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*

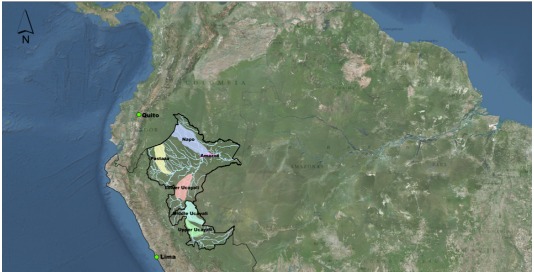
October 7, 2022

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

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

- Deforestation vs. Depletion of other natural resources

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

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

- Deforestation vs. Depletion of other natural resources

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

Q. ***Is it possible to design a policy that resolves these trade-offs?***

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

- Deforestation vs. Depletion of other natural resources

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

Q. ***Is it possible to design a policy that resolves these trade-offs?***

This paper:

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

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

vs.

Higher market access and **agglomeration** benefits in dense areas

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

- Deforestation vs. Depletion of other natural resources

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

Q. ***Is it possible to design a policy that resolves these trade-offs?***

This paper:

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

   Richer resource endowments in sparse areas due to weak **congestion**
   vs.
   Higher market access and **agglomeration** benefits in dense areas

2. Empirically examines whether **population density increases productivity** (**agglomeration**) or **decreases productivity** (**congestion**) in each sector

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

- Deforestation vs. Depletion of other natural resources

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

Q. ***Is it possible to design a policy that resolves these trade-offs?***

This paper:

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

   Richer resource endowments in sparse areas due to weak **congestion**
   vs.
   Higher market access and **agglomeration** benefits in dense areas

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

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

The density externalities are quantitatively important:

e.g. Without the agglomeration externality

$\Rightarrow$ welfare $\downarrow$ 11% & Deforestation $\uparrow$ 32%

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

The density externalities are quantitatively important:

e.g. Without the agglomeration externality

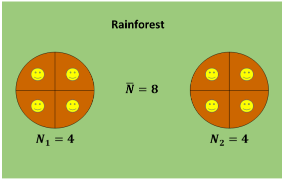
$\Rightarrow$ welfare $\downarrow$ 11% & Deforestation $\uparrow$ 32%

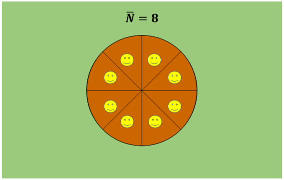
Mechanisms behind the agglomeration externality:

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

This Paper: Counterfactuals

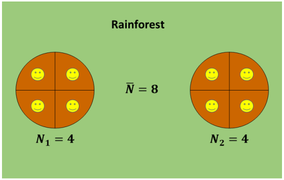
Q. *In the presence of externalities, is it more beneficial to* ***concentrate the ecological footprint in fewer spots*** *than having many small communities?*

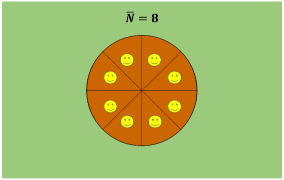




This Paper: Counterfactuals

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

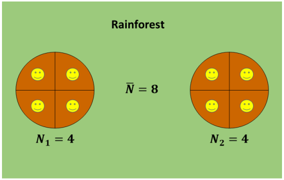


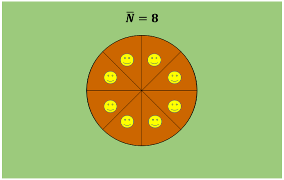


Agglomeration ⇒ possible to achieve agricultural output ↑ & deforestation *per farmer* ↓

This Paper: Counterfactuals

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





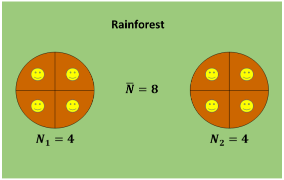
Agglomeration $\Rightarrow$ possible to achieve agricultural output $\uparrow$ & deforestation *per farmer* $\downarrow$

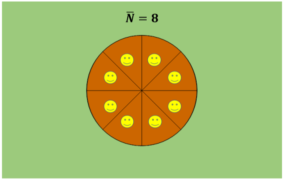
- **Protected areas and investments in transport infrastructure are complementary to eliminate the trade-offs**:

