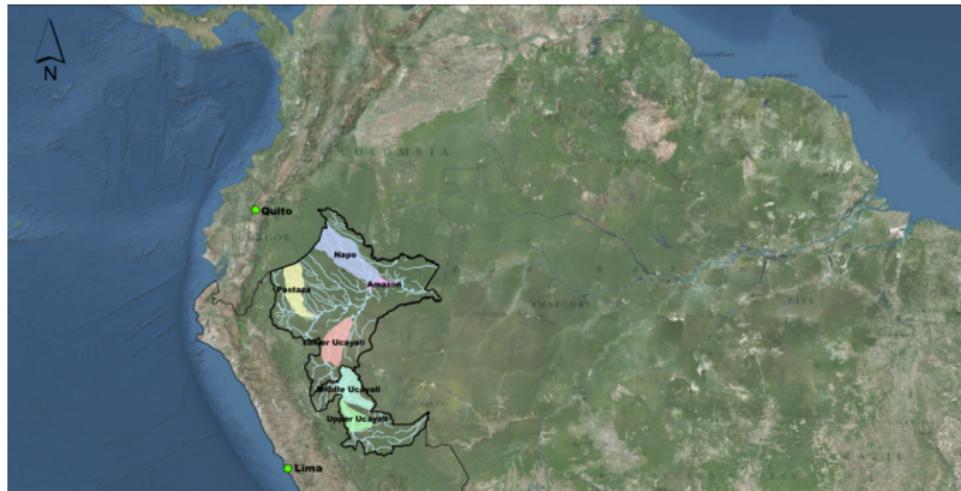
## Contributions

- Applies a quantitative spatial model in the most granular rural setting with new environmental outcomes + a higher external validity
- Density externalities in rainforests and microfoundations

# **Setting & Data**

## 2 Reasons why the Peruvian Amazon is an ideal setting

- ① Underdeveloped areas with limited modern technologies and market access in remote areas & without large-scale external investments
  - ⇒ Attribute resource extractions to small-scale farmers and hunter-gatherers & focus on density externalities caused by them
- ② River networks constitute almost the sole 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 cell-level (1km × 1km) information:

- The unit of analysis in the model
- Distance matrices, taking into account river shapes and orientations
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### 3. National censuses by National Institute of Statistics and Informatics (INEI):

- Peru Population and Housing Census (1993, 2007, 2017)
  - Complement population information (esp. urban ones) to capture the total population in each basin
- Peruvian Agricultural Census (2012) → Technology use by all producers

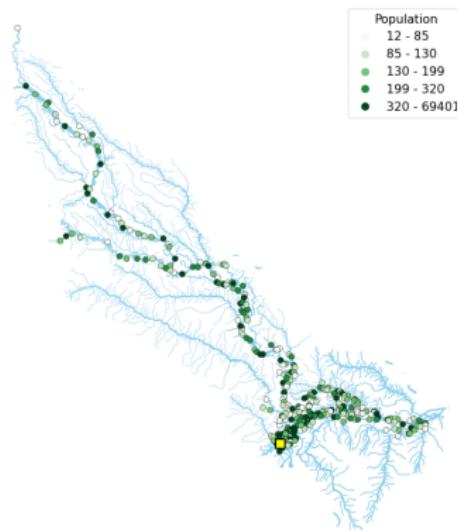
# **Stylized Facts**

## Stylized Facts: Summary

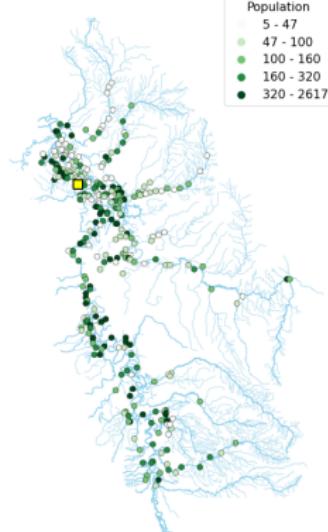
1. Spatial concentration and dispersion of populations and communities
  
- 2A. Human settlements, deforestation, and forest recovery are increasing in Market Access  
*(detail omitted)*
- 2B. Negative and convex relationship between population and per capita land footprint
  
- 3A. Agriculture is widely observed in both concentrated and dispersed areas
- 3B. Natural resource extraction is observed more in communities with lower population densities in the surrounding area

