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Malaria and Economic Development in the Short-term: *Plasmodium falciparum* vs *Plasmodium vivax*[⋆]

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Abstract

Malaria—a disease caused by parasitic microorganisms of the *Plasmodium* genus—has been shown to impede economic growth and socioeconomic development in the long-term. In this paper we use annual regional data from India to show that malaria outbreaks are associated with an immediate decline in economic development approximated by night light intensity. We find the association to be significant for outbreaks of both the globally most prevalent *Plasmodium* species: *Plasmodium falciparum* and *Plasmodium vivax*. The estimated associations are quite sizeable. Severe outbreaks correlate with night light reductions of 5% of the standard deviation for *P. falciparum* and 4% for *P. vivax*.

Keywords: Malaria, Economic development, India, Plasmodium falciparum, Plasmodium vivax, Night light intensity
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1. Introduction

Malaria is bad. It negatively affects health at birth, human capital accumulation and labor market outcomes (Shiff et al., 1996; Sachs and Malaney, 2002; Bleakley, 2010; Lucas, 2010; Hong, 2013; Barofsky et al., 2015; Klejnstrup et al., 2018; Shih and Lin, 2018). The majority of the literature has found that in the end, malaria impedes economic development (Gallup and Sachs, 2001; Sarma et al., 2019; Flückiger and Ludwig, 2020).

Malaria is a disease caused by parasitic microorganisms of the *Plasmodium* genus, of which the two most prevalent species in humans are *Plasmodium falciparum* and *Plasmodium vivax*. The severity of the disease depends on which of these *Plasmodium* species is present. Infections caused by *P. falciparum*, the dominant species in Africa, are the most dangerous as they often develop rapidly and lead to coma or death unless treated properly. Infections caused by *P. vivax* are usually not as severe, but some parasites may remain dormant in the liver for months or even years, leading to a relapse of the disease.

Given that the severity of the malaria caused by the two *Plasmodium* species differs, these species' impact on economic development may well also differ. To date, the literature has primarily focused on the long-term impacts of infections caused by *P. falciparum* (e.g., Flückiger and Ludwig, 2020; Gallup and Sachs, 2001) or on malaria in general (e.g., Sarma et al., 2019), without comparing the effects of different species.

In this paper we estimate the impact of the spread of both the globally most prevalent *Plasmodium* species on economic development using data on India, a country where malaria claimed 30,930 lives in 2010 (WHO, 2021),[1] and where both *Plasmodium* species are present. The Malaria Atlas Project (MAP, Battle et al., 2019; Weiss et al., 2019)[2] estimates that there were 11 million cases of *P. falciparum* and 10 million cases of *P. vivax* in India in 2010 .

We make two contributions to the literature: (a) We estimate the heterogeneous short-term impact of malaria on economic development according to which *Plasmodium* parasite causes the disease. (b) We estimate the impact of malaria on economic development using intra-country regional panel data that allows us to avoid potential bias resulting from inter-country differences in institutional, socioeconomic, or geographical characteristics.

2. Data and estimation sample

We combine two main data sources. Yearly 5×5 km grid data on malaria come from MAP and contain parasite rates for both *Plasmodium* species. Parasite rates represent the share of the infected population estimated from parasite rate survey points using an informed Bayesian geostatistical model with a set of covariates including geographical, climatic, and socioeconomic variables (Battle et al., 2019; Weiss et al., 2019).[3] The parasite rates in MAP differ in their base population: the parasite rate for *P. falciparum* is estimated for the population aged between two and 10 years, while the parasite rate for*P. vivax* is estimated for the whole population.

Standard measures of economic development such as GDP are available only at the level of large regions. To overcome this limitation, we approximate the level of economic development using remotely sensed night light intensity grid data from the Defense Meteorological Satellite Program (DMSP).[4] In the DMSP, night light intensity is measured on a scale from 0 to 63, where 0 indicates no light and 63 is maximum luminosity. The DMSP data set enables us to analyze economic development at sub-national level and independent of the quality of local government statistical infrastructure, size of informal economy, etc. The literature also shows that night light data can be considered a reliable proxy for economic development (see e.g., Henderson et al., 2012; Elvidge et al., 2012).