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

This Paper: Counterfactuals

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





Agglomeration ⇒ possible to achieve agricultural output ↑ & deforestation *per farmer* ↓

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

  Human welfare ↑ Deforestation ↓ Natural resource depletion ↓

* Place-based targeting matters for both types of interventions
* Policies that make the areas enjoying agglomeration benefits 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); Assunçao 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

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); Assunçao 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

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

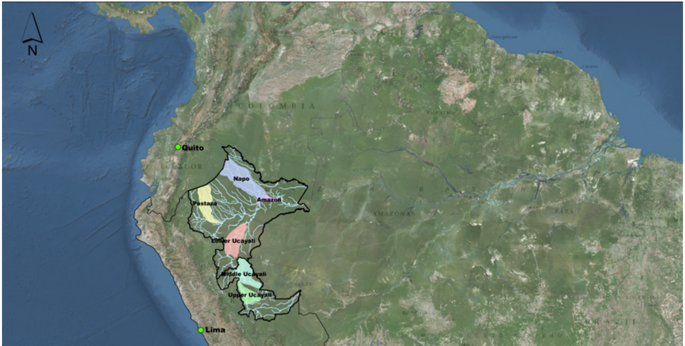
2 Reasons why the Peruvian Amazon is an ideal setting

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 $\times$ 1km) information:
   - The unit of analysis in the model
   - Distance matrices, taking into account river shapes and orientations
   - Forest cover measures constructed by remote sensing experts in the team

Primary Data

1. **Grid cell-level** (1km $\times$ 1km) information:
   - The unit of analysis in the model
   - Distance matrices, taking into account river shapes and orientations
   - Forest cover measures constructed by remote sensing experts in the team
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 cell-level** (1km $\times$ 1km) information:
   - The unit of analysis in the model
   - Distance matrices, taking into account river shapes and orientations
   - Forest cover measures constructed by remote sensing experts in the team
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 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*)

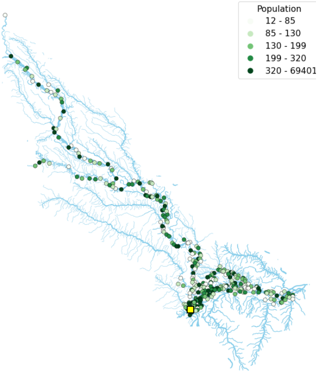
2B. Per capita land footprint is decreasing in population size

3A. Agriculture is widely observed in both concentrated and dispersed areas

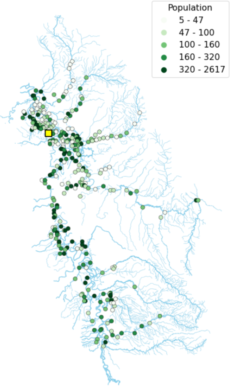
3B. Natural resource extraction is observed more in communities with lower population densities in the surrounding area