## Spatial Concentration and Dispersion of Communities and Populations

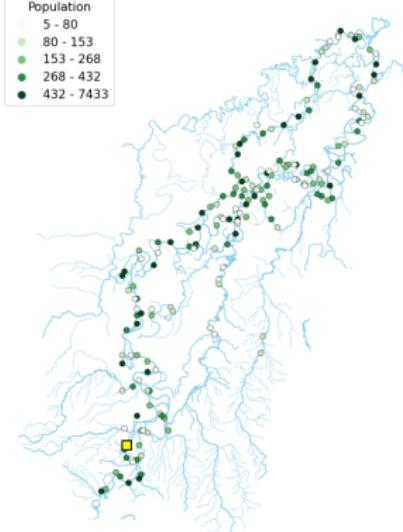
Napo-Amazon



Upper Ucayali

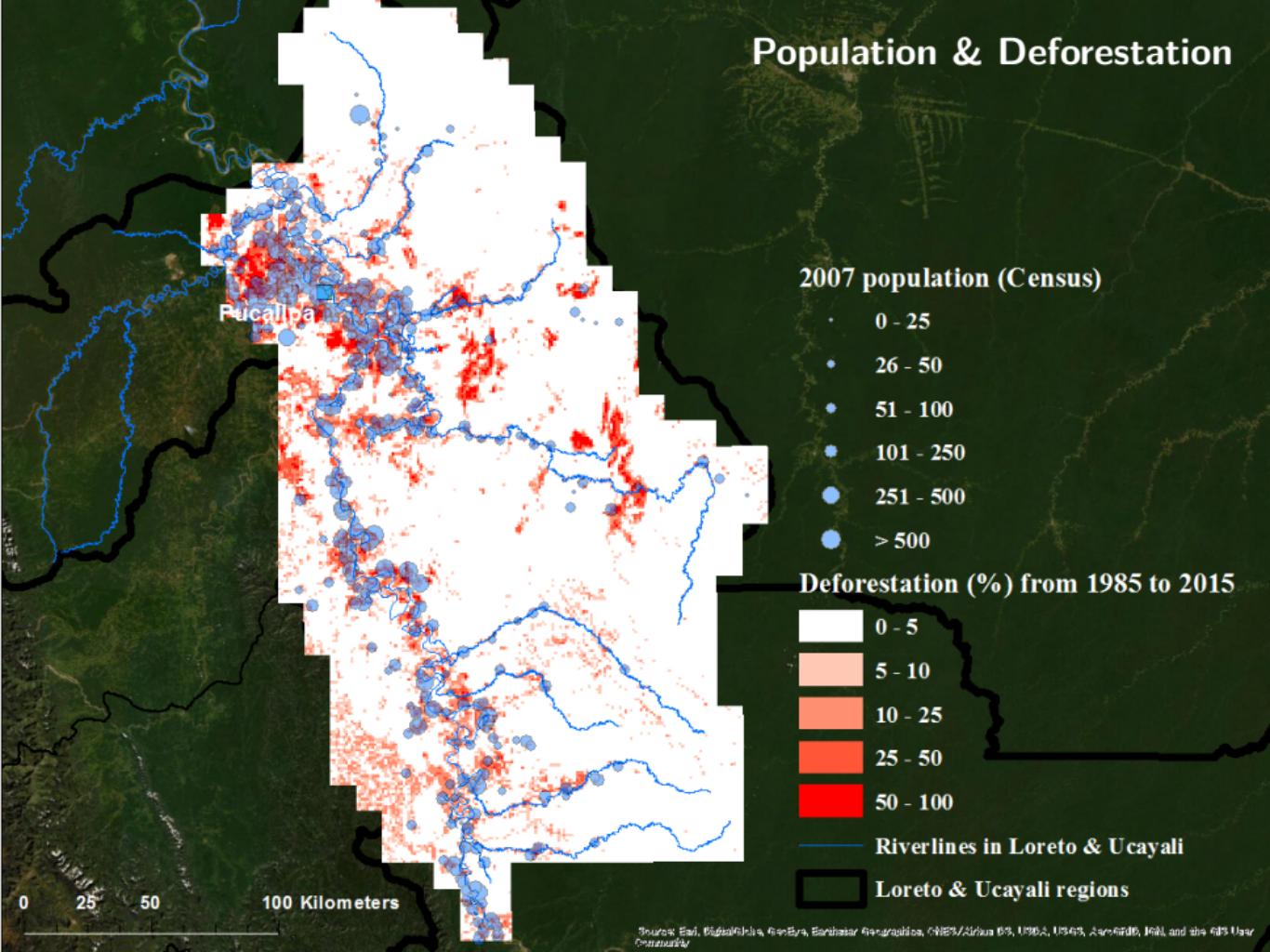


Lower Ucayali



- The legend is based on quantiles (throughout the presentation)
- More than 80% of the rural communities have populations smaller than 450

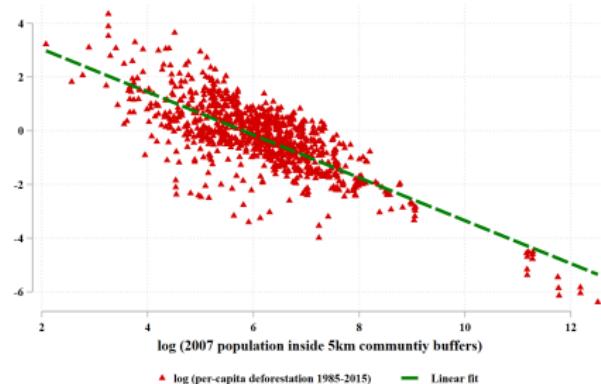
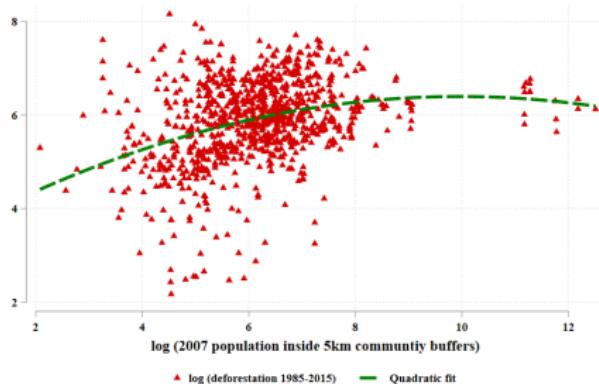
# Population & Deforestation



# Per Capita Land Footprint is Decreasing in Population (OLD)

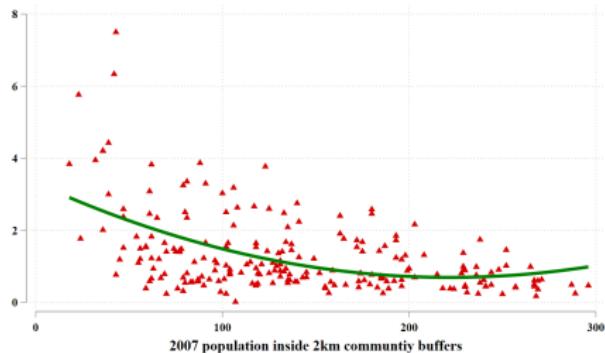
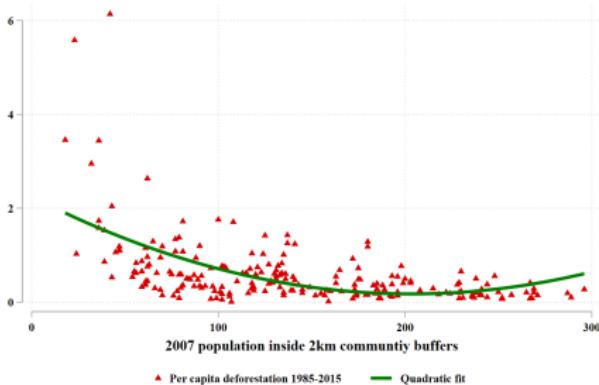
Community (buffer)-level analyses:

- (+) Population & deforestation (forest loss from 1985 to 2015)
- (-) Population & **per capita** deforestation



- Robust results with different buffer sizes
- Robust results with non-forest areas

# 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 land market)
- A mean preserving increase in the variance of settlement size would increase total deforestation

## Stylized Facts: Summary

1. Spatial **concentration** and **dispersion** of populations and communities
  
- 2A.** Human settlements, deforestation, and forest recovery are increasing in Market Access  
*(detail omitted)*
- 2B.** Negative and convex relationship between population and per capita land footprint
  
- 3A.** Agriculture is widely observed in both **concentrated** and **dispersed** areas
- 3B.** Natural resource extraction is observed more in communities with **lower population densities in the surrounding area** ► Detail

# **Model**

## Spatial Model of Rainforest Communities: Intuition

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

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  - 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 ( $1\text{km}^2$  cells)  $o, d \in \mathcal{I} = \mathcal{R} \cup u$ :

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

# Agriculture with Agglomeration & Congestion Externalities

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

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

- $N_{o,L}$  &  $N_{o,C}$ : Employment for forest clearing & cropping
- $N_{o,Ag} = N_{o,L} + N_{o,C}$ : Total employment for agriculture
- $z_{o,Ag}(j)$ : Stochastic term ( $\sim$  Fréchet) of variety  $j$  productivity that governs the comparative advantage
- $\mu_L$ : Parameter governing **congestion force in forest clearing** ▶ Why?
- $\mu_{Ag}$ : Parameter governing **agglomeration force in agricultural production and marketing**

# Natural Resources with Congestion Externality across Space

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

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

## Urban Sector

$$Q_{u,M} = A_{u,M} \cdot N_{u,M}$$

- $N_{u,M}$  ( $= N_u$ ): employment in the urban center
- $A_{u,M}$ : exogenous productivity.