We construct our estimation sample by aggregating the MAP and DMPS grid data at the level of 2,297 mainland districts (as seen in Figures 1)[5] with an average area of 1,369 km^2 and for the period 2001–2013, when both source data sets over-

[1] The Global Health Observatory variable ID 4650, last accessed on 20 July 2021.

[2] See India's country profile on the MAP website: https://malariaatlas.org/trends/country/IND, last accessed on 20 July 2021.

[3] Data from MAP are available at https://malariaatlas.org/malaria-burden-data-download/.

[4] Cleaned DMSP data are available from https://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html.

[5] We use maps of districts (level 3) available at https://gadm.org/download_country_v3.html.

lap.[6] This aggregation yields a yearly balanced panel with 29,861 observations.

3. Empirical models

In this paper we focus on the short-term impacts of malaria outbreaks – i.e. the association between changes in parasite rate and changes in night light intensity.

Figures 1 and 2 show that in 2001 the regions that suffered the highest parasite rates were also the darkest spots on the map of night luminosity. This is in line with findings by Flückiger and Ludwig (2020) who show that—as a result of long-term development—parts of Africa where conditions favour the spread of *P. falciparum* are lower in socioeconomic development.

Adverse living conditions can lead to population sorting (Heblich et al., 2021) or differences in urbanization levels (Flückiger and Ludwig, 2020). To reflect such time-invariant or only slowly changing regional characteristics, our first specification uses a two-way fixed effects estimator:

$$\Delta NL_{i,t} = \gamma_1 \Delta PR_{p,i,t} + \gamma_3 NL_{i,t-1} + \theta_i + \theta_t + \varepsilon_{i,t} \quad (1)$$

where $\Delta NL_{i,t}$ is a change in night light intensity (NL) in district i and year t, PR is the parasite rate for *Plasmodium* species p (i.e. *P. falciparum* or *P. vivax*), θ_i is a full set of district fixed effects including constants that control for time-invariant characteristics, and θ_t is set of year fixed effects that controls for idiosyncratic shocks. Variable ε is an error term. We estimate (1) by OLS with robust standard errors clustered by district.

Model (1) may suffer from spillovers and spatial auto-correlation in the error term. Therefore, we also estimate a spatial autoregressive model with autoregressive disturbances (SARAR):

$$\Delta NL_{i,t} = \lambda \mathbf{W} \Delta NL_{i,t} + \boldsymbol{\beta} \mathbf{x} + u_{i,t}, \quad (2)$$

$$u_{i,t} = \rho \mathbf{W} u_{i,t} + \delta_{i,t} \quad (3)$$

where u is a spatially autocorrelated error term, δ is a well-behaved error term and $\mathbf{W}$ is a row standardized spatial contiguity weight matrix with individual weights that are non-zero for neighboring districts. Vector $\mathbf{x}$ contains covariates from (1) including fixed effects. The system of equations (2) and (3) is estimated by the two-step maximum likelihood procedure implemented by Millo and Piras (2012).

In our alternative specifications we focus on outbreaks—i.e. substantial increases in parasite rates—and we define PR as a vector of three indicator variables for increases in parasite rates between the 75^{th}, 90^{th}, 97.5^{th} and 100^{th} percentiles[7] (see Figure 3) with declines, and increases below 75^{th} percentile being a reference.

As noted above, the parasite rates are estimated for different populations (age groups) and are not directly comparable. Therefore, we first estimate baseline models separately for both *Plasmodium* species and then we extend the baseline specifications to include both parasite rates in one regression.