Spatial Concentration and Dispersion of Communities and Populations

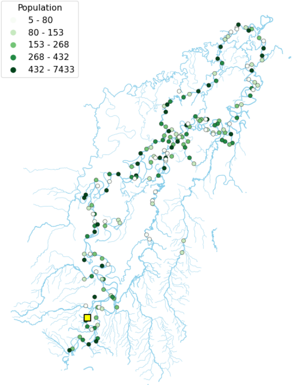
Napo-Amazon



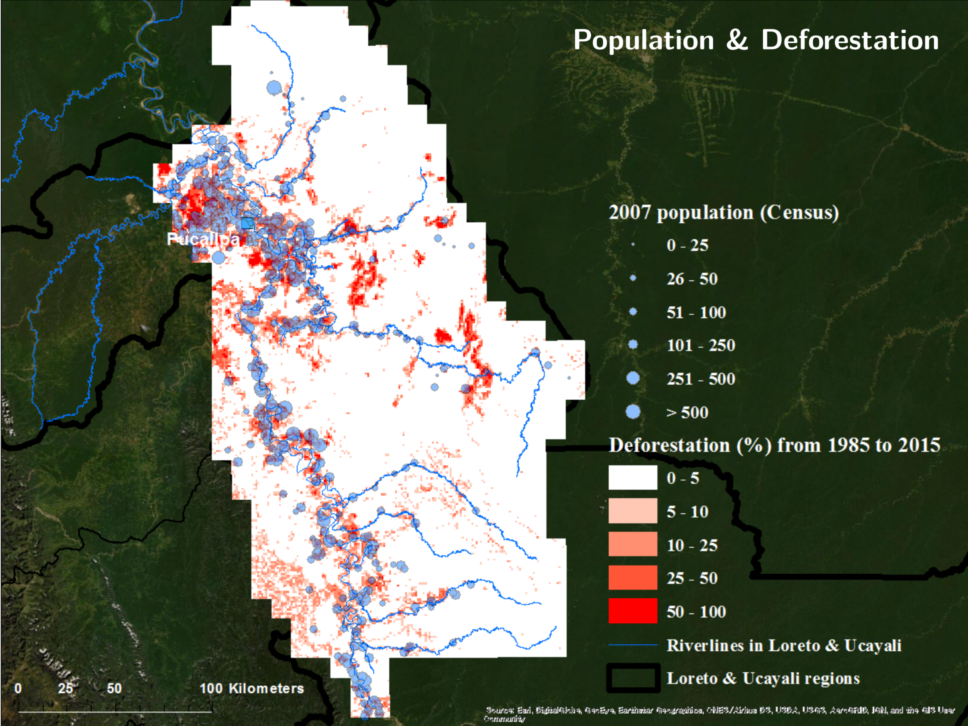
Upper Ucayali



Lower Ucayali



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



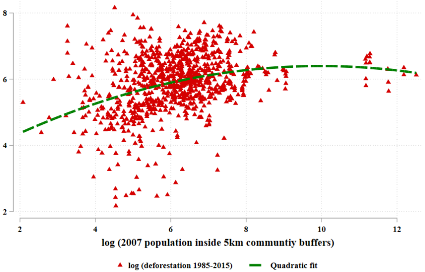
Population & Deforestation
Pucallpa
2007 population (Census)
0 - 25
26 - 50
51 - 100
101 - 250
251 - 500
> 500
Deforestation (%) from 1985 to 2015
0 - 5
5 - 10
10 - 25
25 - 50
50 - 100
Riverlines in Loreto & Ucayali
Loreto & Ucayali regions
0 25 50 100 Kilometers
Source: Esri, DigitalGlobe, GeoEye, Earthstar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

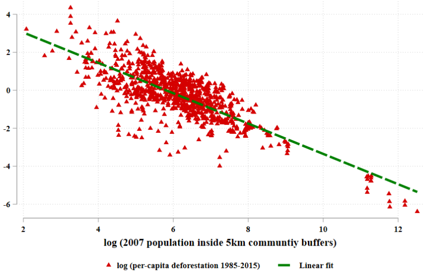
Per Capita Land Footprint is Decreasing in Population

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

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. Per capita land footprint is decreasing in population size

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

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

Geography — Locations differ in:

- Productivity fundamentals: E.g. soil quality, access to water
- Distance to other locations in river networks

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

Geography — Locations differ in:

- Productivity fundamentals: E.g. soil quality, access to water
- Distance to other locations in river networks

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

Geography — Locations differ in:

- Productivity fundamentals: E.g. soil quality, access to water
- Distance to other locations in river networks

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

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
- μ_L: Parameter governing **congestion force in forest clearing** ▸ Why?
- μ_{Ag}: Parameter governing **agglomeration force in agricultural production and marketing**

Natural Resources with Congestion Externality across Space

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

- $N_{o,Nr}$: Total employment for natural resource extraction in o
- $z_{o,Nr}(j)$: the stochastic term
- 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)

Urban Sector

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

- $N_{u,M}$ $(= N_u)$: 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

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

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**
    - δ_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
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. Estimate 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. Estimate 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 endogenous variables as a spatial equilibrium

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. Estimate 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 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:

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

- 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:

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

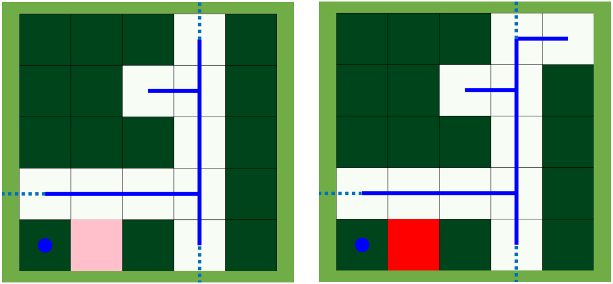
- Empirical specification:

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

- Endogenous: $\ln N_{o,Ag}$
- 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

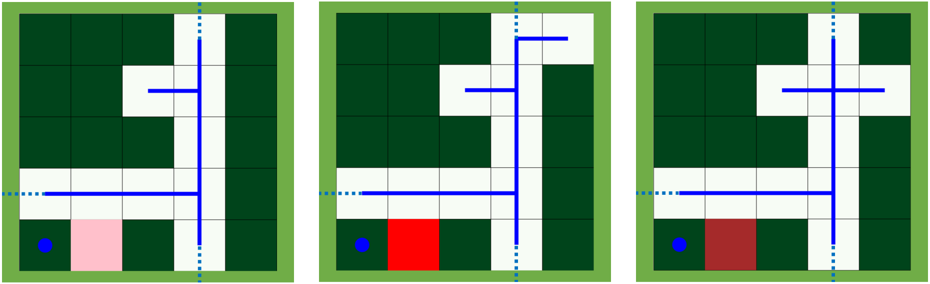
$RNA_o \equiv \sum_{d \in RC} (\tilde{\tau}_{od})^{-\theta}$: River Network Access ($RC$: white cells)



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

Intuition of Identifying the Density Externalities

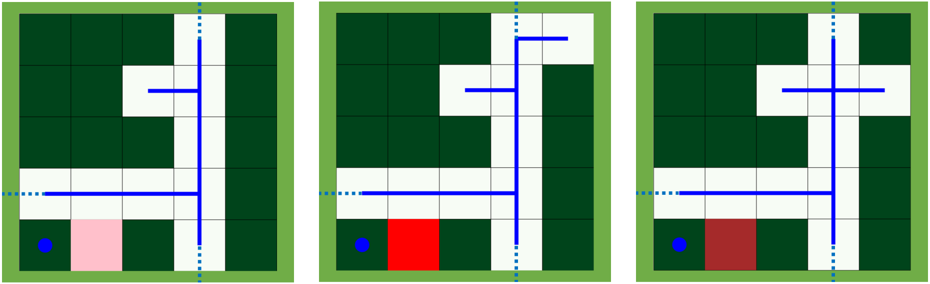
$RNA_o \equiv \sum_{d \in RC} (\tilde{\tau}_{od})^{-\theta}$: River Network Access ($RC$: white cells)



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**

- 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:

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

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

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

- Moment conditions:

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

  - $\epsilon_{o,Nr}$: 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			
$\tilde{\mu}_{Ag}$	0.071	0.009	$= \mu_{Ag} - (1-\gamma)\mu_L$
μ_L	0.498	0.090	Congestion in forest clearing
μ_{Ag}	0.271		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
	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 $x \in \mathcal{X} = \{2, 5, 10, 25, 50, 75, 100\}$ as instruments.

3. Density Externalities in Agriculture and Natural Resource Extraction

Parameter	Point estimate	Standard errror	Description
(A) Agriculture			
$\tilde{\mu}_{Ag}$	0.071	0.009	$= \mu_{Ag} - (1-\gamma)\mu_L$
μ_L	0.498	0.090	Congestion in forest clearing
μ_{Ag}	0.271		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
	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 $x \in \mathcal{X} = \{2, 5, 10, 25, 50, 75, 100\}$ as instruments.

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

Quantitatively large effects of the agglomeration externality on

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

Table: 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%

Quantitatively large effects of the agglomeration externality on

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

Table: 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%

- 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

Maps

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?

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

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?

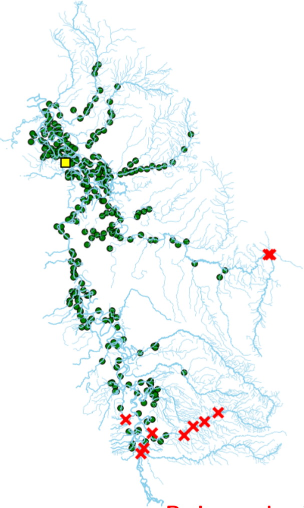
(A) Protected areas that control rural frontier expansion