# Prices & Trade Costs

## Prices:

- $p_{od,K}(j)$ : Price of product  $j$  in sector  $K$  produced in  $o$  to purchase in  $d$
- Perfect competition: Price = Marginal cost

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### Asymmetric iceberg trade costs:

- $p_{od,K}(j) = \tau_{od,K} p_{oo,K}(j)$  where  $\tau_{oo,K} = 1$  &  $\tau_{od,K} > 1$  for  $o \neq d$
- $\tau_{od,K} = \tau_{do,K}$  does NOT necessarily hold due to river orientations
- $\tau_{od,K} = D_{od}^{\delta_K}$ 
  - $D_{od}$ : **Downstream-river-equivalent kilometer**
  - $\delta_K$ : Elasticity of trade cost w.r.t. the effective distance

## 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
$\delta_K$	Elasticity of trade cost ( $K = Ag, Nr, M$ )	Commodity prices from the CC
$\lambda_{up}, \lambda_{land}$	Relative costs in terms of downstream river	Travel time and transport costs survey
$\sigma$	Within-sector elasticity of substitution	Expenditure information from ENAHO
$\bar{\sigma}$	Across-sector elasticity of substitution	Expenditure information from ENAHO
$\gamma$	Labor share in agricultural production	From the literature
$\theta$	Trade elasticity	From the literature
$\mu_L$	Congestion in forest clearing	Linear IV using the community-level data
$\mu_{Ag}$	Agglomeration in agricultural production	Model inversion and linear IV
$\mu_{Nr}$	Congestion in natural resource extraction	Model inversion and non-linear GMM
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- ② Given the parameters obtained in the previous steps, invert the model to recover wages and productivities that rationalize the observable endogenous variables as a spatial equilibrium
- ③ Employ GMM to estimate parameters governing the density externalities in productivities obtained in the previous step

## 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

## Step 3. Density Externalities in Agriculture

- Inverted productivity composites of agriculture:

$$\tilde{A}_{o,Ag} \equiv \underbrace{A_{o,Ag} k_1^\theta}_{\text{fundamentals}} \cdot \underbrace{N_{o,Ag}^{\tilde{\mu}_{Ag} \theta}}_{\text{externalities}} \quad \text{where } \tilde{\mu}_{Ag} \equiv \mu_{Ag} - (1 - \gamma) \mu_L$$

- Procedure:

- 1 Estimate  $\tilde{\mu}_{Ag}$
- 2 Estimate  $\mu_L$
- 3 Back out  $\mu_{Ag}$

## Step 3. Agglomeration Externality in Agriculture via Linear IV

- Inverted composite productivities of agriculture:

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

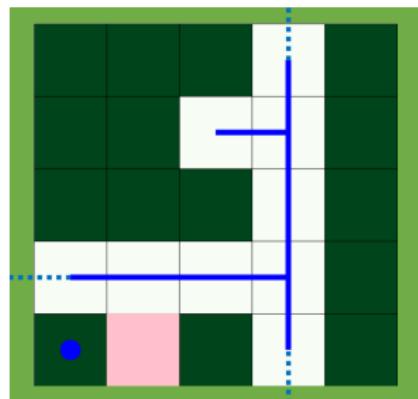
- Empirical specification:

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

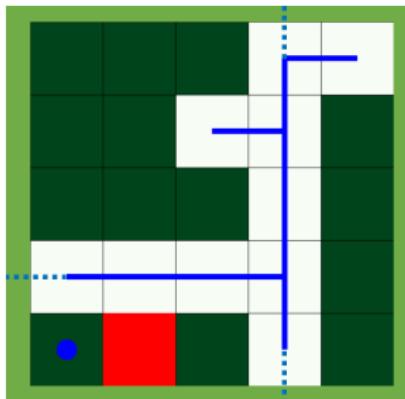
- Endogenous:  $\ln N_{o,Ag}$
- Moment condition:  $\mathbb{E}[\epsilon_{o,Ag} RNA_o] = 0$ 
  - $RNA_o \equiv \sum_{d \in RC} (\tilde{\tau}_{od})^{-\theta}$ : River Network Access ( $RC$ : cells with rivers)

# Intuition of Identifying the Density Externalities

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



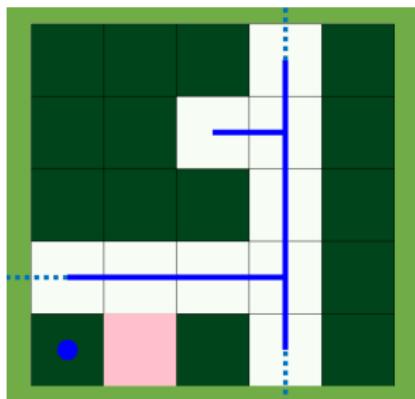
$RNA$  at the pink cell <



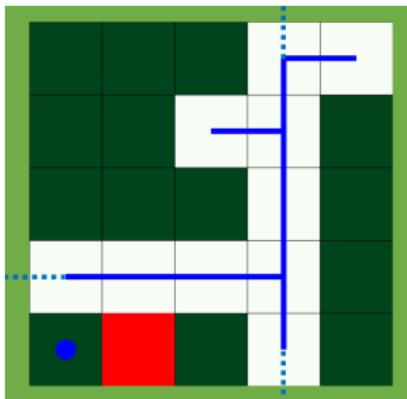
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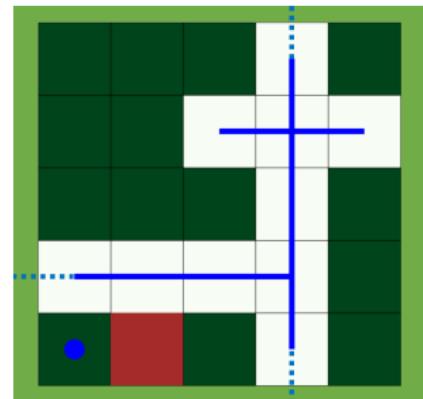
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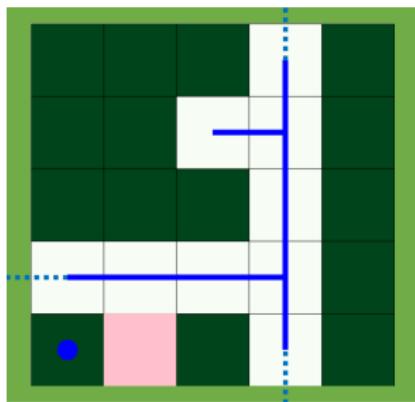
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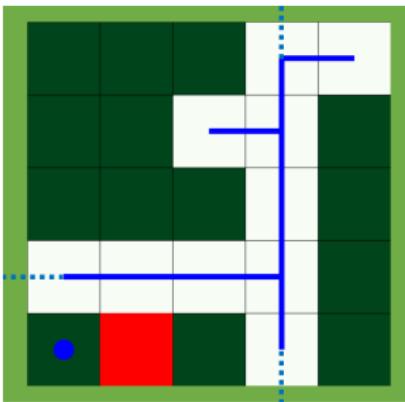
<  $RNA$  at the brown cell

## Intuition of Identifying the Density Externalities

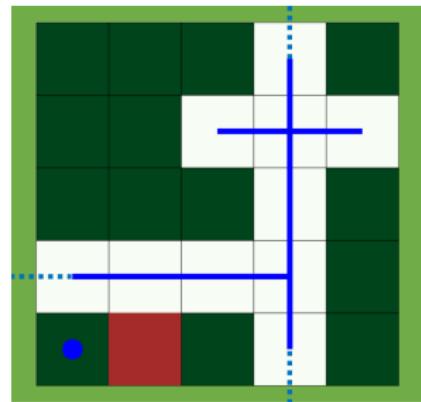
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*RNA at the pink cell*