We also note that neither of the two models distinguishes the channels through which malaria affect economic development. Our measures of malaria spread (parasite rates) are also likely endogenous. The estimates we present, therefore, represent reduced-form associations.

4. Results and concluding remarks

Our estimates of (1), reported in columns (1)–(2) in Table 1, show that increases in the parasite rates of both *Plasmodium* species are negatively associated with changes in night light intensity.

A one standard deviation increase in the *P. falciparum* parasite rate ($\text{SD}_{\text{pf}} = 2.510$) is associated with a decline in night light intensity by 10% of its standard deviation ($\text{SD}_{\text{nl}} = 7.221$). The relationship for the *P. vivax* is weaker: an increase by one standard deviation ($\text{SD}_{\text{pv}} = 3.133$) is associated with a decline in night-light by 1% of standard deviation.

The LM tests reported in the lower panel of Table 1 suggest the presence of spatial lag dependence and spatial auto-correlation in the error term, providing ex-post justification for the use of the SARAR model.

Our estimates of the SARAR model, reported in columns (3)–(4) of Table 1, show a statistically significant and negative association for *P. falciparum*

[6] Technically, our data set also covers the year 2000. However, as we use lagged variables in our regressions (see Section 3) we restrain our descriptive statistics to the 2001–2013 period.

[7] Sample 75^{th}, 90^{th}, and 97.5^{th} percentiles of increases in parasite rates are 0.202, 0.547, 1.660 for *P. falciparum*, and 0.126, 0.420, and 1.500 for *P. vivax*.

Table 1: Parasite rate and economic development

	Dependent variable: Change in night light intensity (t)			
	Fixed effects		Spatial autoregressive model with autoregressive disturbances (SARAR)	
	(1)	(2)	(3)	(4)
Change in *Plasmodium falciparum* parasite rate (t)	-0.039^{***}		-0.025^{***}	
	(0.008)		(0.009)	
Change in *Plasmodium vivax* parasite rate (t)		-0.021^{*}		-0.015
		(0.011)		(0.009)
Night light intensity ($t-1$)	-0.193^{***}	-0.192^{***}	-0.173^{***}	-0.173^{***}
	(0.009)	(0.009)	(0.004)	(0.004)
Spatial autoregressive coefficient λ			-0.487^{***}	-0.488^{***}
			(0.018)	(0.018)
Spatial error parameter ρ			0.713^{***}	0.714^{***}
			(0.009)	(0.009)
District fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
	LM-tests			
Spatial error dependence	$31,181^{***}$	$31,000^{***}$		
Spatial lag dependence	$31,188^{***}$	$31,092^{***}$		
Observations	29,861	29,861	29,861	29,861

Note: The table contains estimated coefficients from regression (1) in columns (1)–(2) and coefficients from equations (2) and (3) in columns (3)–(4). Parentheses contain robust standard errors clustered by district in columns (1)–(2), and KKP standard errors in columns (3)–(4): $^{*} = p < 0.1$, $^{*}{*} = p < 0.05$, $^{***} = p < 0.01$.