(B) Not allowing for small communities

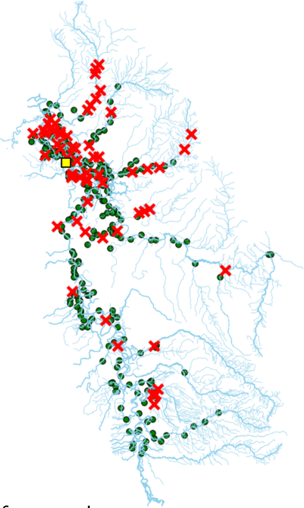
- For meaningful comparison, **each experiment directly treats an equal size of population**—2.5% of rural population in the benchmark equilibrium in each basin

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**
(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)$\Rightarrow$ **natural resource depletion** $\downarrow$ but with a smaller deforestation impact

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

Maps

(B)$\Rightarrow$ **reduces deforestation the most** but **natural resource depletion** $\uparrow$

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

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
- 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

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
- Replace the **downstream-river-equivalent distance** with:

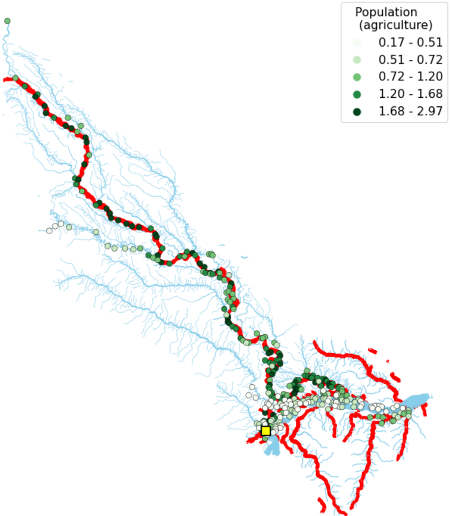
$$D_{od} = D_{od,down} + \lambda_{up} D_{od,up} + \lambda_{land} D_{od,land} + \lambda_{upgraded} D_{od,upgraded}$$

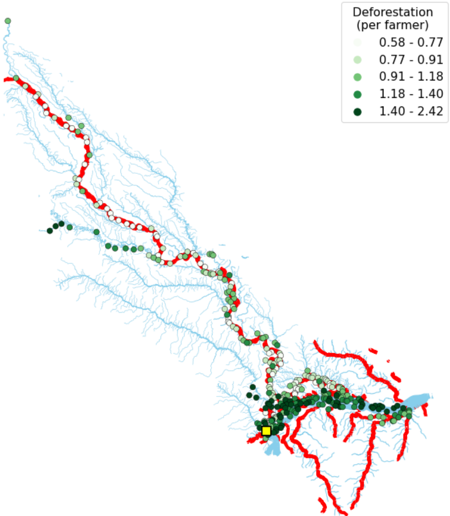
where $\lambda_{upgraded} < 1$ & symmetric transport cost in the "upgraded" part

◦ *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 $\Rightarrow$

- **Welfare $\uparrow$**
- **Deforestation $\downarrow$**
- **Natural resource depletion ($\downarrow$)?**

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

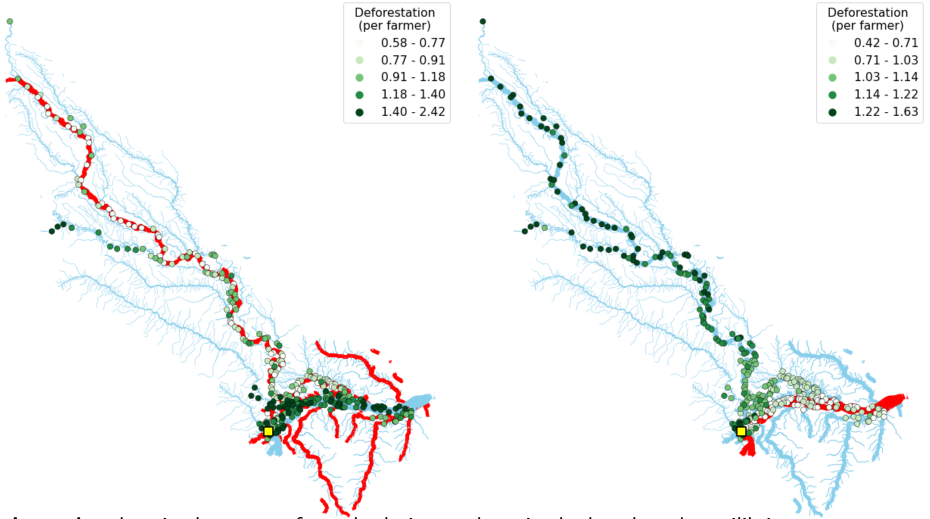
Connecting Hinterlands to the Central Area of Basin $\Rightarrow$