*RNA at the red cell*



*< RNA at the brown cell*

- Given the same agricultural conditions (e.g., soil quality), distance to the nearest river point, lake size nearby, elevation, etc...
- The variation in  $RNA$  (as an exogenous shifter of market potential) affects productivity only through its effect on employment and thus through externalities that arise, rather than through productivity fundamentals

## 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:

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

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

Controlling for geographic characteristics of the own location, productivity fundamentals are uncorrelated with accessibility to other locations

- A similar strategy for estimating  $\mu_L$  using the community-level information of non-forest areas

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

- Inverted productivity composites of natural resource extraction:

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

- Moment conditions:

$$\mathbb{E}[\epsilon_{o,Nr} \ln RCA_o] = 0 \quad \text{and} \quad \mathbb{E}[\epsilon_{o,Nr} \ln \left( \sum_{d|D_{o,d} \leq x} RCA_d \right)] = 0, \quad x \in X$$

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

### 3. Density Externalities in Agriculture and Natural Resource Extraction

Parameter	Point estimate	Standard error	Description
<b>(A) Agriculture</b>			
$\tilde{\mu}_{Ag}$	0.071	0.009	$= \mu_{Ag} - (1 - \gamma)\mu_L$
$\mu_L$	0.498	0.090	Congestion in forest clearing
$\mu_{Ag}$	0.271		Agglomeration in agricultural production
<b>(B) Natural resource extraction</b>			
$\mu_{Nr}$	0.335	0.042	Congestion in natural resource extraction
$\nu$	0.593	0.075	Spatial decay of congestion externality
Hansen $J$ stat = 2.905			
$J$ test $p$ -value = 0.821			

Notes: Estimates of density externalities in agriculture (panel A) are based on the linear specification using  $\ln RCA_o$  as an instrument. 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  $x \in X = \{2, 5, 10, 25, 50, 75, 100\}$  as instruments.

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- How important are these parameter values quantitatively?
- The next slide simulates the equilibrium outcomes by shutting down the agglomeration externality:  $\mu_{Ag} \rightarrow 0$

## 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%

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- Productivity gains from concentration ↓ & more land-intensive agriculture
- 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

# Mechanisms behind the Agglomeration Externality in Agriculture

## ① Economies of scale in transport technology ▶ Detail

- Endogenous transport modes (different types of boats available)
- Trade costs decrease in 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:

- Improves human welfare
- Reduces deforestation
- Reduces natural resource depletion

Counterfactual experiments:

- ① Resettlement and protection policies
- ② Improvement of transport infrastructure
- ③ Combination of them

## Resettlement Policies: Overview

- Q.** Given the fixed total population, is it more beneficial to **concentrate the ecological footprint in fewer spots** than having many small communities?

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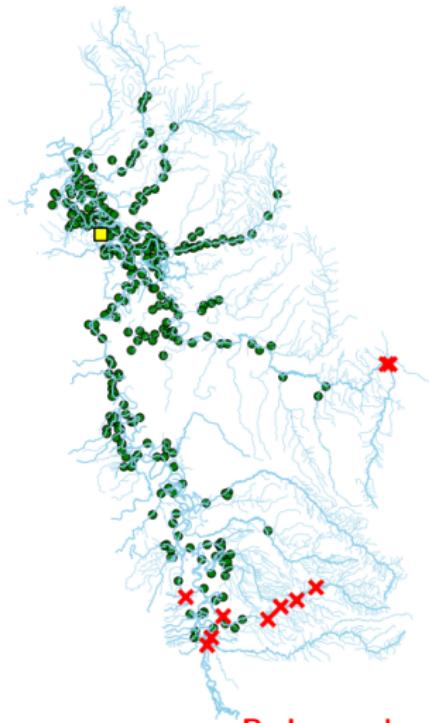
- (A)** Protected areas that control rural frontier expansion
- (B)** Not allowing for small communities

## Resettlement Policies: Overview

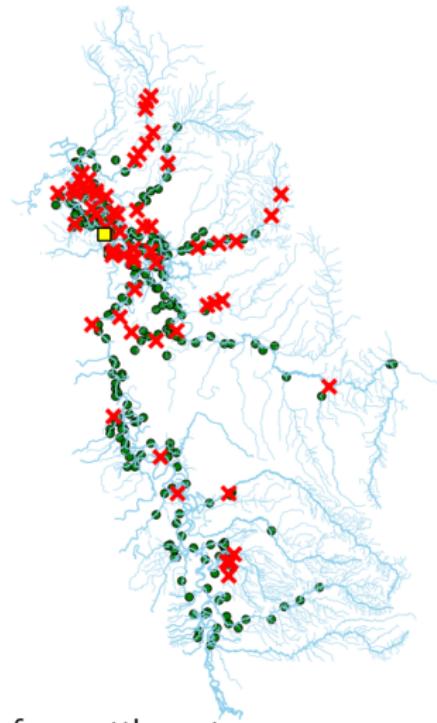
**Q.** Given the fixed total population, is it more beneficial to **concentrate the ecological footprint in fewer spots** than having many small communities?

- (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
<b>(A) Protected areas: controlling rural frontier expansion</b>			
Napo	-0.2%	-5%	-0.3%
UpperUcayali	-0.2%	-2%	-0.8%
<b>(B) Not allowing for small communities</b>			
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 ↑**

# Improvement of Transport Infrastructure: Overview

- **High transport 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

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    - 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:

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

where  $\lambda_{upgraded} < 1$  & symmetric transport cost in the “upgraded” part

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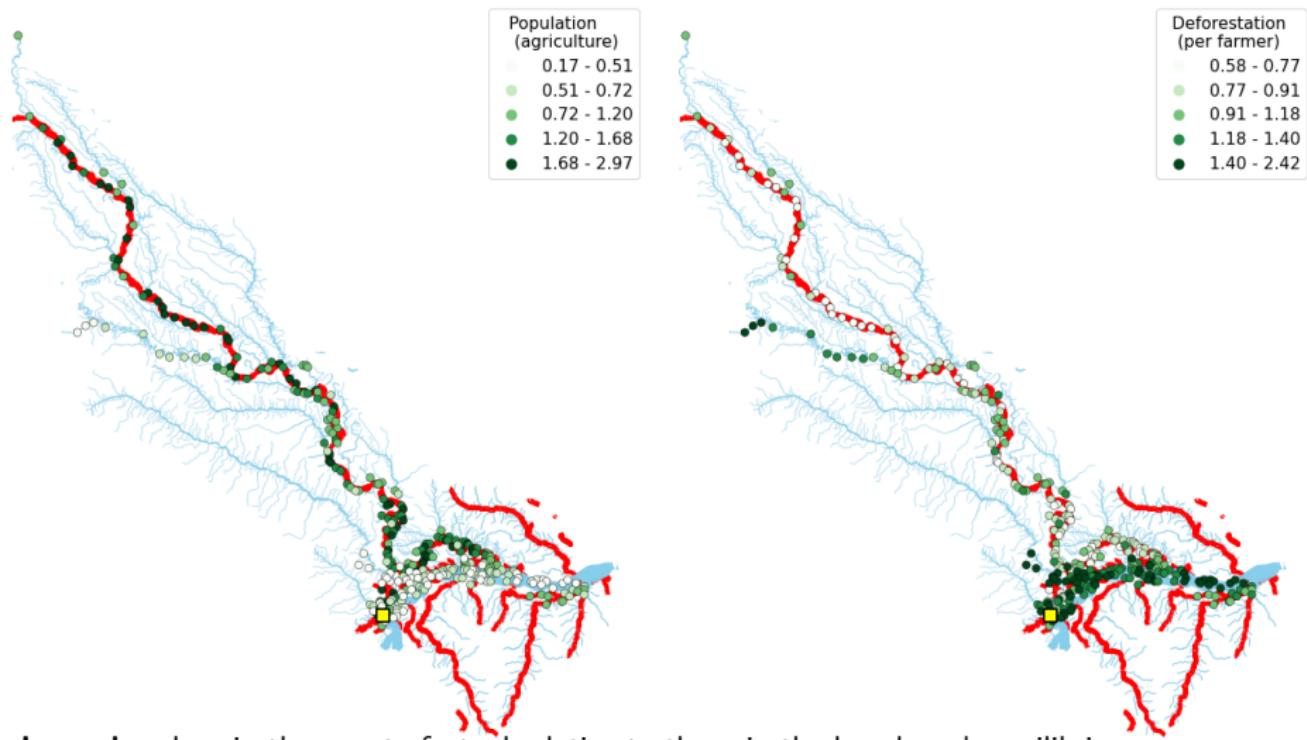
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where  $\lambda_{upgraded} < 1$  & symmetric transport cost in the “upgraded” part