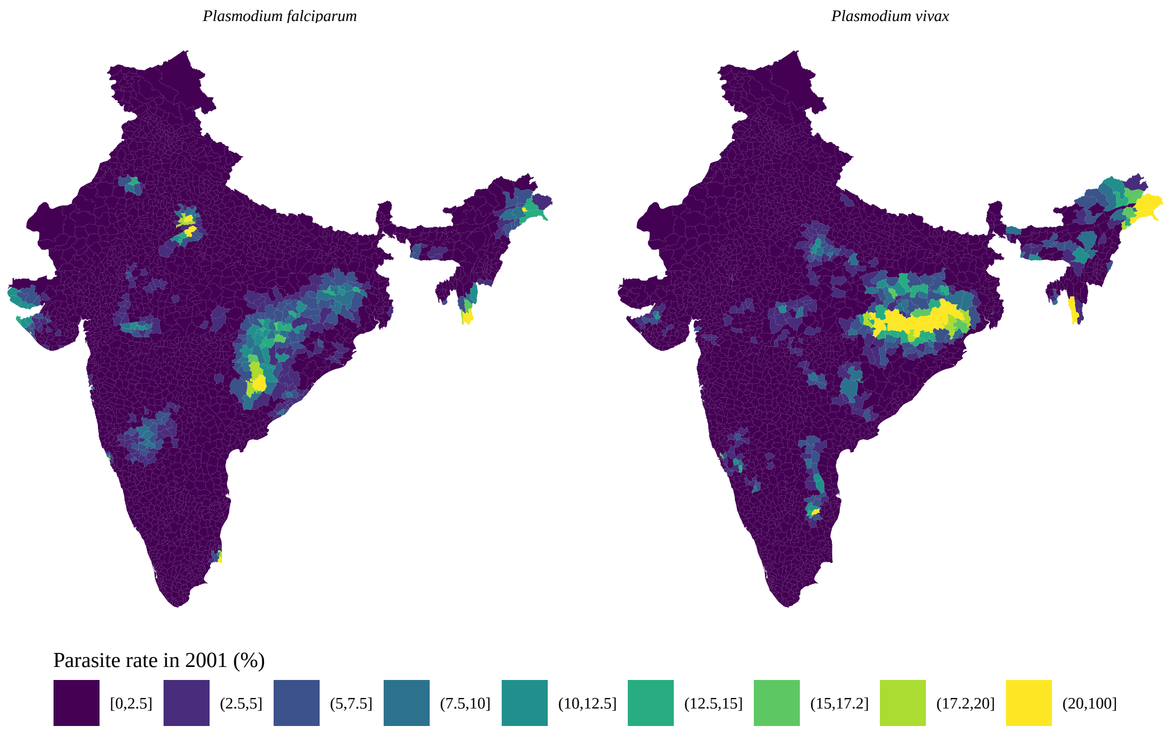

Figure 1: Parasite rates in 2001.
Note: Parasite rates represent the share of the population infected with *Plasmodium* parasites (see Lucas et al., 2018). Source: Malaria Atlas Project, own elaboration.

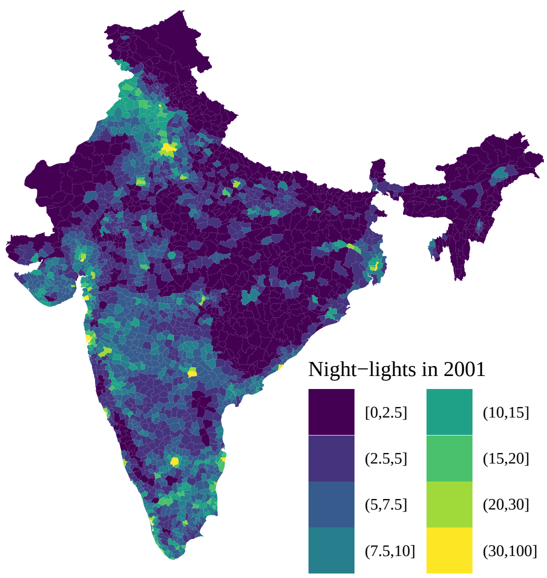

Figure 2: Night light intensity in 2001.
Source: DMSP, own elaboration.

(with a mean total impact of -0.017); however, the estimated coefficient for *P. vivax* is no longer significant (p-value $= 0.105$).

The results of the alternative specifications reported in Table 2 suggest that the estimated association is driven by outbreaks. Our estimates show that the relationship is non-linear and grows stronger with higher increases in the parasite rates. Moreover, the association is negative and significant for both *Plasmodium* species for changes in the parasite rate above the 90^{th} percentile, regardless of the model used. The estimated associations are quite sizeable. The estimates obtained with a fixed effect estimator suggest that the occurrence of a malaria outbreak (above 97.5^{th} percentile) correlates with a decline in night-light of 5% of its standard deviation for *P. falciparum* and 4% for *P. vivax*.

