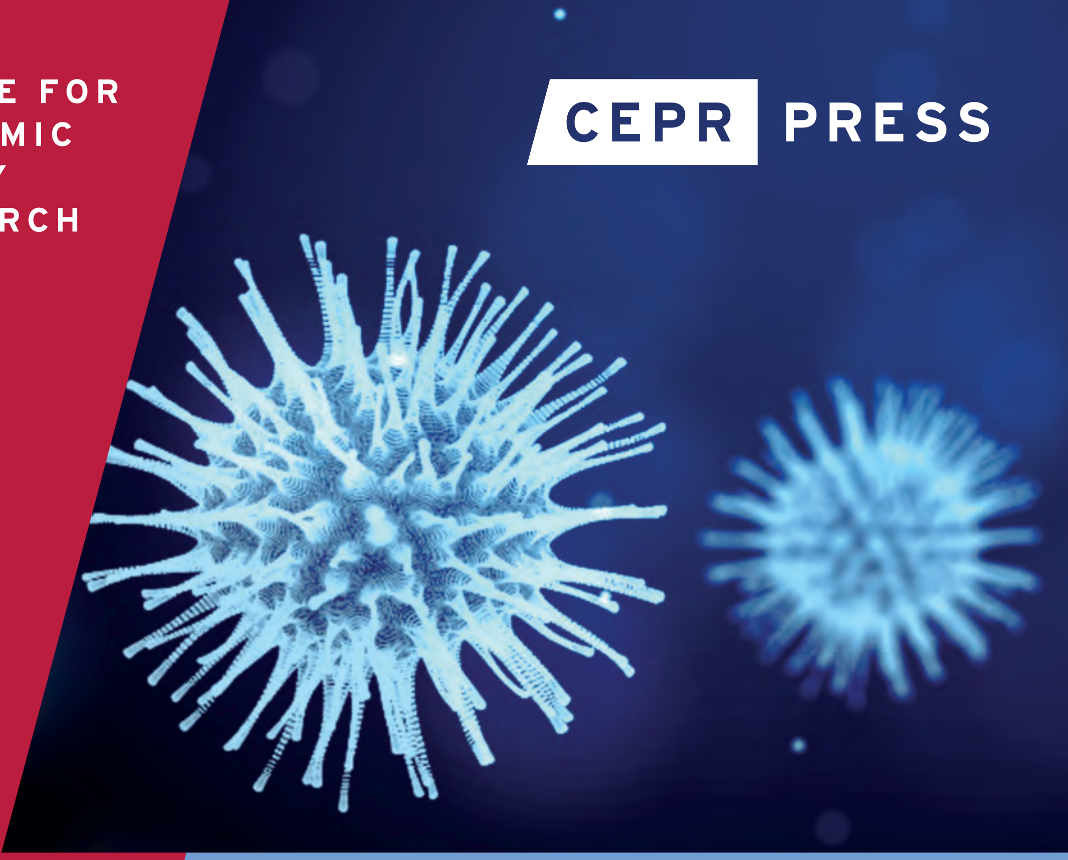
CENTRE FOR ECONOMIC POLICY RESEARCH

CEPR PRESS



COVID ECONOMICS

VETTED AND REAL-TIME PAPERS

ISSUE 53
23 OCTOBER 2020

HERD IMMUNITY COULD BE EASY TO REACH
Glenn Ellison

AMAZON DEFORESTATION
Humberto Laudares

CHINESE EXPORTS
Felix L. Friedt and Kaichong Zhang

Covid Economics
Vetted and Real-Time Papers

Covid Economics, Vetted and Real-Time Papers, from CEPR, brings together formal investigations on the economic issues emanating from the Covid outbreak, based on explicit theory and/or empirical evidence, to improve the knowledge base.

Contact: Submissions should be made at https://portal.cepr.org/call-papers-covid-economics. Other queries should be sent to covidecon@cepr.org.

The Centre for Economic Policy Research (CEPR)

The Centre for Economic Policy Research (CEPR) is a network of over 1,500 research economists based mostly in European universities. The Centre's goal is twofold: to promote world-class research, and to get the policy-relevant results into the hands of key decision-makers. CEPR's guiding principle is 'Research excellence with policy relevance'. A registered charity since it was founded in 1983, CEPR is independent of all public and private interest groups. It takes no institutional stand on economic policy matters and its core funding comes from its Institutional Members and sales of publications. Because it draws on such a large network of researchers, its output reflects a broad spectrum of individual viewpoints as well as perspectives drawn from civil society. CEPR research may include views on policy, but the Trustees of the Centre do not give prior review to its publications. The opinions expressed in this report are those of the authors and not those of CEPR.

