Anthropogenic Land Use Changes and Malaria Burden in the Brazilian Amazon

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Agenda

- Background on Malaria
- Environmental Change
- Malaria in the Brazilian Amazon
- Study Evaluation
- Takeaways and Discussion

Background

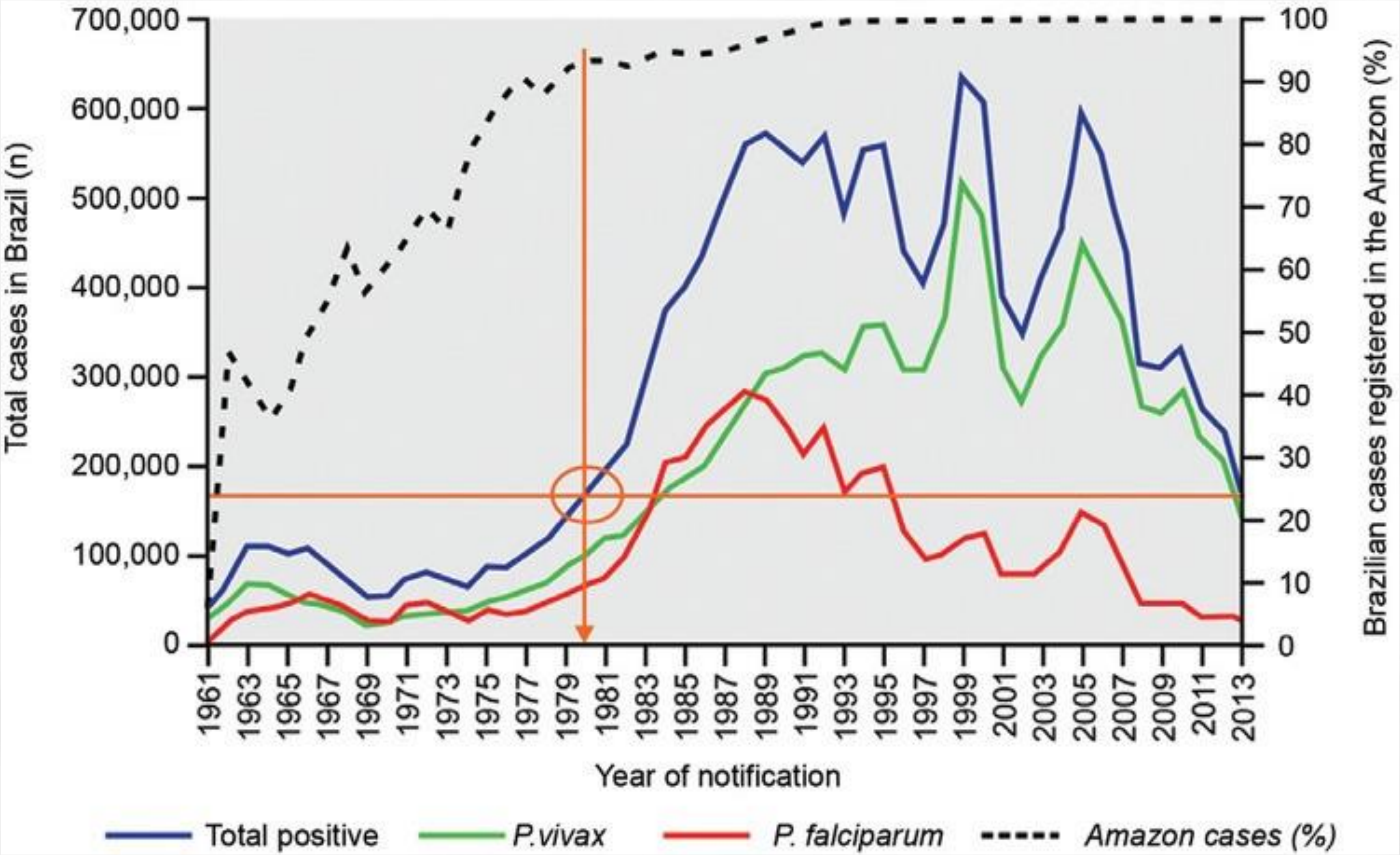
Types	Mosquito-borne	"Airport"	Congenital	Transfusion transmitted
Species	P. Malariae	P. Falciparum	P. Ovale	P. Vivax	P. Kowlesi

(CDC, 2019)