In the last set of regressions we extend the baseline specifications to include both *Plasmodium* species. Changes in their parasite rates are only weakly correlated (Pearson's $\rho = 0.226$, see Figure A.4 in the Appendix). Nevertheless, the estimates reported in Table 3 are, albeit slightly smaller, in

Table 2: Malaria outbreaks and economic development

	Dependent variable: Change in night light intensity (t)			
	Fixed effects		Spatial autoregressive model with autoregressive disturbances (SARAR)	
	(1)	(2)	(3)	(4)
Outbreak of *P. falciparum:*				
Increase in parasite rate between 75^{th} and 90^{th} percentile ($= 1,t$)	-0.069^{***} (0.026)		-0.060^{***} (0.023)	
Increase in parasite rate between 90^{th} and 97.5^{th} percentile ($= 1,t$)	-0.182^{***} (0.040)		-0.132^{***} (0.033)	
Increase in parasite rate between 97.5^{th} and 100^{th} percentile ($= 1,t$)	-0.351^{***} (0.066)		-0.314^{***} (0.057)	
Outbreak of *P. vivax:*				
Increase in parasite rate between 75^{th} and 90^{th} percentile ($= 1,t$)		-0.061^{**} (0.025)		-0.024 (0.024)
Increase in parasite rate between 90^{th} and 97.5^{th} percentile ($= 1,t$)		-0.139^{***} (0.038)		-0.077^{**} (0.034)
Increase in parasite rate between 97.5^{th} and 100^{th} percentile ($= 1,t$)		-0.301^{***} (0.076)		-0.195^{***} (0.058)
Night light intensity ($t-1$)	-0.193^{***} (0.009)	-0.193^{***} (0.009)	-0.173^{***} (0.004)	-0.173^{***} (0.004)
Spatial autoregressive coefficient λ			-0.486^{***} (0.018)	-0.486^{***} (0.018)
Spatial error parameter ρ			0.713^{***} (0.009)	0.713^{***} (0.009)
District fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
	LM-tests			
Spatial error dependence	$31,181^{***}$	$31,000^{***}$		
Spatial lag dependence	$31,188^{***}$	$31,092^{***}$		
Observations	29,861	29,861	29,861	29,861

Note: The table contains estimated coefficients from regression (1) in columns (1)–(2) and coefficients from equations (2) and (3) in columns (3)–(4). The PR variable in (1) and (2) is defined as a vector of three indicator variables for increases in parasite rates between the 75^{th}, 90^{th}, 97.5^{th} and 100^{th} percentiles. Parentheses contain robust standard errors clustered by district in columns (1)–(2), and KKP standard errors in columns (3)–(4): $^{*} = p < 0.1$, $^{*}{*} = p < 0.05$, $^{***} = p < 0.01$.

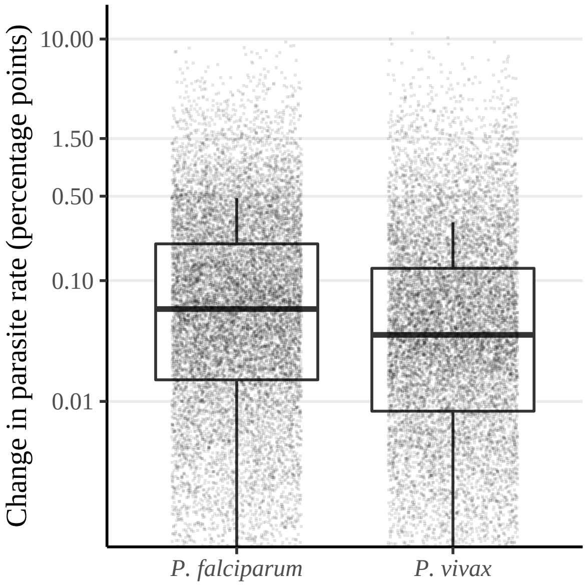

Figure 3: Increases in parasite rate.
Note: Figure is limited to changes in parasite rates above 0.001 percentage points. All observations are in construction of boxplots. Dots represent individual observations.

line with our main results reported above.