Editorial Board

Ethics

Covid Economics will feature high quality analyses of economic aspects of the health crisis. However, the pandemic also raises a number of complex ethical issues. Economists tend to think about trade-offs, in this case lives vs. costs, patient selection at a time of scarcity, and more. In the spirit of academic freedom, neither the Editors of *Covid Economics* nor CEPR take a stand on these issues and therefore do not bear any responsibility for views expressed in the articles.

Submission to professional journals

The following journals have indicated that they will accept submissions of papers featured in *Covid Economics* because they are working papers. Most expect revised versions. This list will be updated regularly.

American Economic Review
American Economic Review, Applied Economics
American Economic Review, Insights
American Economic Review, Economic Policy
American Economic Review, Macroeconomics
American Economic Review, Microeconomics
American Journal of Health Economics
Canadian Journal of Economics
*Econometrica**
Economic Journal
Economics of Disasters and Climate Change
International Economic Review
Journal of Development Economics
*Journal of Econometrics**
Journal of Economic Growth
Journal of Economic Theory
*Journal of the European Economic Association**
Journal of Finance
Journal of Financial Economics
Journal of International Economics
*Journal of Labor Economics**
Journal of Monetary Economics
Journal of Public Economics
Journal of Public Finance and Public Choice
Journal of Political Economy
Journal of Population Economics
Quarterly Journal of Economics
*Review of Corporate Finance Studies**
Review of Economics and Statistics
*Review of Economic Studies**
Review of Financial Studies

(*) Must be a significantly revised and extended version of the paper featured in *Covid Economics*.

Covid Economics
Vetted and Real-Time Papers

Issue 53, 23 October 2020

Contents

Covid Economics **Issue 53, 23 October 2020**

Is deforestation spreading COVID-19 to the indigenous peoples?[1]

Humberto Laudares[2]

Date submitted: 16 October 2020; Date accepted: 20 October 2020

This paper examines deforestation's effect on the COVID-19 transmission to indigenous peoples and its transmission mechanisms. To that end, I analyze the Brazilian case and use new datasets that cover all the country's municipalities daily. Relying on a fixed-effects model, I find that deforestation is a powerful and consistent variable to explain the transmission of COVID-19 to indigenous populations. The estimates show that one unit increase in deforestation per 100 km² is associated, on average, with the confirmation of 2.4 to 5.5 new daily cases of COVID-19 in indigenous people 14 days after the deforestation warnings. One km² deforested today results in 9.5% more new COVID-19 cases in two weeks. In accumulated terms, deforestation explains at least 22% of all COVID-19 cases confirmed in indigenous people until 31 August 2020. The evidence suggests that the main mechanisms through which deforestation intensifies human contact between indigenous and infected people are illegal mining and conflicts.

Covid Economics 53, 23 October 2020: 33-71

1 Pedro Henrique Gagliardi provided outstanding research assistance. I had valued suggestions from Felipe Valencia and from the anonymous reviewer. All remaining errors are mine.

2 Ph.D. in Development Economics, Graduate Institute of International and Development Studies, Geneva, and Ph.D. candidate in Global Health, University of Geneva.

Covid Economics 53, 23 October 2020: 33-71

1 Introduction

The COVID-19 pandemic has grown exponentially in the Developing World. Until the end of August 2020, Brazil ranked second in the number of COVID-19 cases and the death toll, lagging behind the United States. Brazil turned in 2020 not only a worldwide epicenter of COVID-19 but also of deforestation. While the negative externalities of deforestation are well documented in the literature, less is known about how deforestation can affect the transmission of COVID-19 to vulnerable ethnic groups, such as the indigenous peoples[1], enlarging existing income and racial inequality gaps.

Brazil had more than 3.8 million confirmed COVID-19 cases and 120 thousand deaths by the end of August 2020[2]. It represents 15.1% of the confirmed cases and 14.3% of the total deaths reported globally[3]. At the same time, deforestation has increased by 25% from January-June 2020 (3.070 km^2) in comparison to the same period in 2019[4]. 55% of the deforested lands this year have been also burned (Moutinho et al. (2020)). On top of it, deforestation had dramatically expanded in indigenous lands, the *de facto* forest's main guardian (Laudares (2016), Baragwanath and Bayi (2020)), while coronavirus infected more than 20 thousand and victimized more than 800 indigenous people.

This paper asks whether deforestation has been a key driver in the COVID-19 transmission to indigenous peoples. It also focuses on exploring the channels through which deforestation may affect the spread of the disease to this ethnic group relative to the others.