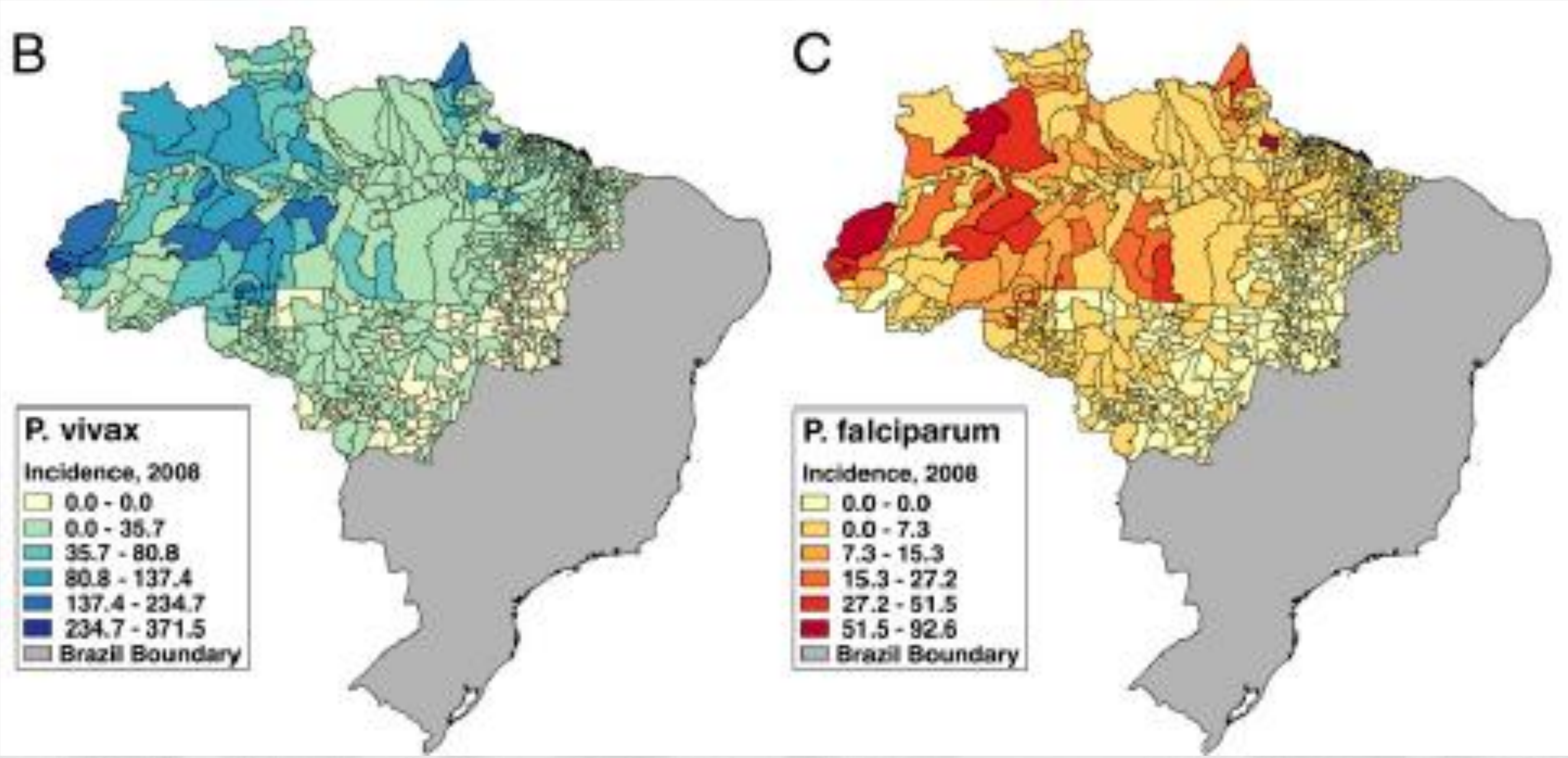
Environmental Change and Malaria

- Anthropogenically driven
  - Biodiversity ↓
  - Carbon storage ↓
  - Infectious disease ↑
    - Pathways?

(MacDonald & Mordecai, 2019)



(de Pina-Costa et al., 2014)



(MacDonald & Mordecai, 2019)

PNAS

Amazon deforestation drives malaria transmission, and malaria burden reduces forest clearing

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Deforestation and land use change are among the most pressing anthropogenic environmental impacts. In Brazil, a resurgence of malaria in recent decades paralleled rapid deforestation and settlement in the Amazon basin, yet evidence of a deforestation-driven increase in malaria remains equivocal. We hypothesize an underlying cause of this ambiguity is that deforestation and malaria influence each other in bidirectional causal relationships—deforestation increases malaria through ecological mechanisms and malaria reduces

change, mosquito vector ecology, and cases of human malaria remains surprisingly ambiguous and even contradictory. Entomological risk for malaria is thought to increase following initial settlement and forest clearing (i.e., in frontier settlements) due to a combination of increased biting rate and available breeding habitat for the primary vector (*A. darlingi*) (5, 6), increased adult mosquito survival in human-altered landscapes (15), and higher entomological inoculation rates in forest and riverine associated frontier set-

(MacDonald & Mordecai, 2019)

Grounds for Study

- Previous theories
  - Entomological risk and frontier settlements
  - Direct link?
- Should we expect increased transmission as a result of human expansion?