To reflect the dynamics of malaria outbreaks and their potential impacts, we extend our specifications with lagged changes in parasite rates (see Tables A.4 and A.5 in the Appendix). The estimated coefficients are not statistically significant, with the exception of the positive coefficients for lagged change in parasite rate and the worst outbreaks of *P. vivax*. These are, however, significant only in regression (1).

Our results suggest that malaria outbreaks caused by either of the *Plasmodium* species are associated with economic development, even in the short-term. This is not an obvious conclusion, since the two *Plasmodium* species we consider tend to impact economic development through different channels. *P. falciparum* has an immediate effect on the infected individuals and is, therefore, more likely to affect economic development in the short-term by decreasing capacity to work among those infected and, for instance, among the family members or others who care for them (see e.g, Gallup and Sachs, 2001). On the other hand *P. vivax* is typically associated with channels that undermine economic development in the long-term—such as human capital accumulation (see e.g., Mendis et al., 2001). However, our results suggest that sufficiently large outbreaks of *P. vivax* also have immediate economic impacts.

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Table 3: Parasite rate, malaria outbreaks, and economic development including both *Plasmodium* species

	Dependent variable: Change in night light intensity (t)			
	Fixed effects		Spatial autoregressive model with autoregressive disturbances (SARAR)	
	(1)	(2)	(3)	(4)
Change in *Plasmodium falciparum* parasite rate (t)	-0.037^{***} (0.008)		-0.024^{***} (0.009)	
Change in *Plasmodium vivax* parasite rate (t)	-0.012 (0.011)		-0.013 (0.010)	
Outbreak of *P. falciparum:*				
Increase in parasite rate between 75^{th} and 90^{th} percentile ($= 1,t$)		-0.061^{**} (0.026)		-0.057^{**} (0.023)
Increase in parasite rate between 90^{th} and 97.5^{th} percentile ($= 1,t$)		-0.154^{***} (0.040)		-0.124^{***} (0.033)
Increase in parasite rate between 97.5^{th} and 100^{th} percentile ($= 1,t$)		-0.305^{***} (0.066)		-0.294^{***} (0.057)
Outbreak of *P. vivax:*				
Increase in parasite rate between 75^{th} and 90^{th} percentile ($= 1,t$)		-0.048^{*} (0.025)		-0.017 (0.024)
Increase in parasite rate between 90^{th} and 97.5^{th} percentile ($= 1,t$)		-0.104^{***} (0.038)		-0.059^{*} (0.034)
Increase in parasite rate between 97.5^{th} and 100^{th} percentile ($= 1,t$)		-0.215^{***} (0.078)		-0.154^{***} (0.059)
Night light intensity ($t-1$)	-0.193^{***} (0.009)	-0.193^{***} (0.009)	-0.173^{***} (0.004)	-0.173^{***} (0.004)
Spatial autoregressive coefficient λ			-0.487^{***} (0.018)	-0.485^{***} (0.018)
Spatial error parameter ρ			0.713^{***} (0.009)	0.712^{***} (0.009)
District fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Observations	29,861	29,861	29,861	29,861

Note: The table contains estimated coefficients from regression (1) in columns (1)–(2) and coefficients from equations (2) and (3) in columns (3)–(4). Parentheses contain robust standard errors clustered by district in columns (1)–(2), and KKP standard errors in columns (3)–(4): $^{*} = p < 0.1$, $^{*}{*} = p < 0.05$, $^{***} = p < 0.01$.