- **Welfare $\uparrow$**
- **Deforestation $\downarrow$**
- **Natural resource depletion ($\downarrow$)?**

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
- 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
(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 $\Rightarrow$ Deforestation $\uparrow$

- 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

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%

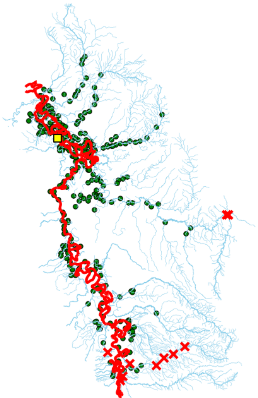
Improving the infrastructure only in densely populated areas ⇒ Deforestation ↑

- 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

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

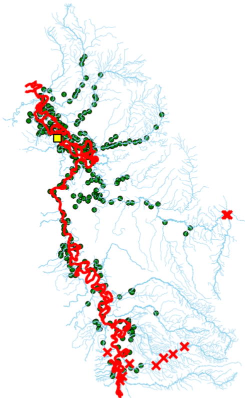
Basin	Welfare	Deforestation	Natural resource depletion
Napo	+1.6%	-7%	-0.6%
Pastaza	+1.1%	-5%	-0.4%
LowerUcayali	+2.3%	-4.9%	-3.1%
UpperUcayali	+1.1%	-3.5%	-0.5%



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

(A) Protected areas that control rural frontier expansion & (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

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

Counterfactuals	**Welfare**	**Deforestation**	**Natural resource depletion**
(A) Protected areas			
i. Controlling rural frontier expansion	−	−	−
ii. Targeting 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)

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

Conclusions

This paper:

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

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

Conclusions

This paper:

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

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

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

Conclusions

This paper:

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

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

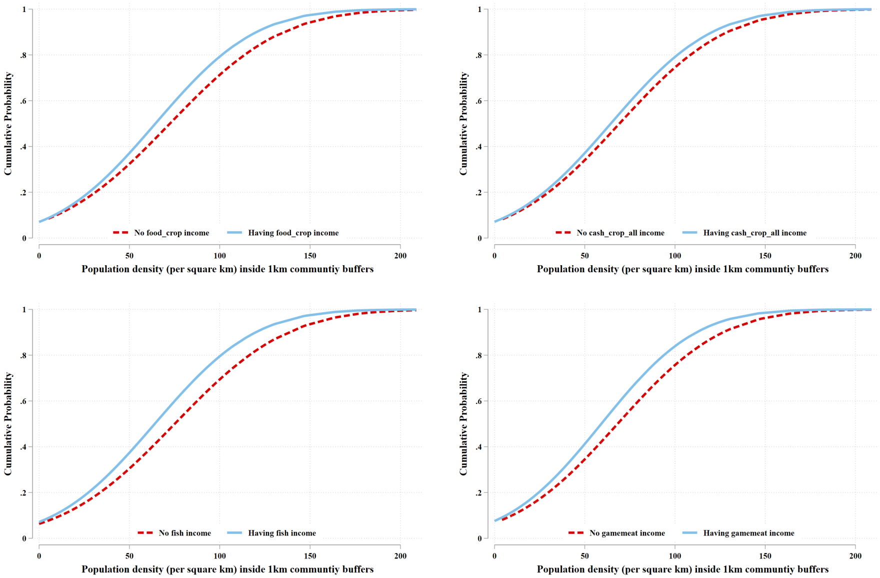
Q. *Is it more beneficial to* ***concentrate the ecological footprint in fewer spots*** *than having many small communities?*