(MacDonald & Mordecai, 2019)

Methods

- 2003-2015 dataset
- 795 municipalities in 9 states
- HYPOTHESIS: bidirectional feedback mechanism

(MacDonald & Mordecai, 2019)

The Data

- SIVEP - Malaria monitoring system
  - All municipalities in 9 state Brazilian Amazon region
    - Incidence rates by month
- GFC dataset - municipality by year measures
  - Annual forest loss
  - Total forest cover

(MacDonald & Mordecai, 2019)

Econometric Regression

- Approximate the gold standard for observational data
- Overcomes two causal limitations
  - Omitted variable bias (confounding)
  - Simultaneity bias

(MacDonald & Mordecai, 2019)

Methods

- Model evaluation
  - Account for heterogeneity of MI and FL
    - Pop density criteria
  - Changes in density over time
  - Effects of poverty/economic development

(MacDonald & Mordecai, 2019)

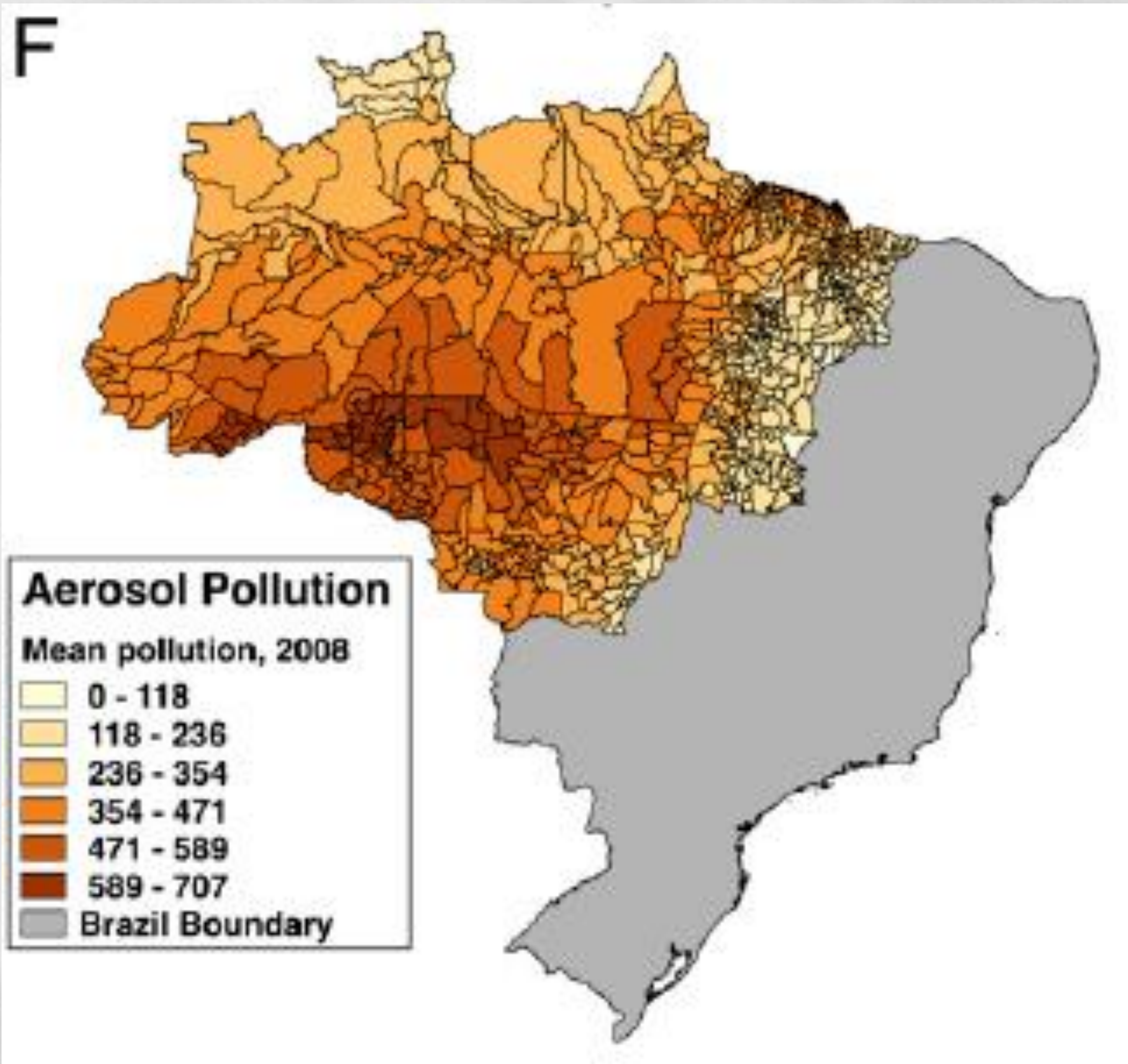
Methods

- Time-invariant variables
  - Elevation, perennial bodies of water, etc.