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A. Appendix

Table A.4: Parasite rate and economic development including lagged change in parasite rates

	Dependent variable: Change in night light intensity (t)			
	Fixed effects		Spatial autoregressive model with autoregressive disturbances (SARAR)	
	(1)	(2)	(3)	(4)
Plasmodium falciparum parasite rate (Δ, t)	-0.050^{***} (0.010)		-0.030^{***} (0.010)	
Plasmodium falciparum parasite rate (Δ, $t-1$)	0.011 (0.010)		0.006 (0.010)	
Plasmodium vivax parasite rate (Δ, t)		-0.049^{***} (0.009)		-0.021 (0.014)
Plasmodium vivax parasite rate (Δ, $t-1$)		0.033^{*} (0.015)		0.006 (0.013)
Night light intensity ($t-1$)	-0.205^{***} (0.009)	-0.204^{***} (0.009)	-0.184^{***} (0.004)	-0.183^{***} (0.004)
Spatial autoregressive coefficient λ			-0.479^{***} (0.019)	-0.480^{***} (0.019)
Spatial error parameter ρ			0.709^{***} (0.010)	0.710^{***} (0.010)
District fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Observations	27,564	27,564	27,564	27,564

Note: The table contains estimated coefficients from regression (1) in columns (1)–(2) and coefficients from equations (2) and (3) in columns (3)–(4). Parentheses contain robust standard errors clustered by district in columns (1)–(2), and KKP standard errors in columns (3)–(4): $^{*} = p < 0.1$, $^{*}{*} = p < 0.05$, $^{***} = p < 0.01$.

Table A.5: Malaria outbreaks and economic development including lagged change in parasite rates

	Dependent variable: Change in night light intensity (t)			
	Fixed effects		Spatial autoregressive model with autoregressive disturbances (SARAR)	
	(1)	(2)	(3)	(4)
Outbreak of *P. falciparum:*				
Increase in parasite rate between 75$^{\text{th}}$ and 90$^{\text{th}}$ percentile (= 1,t)	-0.103^{***}		-0.084^{***}	
	(0.029)		(0.025)	
Increase in parasite rate between 90$^{\text{th}}$ and 97.5$^{\text{th}}$ percentile (= 1,t)	-0.217^{***}		-0.150^{***}	
	(0.044)		(0.036)	
Increase in parasite rate between 97.5$^{\text{th}}$ and 100$^{\text{th}}$ percentile (= 1,t)	-0.435^{***}		-0.3152^{***}	
	(0.075)		(0.063)	
Increase in parasite rate between 75$^{\text{th}}$ and 90$^{\text{th}}$ percentile (= 1,$t-1$)	0.024		0.010	
	(0.029)		(0.024)	
Increase in parasite rate between 90$^{\text{th}}$ and 97.5$^{\text{th}}$ percentile (= 1,$t-1$)	0.016		−0.27	
	(0.045)		(0.036)	
Increase in parasite rate between 97.5$^{\text{th}}$ and 100$^{\text{th}}$ percentile (= 1,$t-1$)	0.191^{**}		0.083	
	(0.074)		(0.063)	
Outbreak of *P. vivax:*				
Increase in parasite rate between 75$^{\text{th}}$ and 90$^{\text{th}}$ percentile (= 1,t)		-0.074^{***}		−0.028
		(0.027)		(0.096)
Increase in parasite rate between 90$^{\text{th}}$ and 97.5$^{\text{th}}$ percentile (= 1,t)		-0.182^{***}		-0.096^{**}
		(0.039)		(0.041)
Increase in parasite rate between 97.5$^{\text{th}}$ and 100$^{\text{th}}$ percentile (= 1,t)		-0.421^{***}		-0.236^{***}
		(0.081)		(0.071)
Increase in parasite rate between 75$^{\text{th}}$ and 90$^{\text{th}}$ percentile (= 1,$t-1$)		0.042		0.019
		(0.0231)		(0.0027)
Increase in parasite rate between 90$^{\text{th}}$ and 97.5$^{\text{th}}$ percentile (= 1,$t-1$)		0.015		0.023
		(0.045)		(0.040)
Increase in parasite rate between 97.5$^{\text{th}}$ and 100$^{\text{th}}$ percentile (= 1,$t-1$)		0.169		0.014
		(0.073)		(0.070)
Night light intensity ($t-1$)	-0.205^{***}	-0.205^{***}	-0.184^{***}	-0.184^{***}
	(0.009)	(0.009)	(0.004)	(0.004)
Spatial autoregressive coefficient λ			-0.477^{***}	-0.478^{***}
			(0.019)	(0.019)
Spatial error parameter ρ			0.709^{***}	0.709^{***}
			(0.010)	(0.010)
District fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Observations	27,564	27,564	27,564	27,564