A. ***It depends***

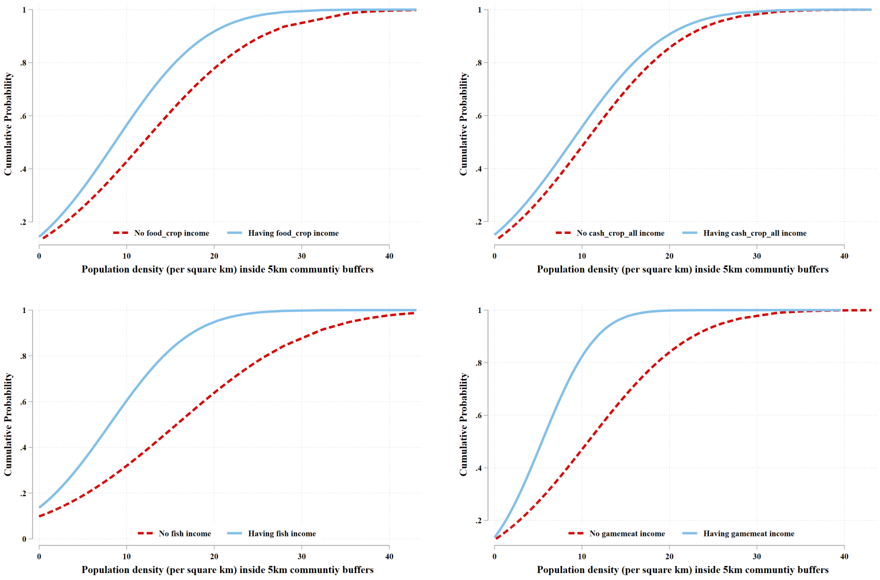
- * Concentration is good for environment, but too much concentration is not
- * Policies that cause more medium-sized communities evenly across the river basin are desirable to reduce deforestation

Appendix

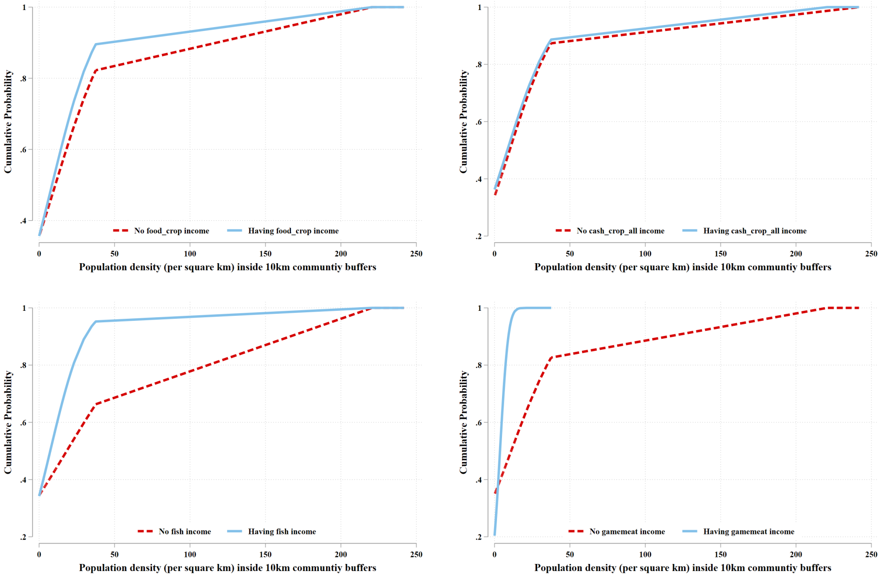
Population Density (*1km* buffer) & Activity/Occupation: Agricultural Sector vs. Wild Animal Extractions



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** ($x = 5km, 10km$ compared to $x = 1km, 2km$)

Back

Why Congestion (on net) in Land Access? ▸ Back

Community population$\uparrow$ $\Rightarrow$

- 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
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

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

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)	(2)	(3)	(4)	(5)	(6)
	OLS	IV	OLS	IV	OLS	IV
$\log(N_{o,Ag})$	0.676^{***}	0.557^{***}	0.794^{***}	0.466	0.541^{***}	0.323^{*}
	(0.0205)	(0.0706)	(0.0459)	(0.318)	(0.0411)	(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***	-0.498***	-0.658***	-0.251	-0.653***	-0.525**
	(0.0306)	(0.0899)	(0.0605)	(0.553)	(0.0672)	(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 anaylysis 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.