(MacDonald & Mordecai, 2019)

Methods

- Abiotic and environmental characteristics
  - Optimal temperature for transmission
  - Average precipitation by municipality
  - Aerosol pollution



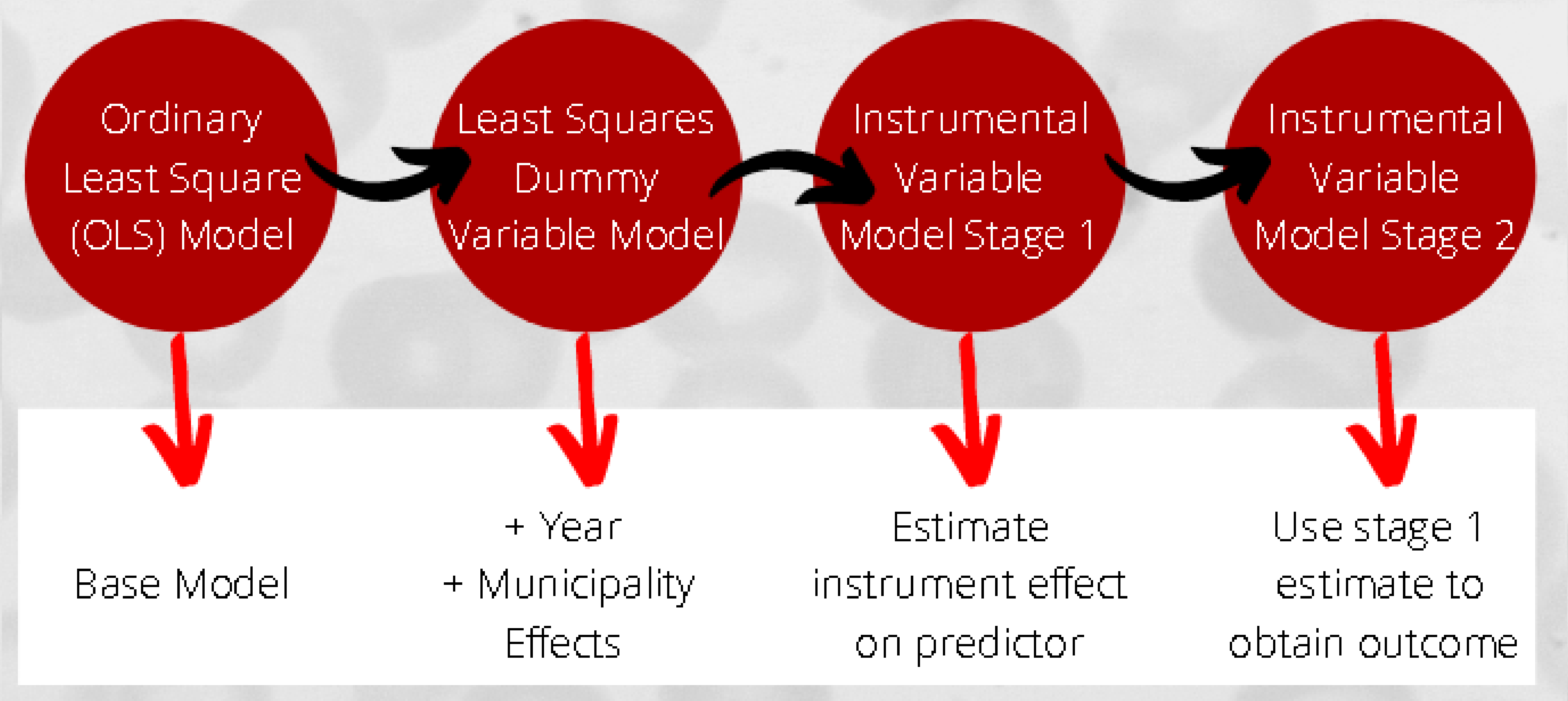
(MacDonald & Mordecai, 2019)

Addressing the Major ?s

- 1. Effects of deforestation on malaria?
- 2. Effects of malaria on deforestation?

(MacDonald & Mordecai, 2019)

Econometric Regression Process



Econometric Methods: OLS Model

$$\log(M_{it}) = \beta_0 + \beta_1 \log(FL_{it}) + \beta_2 X_{it} + \varepsilon_{it},$$

Malaria incidence

Effect of forest loss on incidence

Vector of control variables

Error

(MacDonald & Mordecai, 2019)

Econometric Methods: LSDV Model

$$\log(M_{it}) = \beta_0 + \beta_1 \log(FL_{it}) + \beta_2 X_{it} + \gamma_t + M_i + \varepsilon_{it},$$