- *Negative externality of infrastructure investments on natural resource endowments? (ongoing)*

## 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%

- Populations in remote areas enjoy more agglomeration benefits
- The total deforestation decreases because deforestation *per farmer* in remote areas decreases and this effect dominates

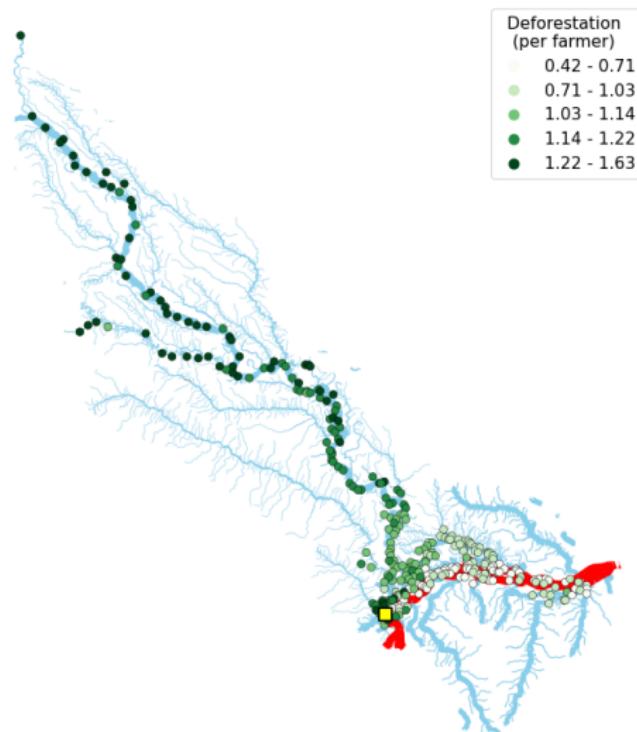
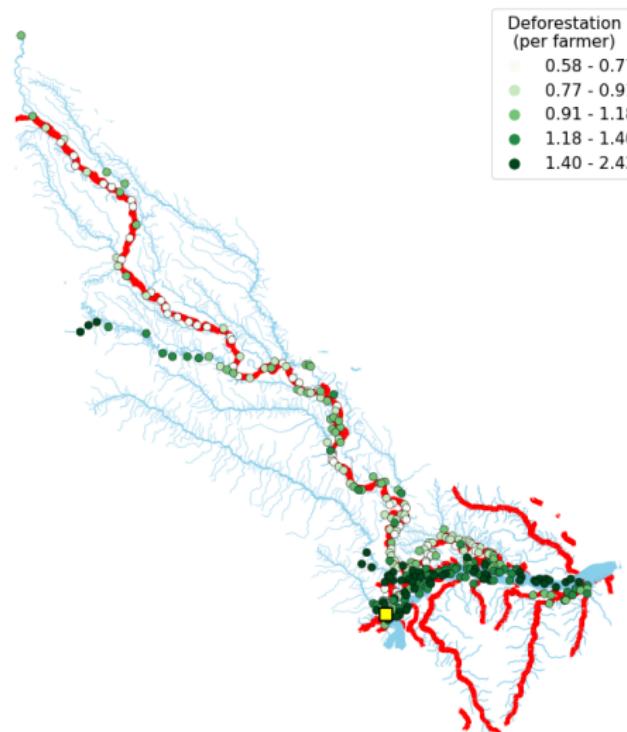
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- Populations in remote areas enjoy more agglomeration benefits
- The total deforestation decreases because deforestation *per farmer* in remote areas decreases and this effect dominates
- Close to the win-win policy, but not perfect (see Upper Ucayali)
- An important takeaway toward the external validity

# 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
<b>(A) Transport infrastructure improved by connecting hinterlands to the center</b>			
Napo	+1.8%	-1.6%	-0.3%
<b>(B) Transport infrastructure improved by concentrating investments in the center</b>			
Napo	+1%	+7%	-0.4%

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Improving the infrastructure only in densely populated areas  $\Rightarrow$  Deforestation  $\uparrow$

- The population is more concentrated in the central area of the basin
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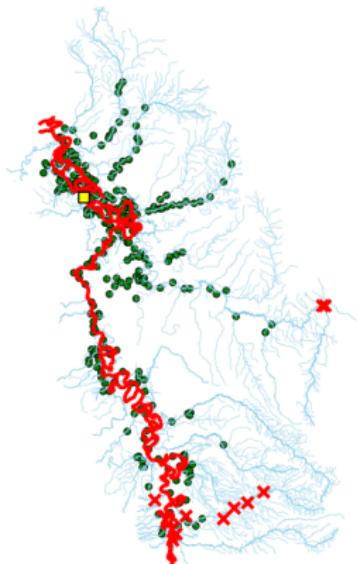
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Interventions that make the **agglomeration benefits spread more evenly across the basin** are preferable in terms of reducing deforestation

**(A) Protected areas that control rural frontier expansion &**  
**(B) Transport infrastructure that connects hinterlands to the center**

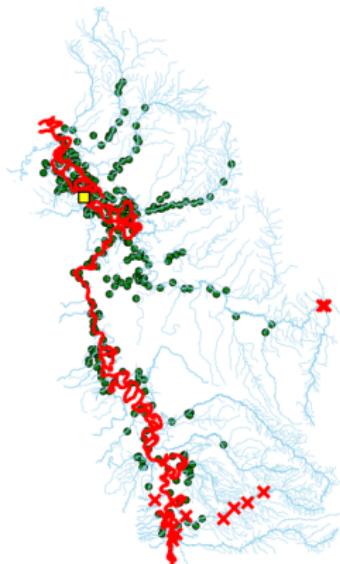
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LowerUcayali	+2.3%	-4.9%	-3.1%
UpperUcayali	+1.1%	-3.5%	-0.5%