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

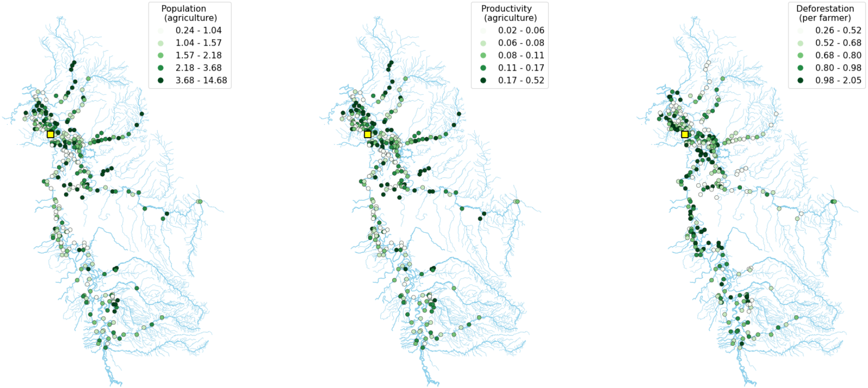
Table: Congestion Externality in Natural Resource Extraction with Spatial Spillovers

	The calibrated value of $\log(\tilde{A}_{o,Nr})$									
	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
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



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)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
$\log(N_{o,Ag})$	0.0463***	0.166***	0.0477***	0.0290	0.0511***	0.0627**	-0.00517	0.00506
	(0.0111)	(0.0442)	(0.0115)	(0.0390)	(0.0107)	(0.0288)	(0.00569)	(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 anaylysis 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.

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

- 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)

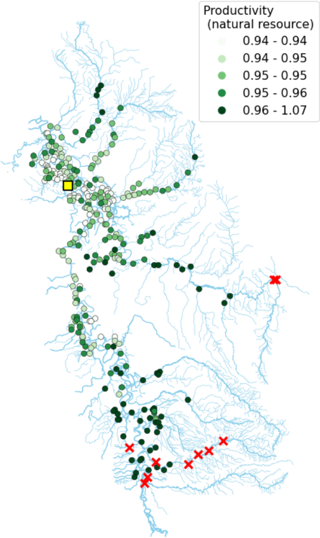
Table: Community Population and Modern Technology Use

(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
$\log(N_{o,Ag})$	-0.00309*	-0.00406	0.0000856	-0.000788	0.00410**	0.000584
	(0.00182)	(0.00423)	(0.000592)	(0.000878)	(0.00195)	(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) Inputs into land and crops	(1) Guano/manure/compost	(2) Chemical fertilizers	(3) Insecticides	(4) Herbicides	(5) Fungicides	(6) Biologic control
$\log(N_{o,Ag})$	0.000726	0.00215*	0.0207***	0.0300***	0.0106***	-0.00416*
	(0.00110)	(0.00111)	(0.00349)	(0.00361)	(0.00214)	(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
(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
$\log(N_{o,Ag})$	-0.000784	-0.000261	-0.000179	-0.00102*	0.00194**	0.0195***
	(0.000501)	(0.000287)	(0.000297)	(0.000547)	(0.000805)	(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
(D) Electrical or mechanical energy	(1) Grain mill	(2) Grass chopper	(3) Thresher	(4) Electric generator	(5) Wheel tractor	(6) Boat/canue/speedboat
$\log(N_{o,Ag})$	0.00590***	0.000397	-0.000964	-0.0101***	0.000997*	-0.0286***
	(0.00188)	(0.000419)	(0.000644)	(0.00320)	(0.000599)	(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

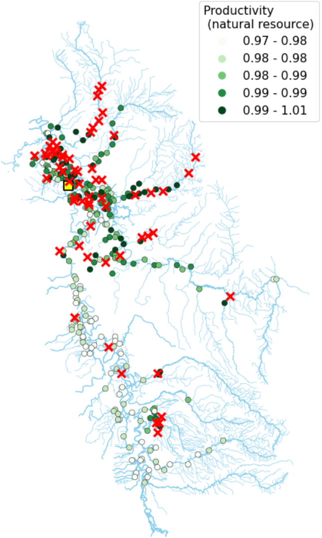
Notes: Robust standard errors in parentheses. The unit of anaylysis is a household in the 2012 Peruvian Agricultural Census. We use $\log(RA_o)$ and initial community existence (in 1910 and 1940) as instruments for $\log(N_{o,Ag})$. Geographical controls include a dummy of high river orders (4 and 5), 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.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

▸ 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