Malaria incidence

Effect of forest loss on incidence

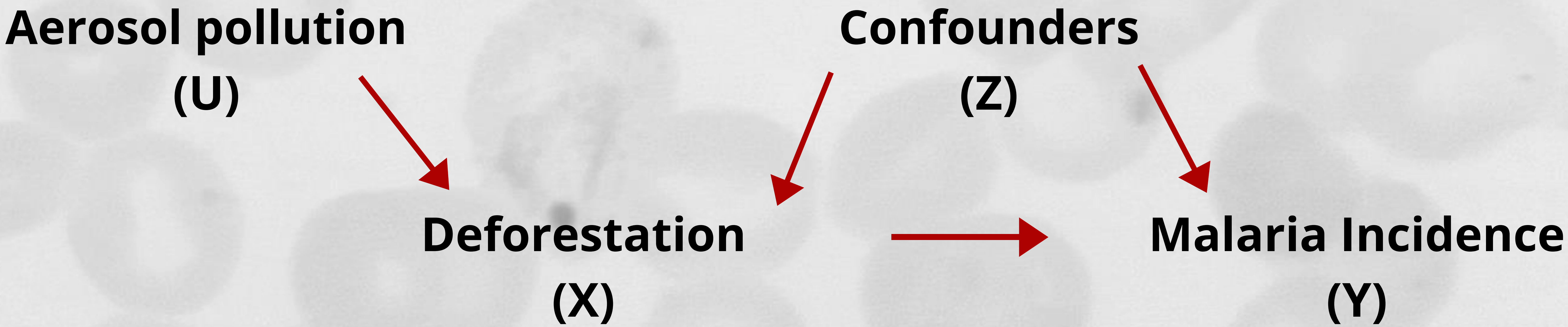
Vector of control variables

Year and municipality dummy vars

Error

(MacDonald & Mordecai, 2019)

Instrumental Variable Regression



Econometric Methods: LSIV 1 Model

$$\log(FL_{it}) = \alpha_0 + \alpha_1 \log(Aerosol_{it}) + \alpha_2 X_{it} + \gamma_t + M_i + \mu_{it},$$

Forest loss

COI on aerosol pollution

Vector of control variables

Year and municipality dummy vars

Error

(MacDonald & Mordecai, 2019)

Econometric Methods: LSIV 2 Model

$$\log(M_{it}) = \beta_0 + \beta_1 \widehat{\log(FL_{it})} + \beta_2 X_{it} + \gamma_t + M_i + \varepsilon_{it}.$$