To that end, I construct a daily panel with 5,417 municipalities from 1 March 2020 to 31 August 2020 with COVID-19 cases and deforestation data. I use a fixed-effects model to exploit the effects of deforestation on COVID-19's morbidity of indigenous populations. The independent variables are lagged in 5 or 14 days, following the clinical evidence of asymptomatic period after the contamination. This method is particularly interesting to analyze such big panel data because it captures municipality within variation and controls for the effects of time-invariant variables. I also conduct the empirical analysis in a cross-section format because I can add more covariates

[1] The WHO Executive-Director recently highlighted that 'indigenous peoples often have a high burden of poverty, unemployment, malnutrition and both communicable and non-communicable diseases, making them more vulnerable to COVID-19 and its severe outcomes.' – United Nations news, July 2020

[2] Retrieved at 23 September 2020 from COVID-19 Dashboard - Johns Hopkins University

[3] Retrieved at 21 September 2020 from WHO Coronavirus Disease (COVID-19) Dashboard

[4] Data from the Real Time Deforestation Detection System (Deter) of the National Institute for Space Research - INPE

Covid Economics 53, 23 October 2020: 33-71

and explore the potential mechanisms through which deforestation affects COVID-19 transmission in indigenous peoples.

Deforestation is a powerful and consistent variable to explain the transmission of COVID-19 to indigenous populations. Relying on the fixed-effects model, I find that one unit increase in deforestation per 100 Km^2 is associated, on average, with the confirmation of 2.1 to 2.4 new daily cases of COVID-19 in indigenous people 14 days after the deforestation warnings. If I add nonlinearity in the model, the coefficient jumps to 5.5. The deforestation per Km^2 that takes place in $t = 1$ will increase the COVID-19 cases among indigenous people by 9.5% fourteen days later ($t = 15$). Using weekly panel data, a unit increase in deforestation warnings per 100 Km^2 elevates the new COVID-19 by 30% two weeks after the event.

My main cross-section results, based on a state-fixed effects estimation, show that one unit change in warning areas for deforestation per 100 km^2 within the Amazon Forest and the Cerrado ecosystem in Brazil increases the number of COVID-19 cases confirmed in originary peoples by 55. A straightforward linear calculation suggests that, on average, deforestation explains at least 22% of all COVID-19 cases confirmed in indigenous people until 31 August 2020. Population density and economic inequality are the most relevant control variables correlated with coronavirus transmission among originary peoples.

Under the 'bad controls' framework (Angrist and Pischke (2008)), I also test the key transmission mechanisms – namely, wildfires, cattle ranching, illegal mining, and conflicts involving indigenous people – as controls. The evidence suggests that the two strongest mechanisms through which deforestation affects the spread of COVID-19 in indigenous communities are illegal mining and conflicts. But deforestation explains a large part through which illegal mining (84 to 91%) and conflicts (81 to 97%) contribute to new COVID-19 cases of indigenous people, considered that, as a 'bad control', it affect the spread of COVID-19 through other channels as well.

I run the robustness checks regression deforestation in COVID-19 hospitalizations, following the primary panel data's same econometric approach. The effect of deforestation on COVID-19 hospitalizations is not as direct as is the case of COVID-19 transmission. Besides, the clinical development of the patient requires to take into consideration additional individual characteristics. In light of those circumstances, I use the hospitalization data as a proxy for COVID-19 incidence. While this dataset from the Ministry of Health provides the possibility to compare COVID-19 hospitalizations by race, there are much fewer observations for indigenous peoples. Using this database, I find that deforestation is only positively correlated – and statistically sig-

CEPR PRESS

Covid Economics 53, 23 October 2020: 33-71

nificant – with COVID-19 hospitalization in indigenous people, but not with other races. I estimate that 9.14% of all COVID-19 hospitalizations of indigenous people relate to deforestation.

A larger literature explores the negative externalities of deforestation on the economy and society (Nordhaus (2019), Malhi et al. (2008), Castro et al. (2019)). A growing amount of evidence shows policy (Souza-Rodrigues (2019) Assunção et al. (2019)) Burgess, Costa, and Olken (2019) Chimeli and Soares (2017)) , political (Pailler (2018)), and economic forces (Sonter et al. (2017)) play a role in deforestation in Brazil, especially in the Amazon region. A growing stream of works has been developing on the impact of the COVID-19 on racial (Bertocchi and Dimico (2020), McLaren (2020)), gender (Alon et al. (2020)), opportunity (Bacher-Hicks, Goodman, and Mulhern (2020)) and economic inequalities (Campello, Kankanhalli, and Muthukrishnan (2020)). In the case of Brazil, Baqui et al. (2020) and Bruce et al. (2020) evaluated the impact of COVID-19 in different ethnicities using the Ministry of Health database[5] that does not incorporate the indigenous health statistics, since they are not harmonized.