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

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- The trade-offs are resolved:

- Welfare ↑
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- 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

## Summary: A protection policy and investments in transport infrastructure are complementary to eliminate the trade-offs

Counterfactuals	Welfare	Deforestation	Natural resource depletion
<b>(A) Protected areas</b>			
i. Controlling rural frontier expansion	-	-	-
ii. Targeting smallest communities	-	-	+
<b>(B) Transport infrastructure</b>			
i. Connecting hinterlands to the center	+	-	?
ii. Concentrating in the center	+	+	?
<b>(A) i. + (B) i.</b>	+	-	-

## Conclusions

This paper:

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**Q. *Is it possible to design a policy that eliminates the trade-offs (between human welfare and different types of environmental costs)?***

**A. Yes**

- \* Combination of a protection policy and transport infrastructure investments
- \* Spatial targeting matters for both
- \* Limitations: dynamics, community formation, entry of external investments

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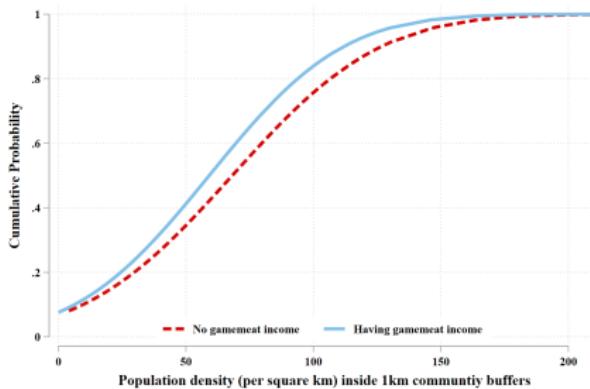
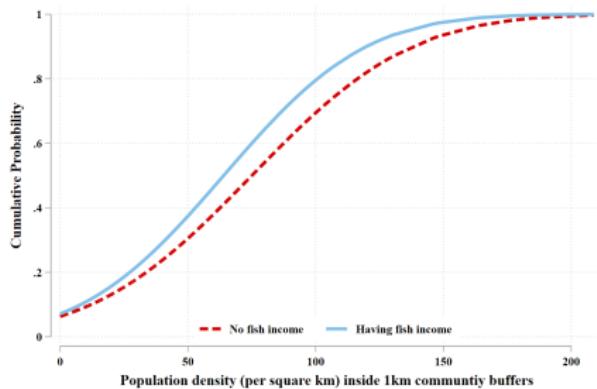
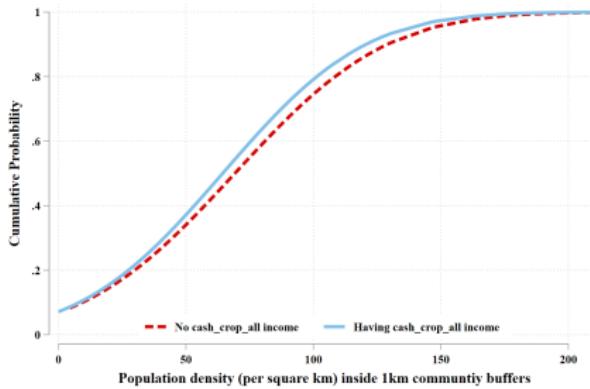
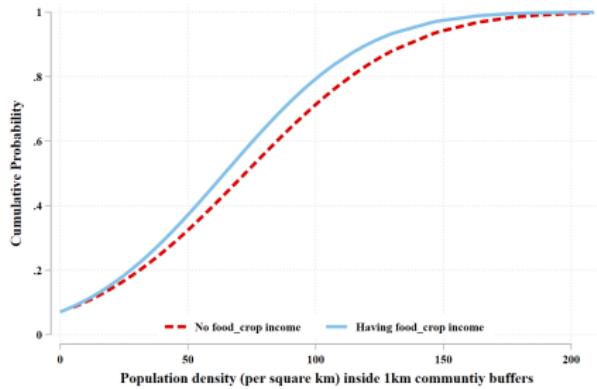
**Q. Is it more beneficial to concentrate the ecological footprint in fewer spots than having many small communities?**

**A. It depends**

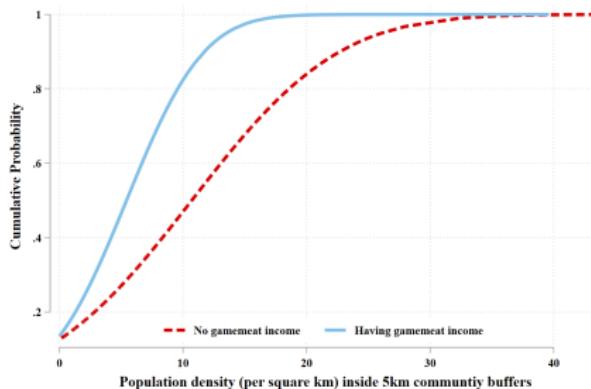
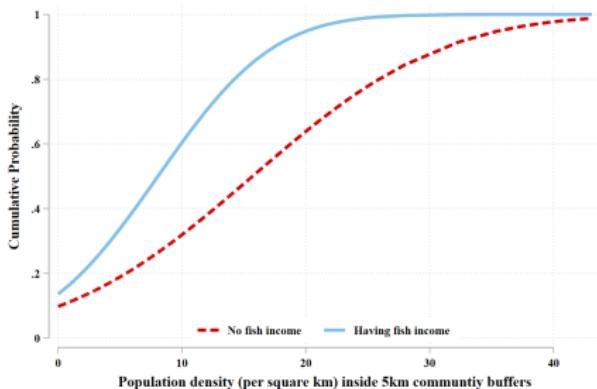
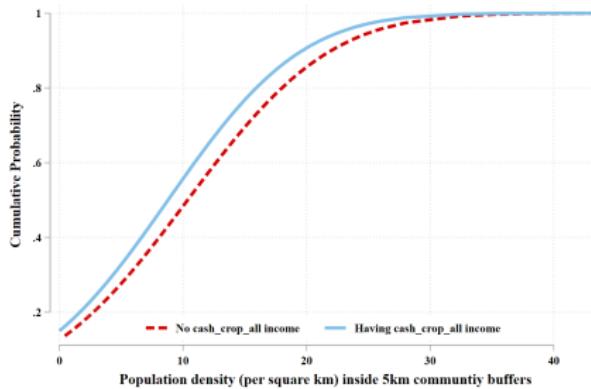
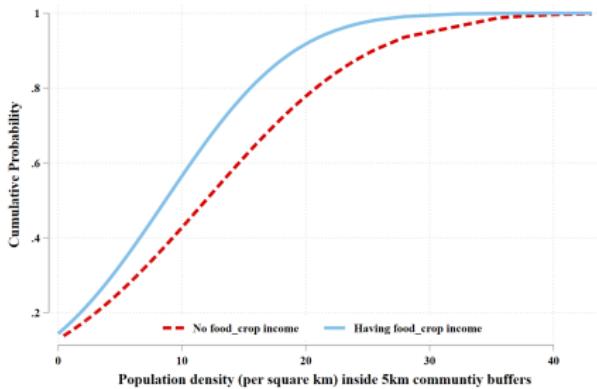
- \* Concentration is good for environment, but too much concentration is not
- \* Policies that cause more medium-sized communities evenly across the river basin are desirable to reduce deforestation