Malaria incidence

First stage estimates of deforestation

Vector of control variables

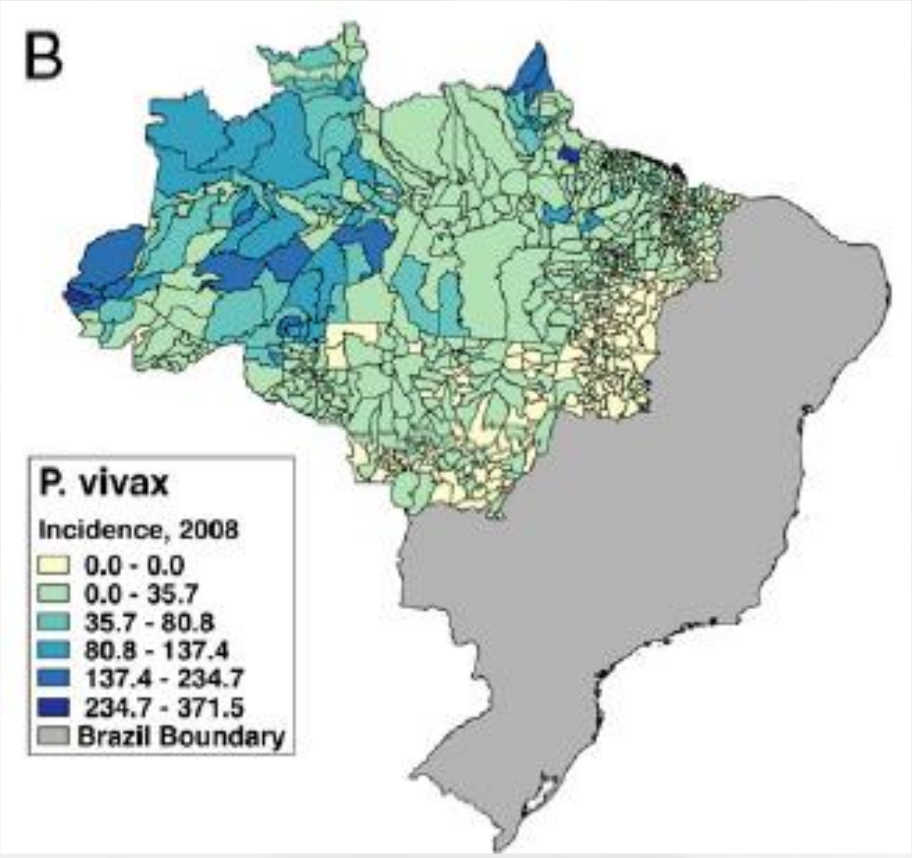
Year and municipality dummy vars

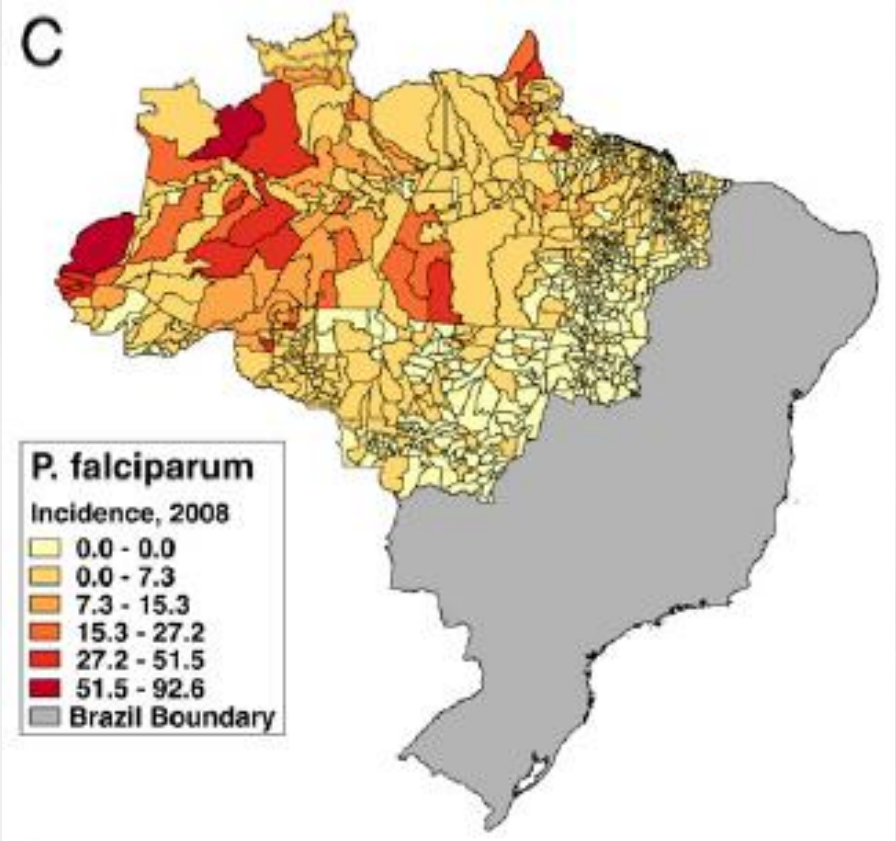
Error

(MacDonald & Mordecai, 2019)

Ensuring a Robust Model

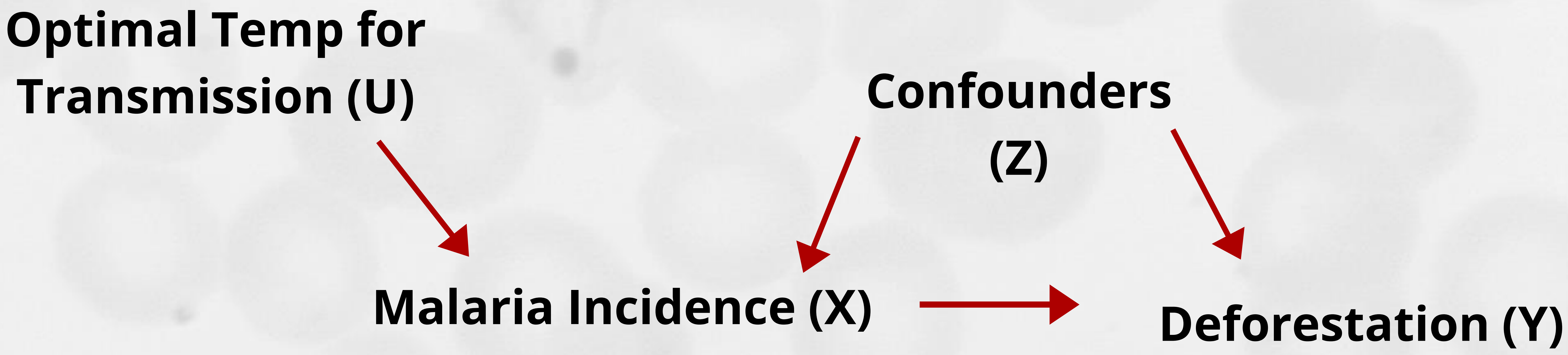
- Sub models by:
  - Total malaria vs species types
    - Vivax relapse effects
  - Interior vs outer states
    - Malaria burden + settlement effects





(MacDonald & Mordecai, 2019)

Instrumental Variable Regression



Econometric Methods: LSIV 1 In Reverse

$$\log(M_{it}) = \delta_0 + \delta_1 \log(Temp_{it}) + \delta_2 \Psi_{it} + \gamma_t + M_i + \mu_{it},$$

Malaria incidence

Temp suitability during dry season

Vector of explanatory control variables

Year and municipality dummy vars

Error

(MacDonald & Mordecai, 2019)