Note: The table contains estimated coefficients from regression (1) in columns (1)–(2) and coefficients from equations (2) and (3) in columns (3)–(4). The PR variable in (1) and (2) is defined as a vector of three indicator variables for increases in parasite rates between the 75$^{\text{th}}$, 90$^{\text{th}}$, 97.5$^{\text{th}}$ and 100$^{\text{th}}$ percentiles. Parentheses contain robust standard errors clustered by district in columns (1)–(2), and KKP standard errors in columns (3)–(4): $^{*} = p < 0.1$, $^{*}* = p < 0.05$, $^{***} = p < 0.01$.

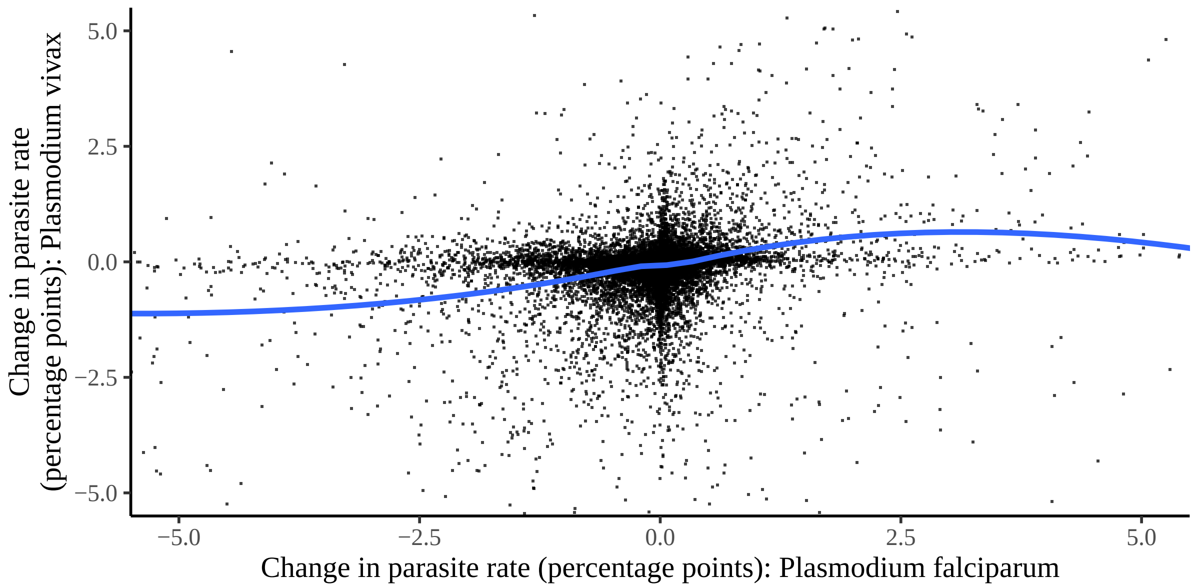

Figure A.4: Correlation in changes in parasite rates.
Note: Figure is limited to changes in parasite rates between −5 and 5 percentage points. All observations are used in the construction of smoothing line. Dots represent individual observations.

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