# **Appendix**

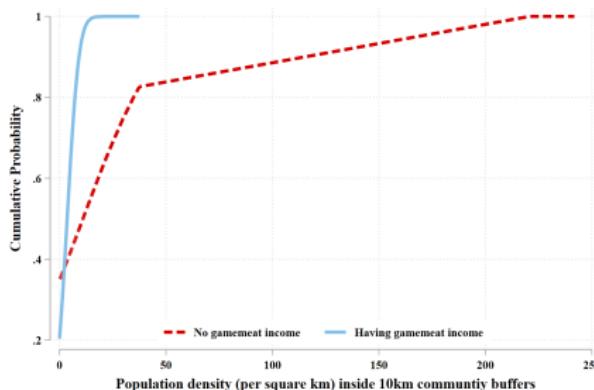
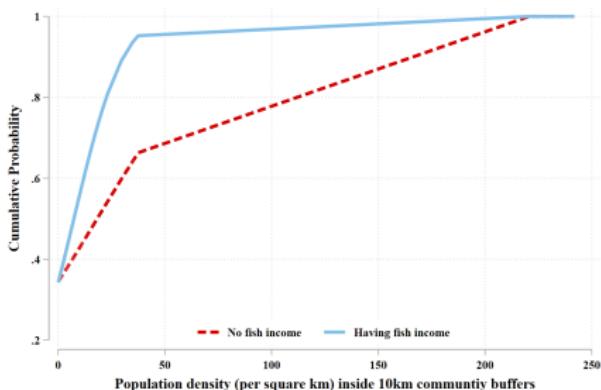
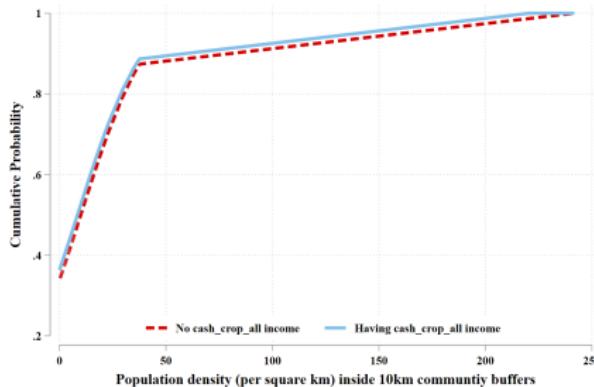
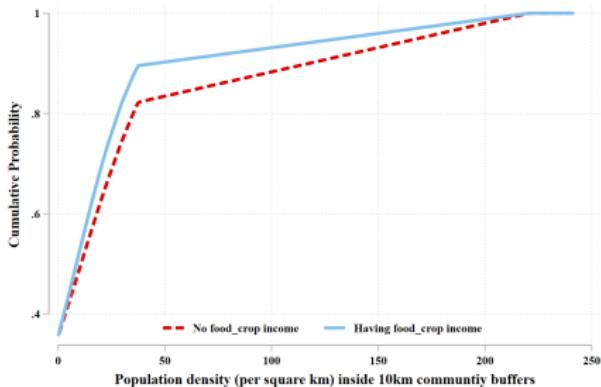
# Population Density (1km buffer) & Activity/Occupation: Agricultural Sector vs. Wild Animal Extractions



# 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 ( $x = 5\text{km}, 10\text{km}$  compared to  $x = 1\text{km}, 2\text{km}$ )**

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## Why Congestion (on net) in Land Access? ▶ Back

Community population↑ ⇒

- More costly to find and negotiate areas for forest clearing
- Longer travel time from a community center to agricultural fields



- There may also be a gain from increasing population due to the cooperative nature of forest clearing
- The net effect may vary in population size

## Why Agglomeration in Agriculture? ▶ Back

- ① Economies of scale in transport technology and transaction costs
- ② Spillover of knowledge/technology and agricultural intensification
- ③ Input sharing such as crop seed

# Step 1. Estimating Parameters without Solving the Model

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

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## 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

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**Table:** Agglomeration Externality in Agriculture

	The calibrated value of $\log(\tilde{A}_{o,Ag})$					
	All locations		$N_{o,Ag} < 75$		$N_{o,Ag} \geq 75$	
	(1) OLS	(2) IV	(3) OLS	(4) IV	(5) OLS	(6) IV
$\log(N_{o,Ag})$	0.676*** (0.0205)	0.557*** (0.0706)	0.794*** (0.0459)	0.466 (0.318)	0.541*** (0.0411)	0.323* (0.194)
Basin FE	Yes	Yes	Yes	Yes	Yes	Yes
Mean (Dep. var.)	-0.096	-0.096	-0.754	-0.754	0.546	0.546
SD (Dep. var.)	4.578	4.578	4.823	4.823	4.234	4.234
First stage F-stat		22.959		2.855		5.249
Observations	893	893	441	441	452	452

Notes: Robust standard errors in parentheses. The sample includes 1 square km grid cells that have positive populations. We use  $\log(RA_o)$  and initial community existence (in 1910 and 1940) as instruments for  $\log(N_{o,Ag})$ . 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, and geology measures.

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

**Table:** Density Externality in Forest Clearing

	log (per capita deforestation)					
	All locations		$N_{o,Ag} < 75$		$N_{o,Ag} \geq 75$	
	(1) OLS	(2) IV	(3) OLS	(4) IV	(5) OLS	(6) IV
log( $N_{o,Ag}$ )	-0.653*** (0.0306)	-0.498*** (0.0899)	-0.658*** (0.0605)	-0.251 (0.553)	-0.653*** (0.0672)	-0.525** (0.239)
Basin FE	Yes	Yes	Yes	Yes	Yes	Yes
Mean (Dep. var.)	0.929	0.929	1.478	1.478	0.372	0.372
SD (Dep. var.)	1.231	1.231	1.149	1.149	1.049	1.049
First stage F-stat		24.002		2.252		7.290
Observations	895	895	451	451	444	444

Notes: Robust standard errors in parentheses. The unit of analysis is a community in the PARLAP Community Census (CC) in 2014. We use  $\log(RA_o)$  and initial community existence (in 1910 and 1940) as instruments for  $\log(N_{o,Ag})$ . 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, and geology measures for a grid cell where each census community belongs.