Econometric Methods: LSIV 2 In Reverse

$$\log(FL_{it}) = \lambda_0 + \lambda_1 \widehat{\log(M_{it})} + \lambda_2 \Psi_{it} + \gamma_t + M_i + \varepsilon_{it}.$$

Forest loss

First stage predicted values of malaria

Vector of explanatory control variables

Year and municipality dummy vars

Error

(MacDonald & Mordecai, 2019)

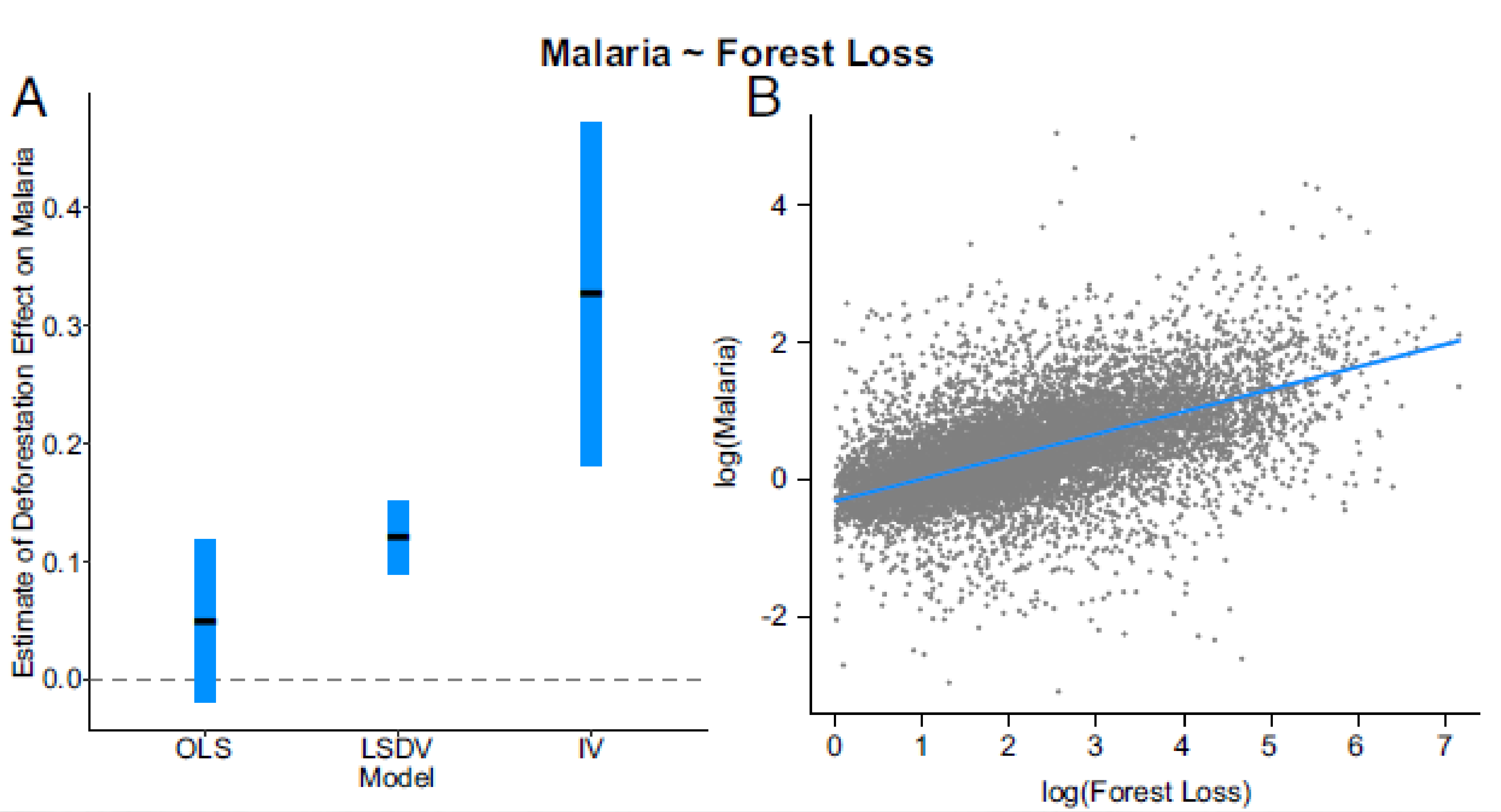
Ensuring a Robust Model

- Sub models by:
  - Full Amazon
  - Interior vs exterior

(MacDonald & Mordecai, 2019)

Results: Deforestation on Malaria

- ↑Deforestation = ↑ Malaria
  - $\beta=0.327$, $p=0.024$*
- Significant in inner Amazon states



(MacDonald & Mordecai, 2019)

Results

- Malaria incidence in the dry season
    - Precipitation and Optimal temp
- Population density, GDP per capita
- P. falciparum vs P. vivax
    - Relapse effects

(MacDonald & Mordecai, 2019)

