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Survey

The Impact of Deforestation on Malaria Infections in the Brazilian Amazon☆

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ABSTRACT

The aim of this study was to analyze the relationship of cases of malaria with deforestation in the municipalities of the Amazon, between 2003 and 2012. Among the main results: (1) we find that deforestation has direct and spillovers effects on malaria cases; (2) we find a quadratic relationship between deforestation and malaria, where deforestation areas increase the cases of the disease; but, on the other hand, (3) if this deforestation is intensive, this relationship continues to be positive, but at decreasing rates. The study also found a positive relationship between health public expenditures, inadequate sanitary conditions, GDP (direct effects), forest stock, crops in the region and temperature with cases of the disease. Livestock and spillovers effects for GDP and population density have shown negative relationships with malaria infection. Moreover, no evidence was found that soybean area can affect the dynamics of malaria infection.

1. Introduction

It is well known that tropical countries spend millions of dollars each year to control and treat individuals infected with malaria. In Brazil, 3.8 million clinical cases of malaria were reported in the last decade, and most of these cases (above 99%) were in the Amazon Forest region.[1] There are three species of protozoa associated with human malaria in the country: *Plasmodium vivax*, *P. falciparum*, and *P. malariae* (Ministry of Health, 2015). One of the most common vector mosquitoes in the region is the *Anopheles darlingi* (Ministry of Health, 2015).

The costs of malaria go far beyond the hospital expenses associated with the treatment and prevention of the disease (Sachs and Malaney, 2002). The symptoms caused by the infection can have negative effects on the productivity of workers, retarding the economic development of the regions that are at risk of contamination (Barlow, 1967; Sachs and Malaney, 2002; Cutler et al., 2010). However, the most harmful effects of malaria are among children; the disease compromises their future physical and cognitive development, potentially reducing their ability to achieve significant school progress (Lucas, 2010). Moreover, adult's labor productivity has been shown to be affected by childhood malaria exposure (Bleakley, 2010).

Beyond the effects on education and productivity, other economic costs of malaria include trade impacts, migration out of endemic areas, and reduced tourism and foreign investment (Sachs and Malaney, 2002). There is also strong evidence that malaria is associated with some economic activities, particularly those related to the deforestation of native forests (Vittor et al., 2006; Garg, 2014; Hahn et al., 2014).

Large areas in the tropical rainforest region present ideal conditions for the reproduction of mosquitoes: high temperatures, high precipitation levels, and high air humidity (Vittor et al., 2006). In the Amazon region, the *Anopheles darlingi* mosquito is most often found on the forest fringes, which provide favorable conditions for its proliferation, such as abundant water, ideal temperatures, access to the intermediate hosts of the protozoan, and proximity to local populations (Vittor et al., 2006; Garg, 2014).

The process of deforestation, in addition to extending forest fringes, also transforms the Amazon rainforest and its surroundings, generating potential changes in the microclimate, changes in biodiversity (including the extinction of natural predators of the mosquito), and favorable environments for vector reproduction (Patz et al., 2000; Singer

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[1] The Brazilian part of the Amazon forest is located in the states of Acre, Amapá, Amazonas, Pará, Rondônia, Roraima, southwest Maranhão, northwest Tocantins, and north Mato Grosso (See Fig. 1).

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and Castro, 2001; Bauch et al., 2014). Thus, each environmental change, whether due to natural or anthropogenic phenomena, has an effect on the local ecological balance and may affect the transmission dynamics of parasites, thus providing conditions for the proliferation of the vector that transmits malaria (Vittor et al., 2006).

The objective of this paper is to assess the impacts of deforestation on the incidence of malaria infections as recorded in the municipalities of seven Brazilian states that are part of Amazon region. We combine traditional econometric methods with spatial econometric methods to capture the spillover effects between the process of malaria contamination and among the agents in the forest and in their interrelated economic system in all Amazon regions and between municipalities that are part of it (Faria and Almeida, 2015). This approach is justified due to the extraordinary capacity of *Anopheles darlingi* (and other *Anopheles* species in the region) to disperse from its breeding source to infect humans as much as 7–12 km away from the forest edge and as long as deforestation takes place (Charlwood and Alecrim, 1989; Kauffman and Briegel, 2004).

The rest of this paper is organized as follows: The next section briefly reviews the literature related to the malaria and deforestation, while Section 3 presents the econometric approach and data used. The results are presented in Section 4, and we conclude with remarks on our results in Section 5.