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

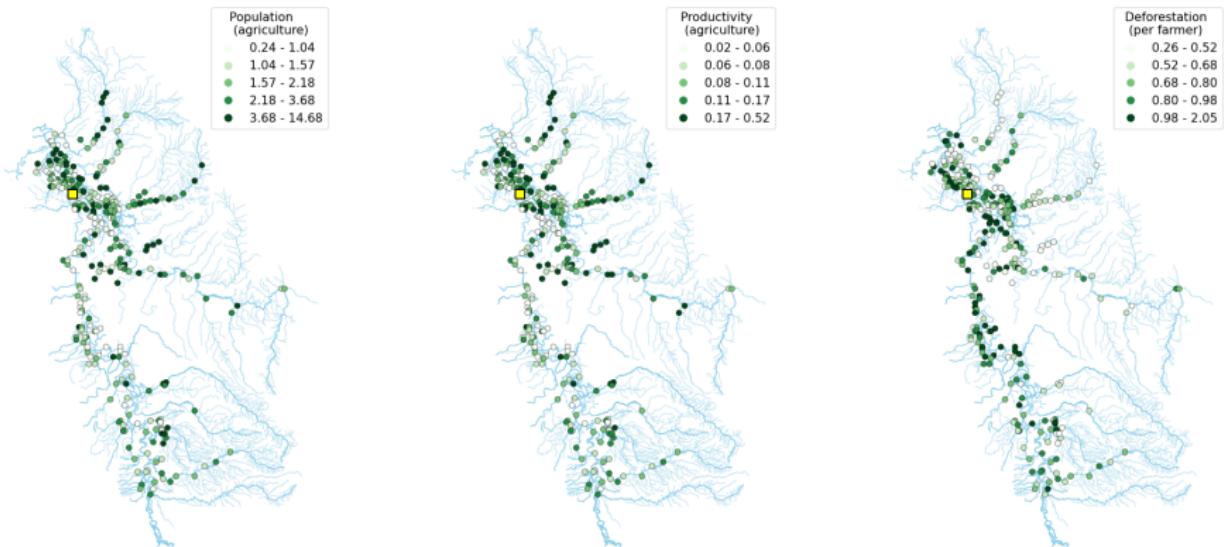
**Table:** Congestion Externality in Natural Resource Extraction with Spatial Spillovers

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

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

# Spatial Distribution of Agriculture and Deforestation without the Agglomeration Externality



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## 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



**Peque-peque** (most widely available)



Lancha



**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( $N_{o,Ag}$ )	0.0463*** (0.0111)	0.166*** (0.0442)	0.0477*** (0.0115)	0.0290 (0.0390)	0.0511*** (0.0107)	0.0627** (0.0288)	-0.00517 (0.00569)	0.00506 (0.0153)
Basin FE	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		24.313		24.313		24.313		24.313
Observations	906	906	906	906	906	906	906	906

*Notes:* Robust standard errors in parentheses. The unit of analysis is a community in the PARLAP Community Census (CC) in 2014. We use log( $RA_i$ ) and initial community existence (in 1910 and 1940) as instruments for log( $N_{o,Ag}$ ). 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, and geology 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

## 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)

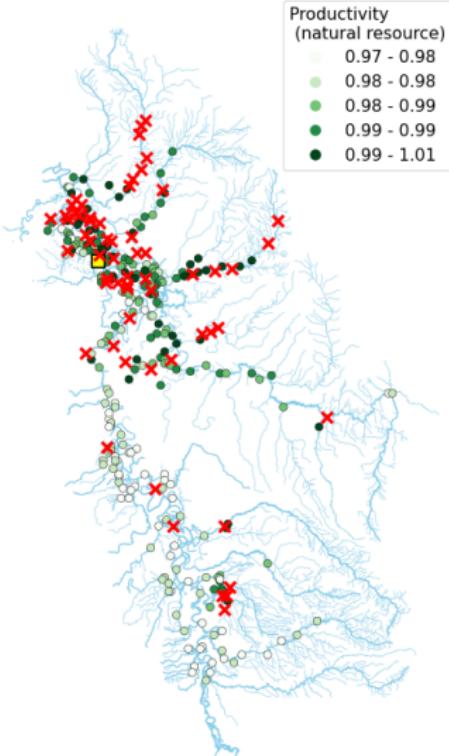
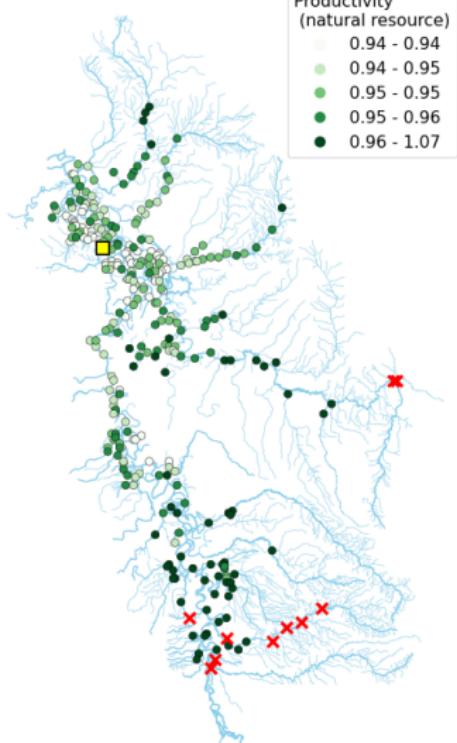
**Table:** Community Population and Modern Technology Use

<b>(A) Basic infrastructure</b>						
	(1)	(2)	(3)	(4)	(5)	(6)
Irrigation	Certified seed	Crops have been certified organic	Electricity for agricultural work	Animals for agricultural work	Tractors for agricultural work	
log( $N_{o,Ag}$ )	-0.00309* (0.00182)	-0.00406 (0.00423)	0.0000856 (0.000592)	-0.000788 (0.000878)	0.00410** (0.00195)	0.000584 (0.000822)
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	1090.954	1090.954	1090.954	1090.954	1090.954	1090.954
Observations	25827	25827	25827	25827	25827	25827
<b>(B) Inputs into land and crops</b>						
	(1)	(2)	(3)	(4)	(5)	(6)
Guano/manure/compost	Chemical fertilizers	Insecticides	Herbicides	Fungicides	Biologic control	
log( $N_{o,Ag}$ )	0.000726 (0.00110)	0.00215* (0.00111)	0.0207*** (0.00349)	0.0300*** (0.00361)	0.0106*** (0.00214)	-0.00416* (0.00237)
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	1090.954	1090.954	1090.954	1090.954	1090.954	1090.954
Observations	25827	25827	25827	25827	25827	25827
<b>(C) Animal, electrical, or mechanical energy</b>						
	(1)	(2)	(3)	(4)	(5)	(6)
Iron plow of animal traction	Wooden plow of animal traction	Harvester	Foot plow	Motorized sprayer	Manual sprayer	
log( $N_{o,Ag}$ )	-0.000784 (0.000501)	-0.000261 (0.000287)	-0.000179 (0.000297)	-0.00102* (0.000547)	0.00194** (0.000805)	0.0195*** (0.00388)
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	1090.954	1090.954	1090.954	1090.954	1090.954	1090.954
Observations	25827	25827	25827	25827	25827	25827
<b>(D) Electrical or mechanical energy</b>						
	(1)	(2)	(3)	(4)	(5)	(6)
Grain mill	Grass chopper	Thresher	Electric generator	Wheel tractor	Boat/canoe/speedboat	
log( $N_{o,Ag}$ )	0.00590*** (0.00188)	0.000397 (0.000419)	-0.000964 (0.000644)	-0.0101*** (0.00320)	0.000997* (0.000599)	-0.0286*** (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	1090.954	1090.954	1090.954	1090.954	1090.954	1090.954
Observations	25827	25827	25827	25827	25827	25827
Basin FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors in parentheses. The unit of analysis is a household in the 2012 Peruvian Agricultural Census. We use log( $RA_o$ ) and initial community existence (in 1910 and 1940) as instruments for log( $N_{o,Ag}$ ). 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, and geology measures for a grid cell where each census community belongs.

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

## (A) Protected areas by rural frontier   (B) Small communities not allowed



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