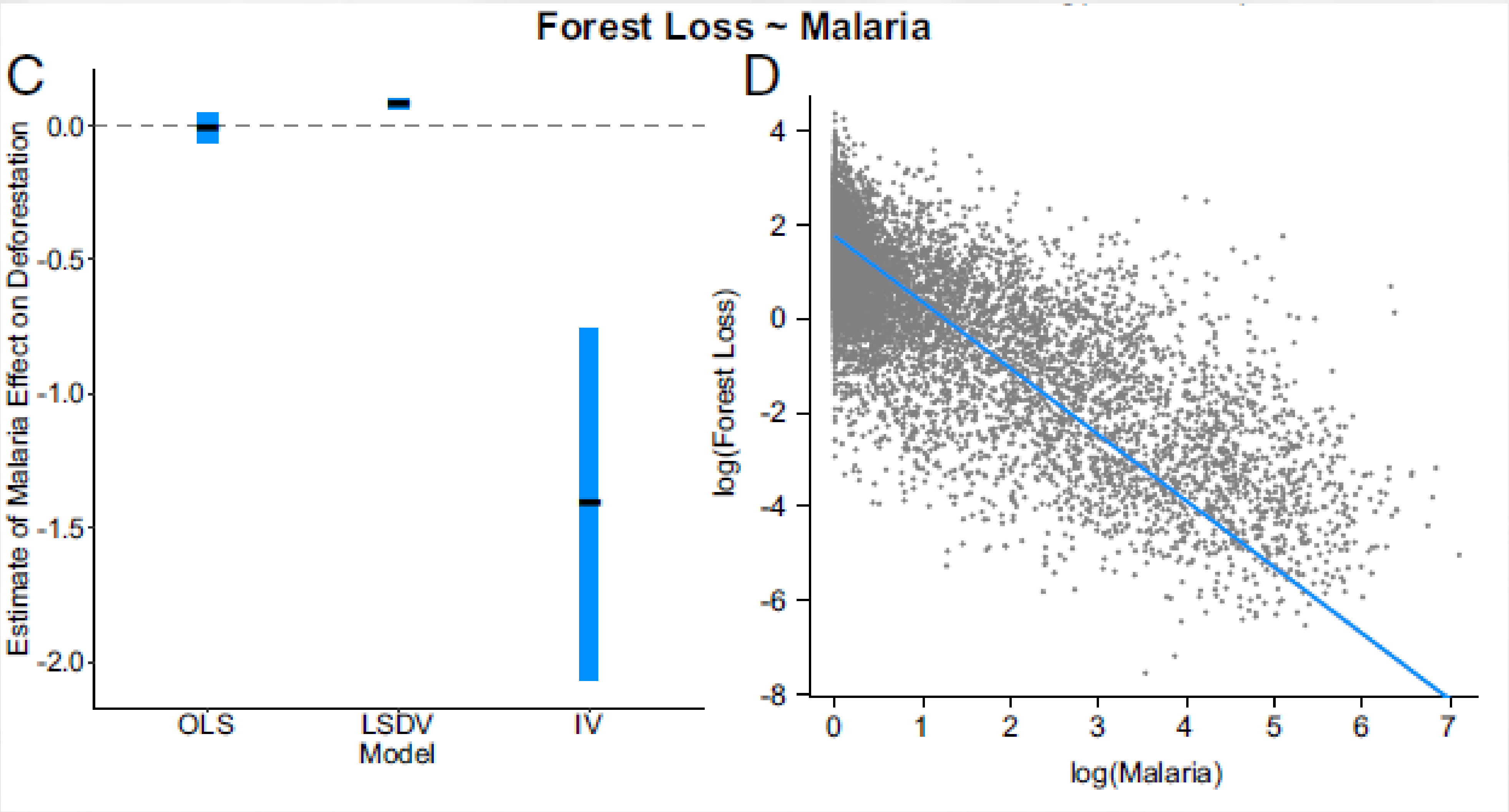
Results: Malaria on Deforestation

- ↑Malaria =

  ↓ Forest Loss

  - β= -1.410, p=0.031*

- Consistent in interior states



(MacDonald & Mordecai, 2019)

Strengths and Limitations

- Strengths
  - Scale of analysis
- Limitations
  - Aggregate data
  - Observational studies and confounding
- Moving forward: local mechanistic studies

(MacDonald & Mordecai, 2019)

Takeaways

- Early vs late stage deforestation effects
- Socio-ecological feedback of Malaria incidence
- Underlying mechanisms of these relationships?
- Policy implications

(MacDonald & Mordecai, 2019)

Sources

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Discussion Questions

1. Given the demonstrated inhibition of deforestation via malaria burden, what implications does this have on the new era of economic development (given the historical role of land use changes in economic growth)?

2. At the policy level, what measures do you think could or should be taken to address this complex phenomenon?

3. What other infectious diseases do you hypothesize may exhibit a similar feedback mechanism to an anthropogenically-driven event?