2. Summary of Related Literature

Although the literature focusing on deforestation in developing countries is growing, to our best knowledge, there are still few applied papers that address the relationship between deforestation and socio-economic factors with malaria cases. Vittor et al. (2006) conducted a study to verify the incidence of the *Anopheles darlingi* mosquito in degraded areas of tropical forests in Peru. The authors found evidence that the incidence of mosquitoes is 278 times higher in degraded areas than in native forest. In Brazil, Olson et al. (2010) found that the number of malaria cases increased by 50% to every 4% of deforested area in the municipality of Mancio Lima (state of Acre). Achcar et al. (2011) corroborated the findings that deforestation in the Amazon is an important factor for the prediction of malaria in Brazil, but it was not the objective of the authors to calculate the intensity of the infections, which is our major motivation.

Parente et al. (2012), found a similar relationship between increased deforestation and increased cases of malaria in the municipalities of Anajás, Itaituba, Santana do Araguaia, and Viseu. This relationship was later confirmed by Bauch et al. (2014); using the methodology of quantile regression and focusing on the analysis of municipalities of the Brazilian Amazon, they found fewer incidences of malaria in areas that are subject to environmental protection.

Garg (2014) proposed a study between the incidence of malaria and deforestation in Indonesia. The author, using a logit model, has found evidence that deforestation can explain more than a million cases of malaria. In addition, Garg (2014) estimated that an increase of 1000 deforested hectares in a district could lead to a 2%–7% increase in malaria cases, culminating in 45,000 to 162,000 additional cases of the disease.

Using a Poisson regression, Saccaro Junior et al. (2015), found that deforestation is related to the incidence of malaria infection. The results indicate that for every 1% of deforested area, a 23% increase in malaria incidence rates may occur. Terrazas et al. (2015), using a linear regression, found that the annual average deforestation rate in the Brazilian Amazon is positively correlated with the incidence of malaria in the region.

On the other hand, large-scale deforestation can adversely affect malaria cases when it results in an increase in the distance between the forest edge and the nearest urban centers. Total forest clearing reduces the availability of optimal conditions for malaria vectors. In this sense, Valle and Clark (2013) have found divergent results on the subject. The authors found that cities near protected areas tend to have a higher incidence of malaria than the more distant cities. Thus, the authors concluded that reducing deforestation by 10% might result in a twofold increase in the incidence of malaria by 2050; however, total deforestation might significantly reduce the incidence of disease, since localities without forest reserves are less susceptible to an epidemic of malaria.

Until the present date, there have been few studies in the literature that included in the estimation of regression the spatial relationship between environment and malaria. For instance, Olson et al. (2010) argued that there are associations between malaria incidence and deforestation patterns across space, rather than a trend of malaria incidence and deforestation over time. Hahn et al. (2014) suggest that deforestation tends to be spatially clustered within municipalities, making it difficult to match deforestation levels and malaria incidence across municipal boundaries. Moreover, malaria infection in the Amazon cannot be analyzed only in medical and biological terms; the relationships between economic activities and infection are also of great importance for understanding the spread of the disease (Singer and Castro, 2001).

Our proposed analysis examines the distribution of the disease in space as deforestation advances. We are interested not only in the local average effects of the covariates but also in the occurrence of spillover effects through space. The use of spatial econometric analyses of this problem at the municipality level brings a new approach to the scientific literature on the malaria epidemic, aiming to contribute to the formulation of more specific and targeted public health policies to combat malaria infection.

3. Methodology

3.1. Empirical Strategy

The objective of this study is to investigate the relationship between deforestation in the Brazilian Amazon region and malaria cases. The proposed analysis takes its point of departure from the following relation:

$$Mal_{it} = f\,(Defor_{it}, \beta) \tag{1}$$

where Mal_{it} are the cases of malaria in municipality i and at time t, $Defor_{it}$ represents the deforested area, and β is the vector of parameters associated with deforestation. In order to estimate the function represented by Eq. (1), we can rewrite it as

$$Mal_{it} = Defor_{it}\beta + \mu_i + \xi_t + e_{it} \tag{2}$$

where μ_i is the unobserved heterogeneity[2] of each cross-section unit, invariant in time, such as altitude or protected forest reserves, which affects the incidence of malaria (Bødker et al., 2003). ξ_t is the unobserved heterogeneity of each year, invariant in cross-section unity, such as the climate phenomenon El Niño or changes in federal laws, which has the capacity to affect malaria cases (Bosello et al., 2006). Finally, e_{it} are the idiosyncratic deviations of the regression.

In this proposed analysis, there is also some evidence that the relationship may be nonlinear. While many authors argue that deforestation increases cases of malaria (e.g., Garg, 2014), others have found a negative relationship between malaria and deforestation (Valle and Clark, 2013). Thus, in order to test whether there is any nonlinearity in the relationship (insertion of the quadratic term) we modify Eq. (2) to obtain

[2] The Breusch and Pagan test indicated the use of models that control heterogeneity ($\chi^2 = 9560.11$), while the Hausman test indicated that heterogeneity is correlated ($\chi^2 = 224.03$) with the dependent variables of the model, so we use the fixed-effect models hereinafter.