This paper innovates in analyzing an additional negative externality of deforestation in the context of a pandemic affecting indigenous populations. As a result, it also shed light on a specific mechanism on how ethnic and health inequalities have been deepening as the pandemic develops, and the government fails to respond.

To my knowledge, this is the first paper that estimates the relationship between deforestation and the spread of COVID-19 affecting indigenous peoples. Also, this is the first paper that uses the COVID-19 datasets published by the Special Department of Indigenous Health (SESAI)[6]) at the Ministry of Health and the Articulation of Indigenous Peoples of Brazil (APIB), the Brazilian indigenous peoples' major representative organization.

I believe the findings are of relevance to policymakers as well. Ending deforestation – and fighting all the illegal economic activities related to it – brings enormous benefit for the climate and the environment as a whole and contributes to curb the transmission of COVID-19 among indigenous populations.

The rest of the paper is organized as follows. The next section presents the background of the context in which indigenous peoples in Brazil are dealing with increasing deforestation and COVID-19 transmission. I then detail the data and the empirical strategy in Sections 3 and 4. Subsequently, I will present the empirical results, followed by sections 6 and 7 on the transmission mechanisms and robustness check. I

[5]SIVEP-Gripe (Sistema de Informação de Vigilância Epidemiológica da Gripe)
[6]Secretaria Especial de Saúde Indígena

conclude with the main takeaways of the study.

2 Indigenous peoples, deforestation, and COVID-19

There are 311 indigenous peoples living in Brazil, totaling 760 thousand people (0.36% of the total population). As of 31 August 2020, the COVID-19 pandemic affected 158 of those communities. The COVID-19 cases in the indigenous people represent 0.6 to 0.8% of the total[7]. In the Amazon region, the indigenous mortality is the highest among all the ethnic groups (Fellows et al. (2020)), while for the whole country, 'pardos' and black people present the highest coronavirus death toll (Baqui et al. (2020)).

However, the existing comparison of COVID-19 transmission – not mortality – among races using Brazil as a case study underestimates the effects of COVID-19 on the indigenous peoples (Baqui et al. (2020), Bruce et al. (2020)). The main reason is that indigenous public health department statistics do not integrate the universal health system's statistics[8]. The Ministry of Health assistance to indigenous communities is run separately from the universal health system and decentralized in the Indigenous Special Sanitary Districts (ISSD[9]). There are 34 ISSDs in Brazil, and their borders do not follow the country's original administrative boundaries. The government reports COVID-19 statistics of the indigenous peoples exclusively at the ISSD level, which aggregates 219 municipalities and several indigenous peoples.

Besides, the access of indigenous communities to health equipment is scarce. Given the level of severity observed in the case of COVID-19[10] and the geographical barriers, isolated indigenous communities face relevant obstacles to reach on time specialized health facilities or intensive care units. On top of it, there are 120 communities uncontacted, and 76% of those have not been confirmed yet. The existing concern is the chance of illegal miners, missionaries, or illegal 'land grabbers' transmit COVID-19 to the uncontacted indigenous peoples[11].

All the factors mentioned above may increase the sub-notification of COVID-19 cases and delay their reporting. Oviedo et al. (2020) and Azevedo et al. (2020) estimate

[7]The lower bound is the Ministry of Health data and the upper bound, the The Articulation of Indigenous Peoples of Brazil (APIB) data.

[8]Sistema Unico de Saúde, SUS, as it is called in Portuguese.

[9]The acronym in Portuguese is DSEIs

[10]Reuters/G1, 15 May 2020

[11]Data from Instituto Socioambiental (ISA)

Covid Economics 53, 23 October 2020: 33-71

Covid Economics 53, 23 October 2020: 33-71

the vulnerability of the indigenous communities to COVID-19, where they have also considered demographic and infrastructure aspects. The Articulation of Indigenous Peoples of Brazil (APIB)[12], a representative organization of the indigenous peoples, highlights other reasons of sub-notification, such as racism, misreporting, and lack of transparency of the official authorities (APIB (2020)).

The Amazon region detains the highest concentration of COVID-19 cases, hospitalization, and indigenous deaths for COVID-19. The states of Amazonas and Pará represents 38% of the Covid-19 cases reported in indigenous people. Map 1 also displays that this is the region where the highest deforestation incidence[13].

While shreds of evidence show that deforestation might be one of the key variables to explain the spread of COVID-19 among indigenous communities, analysts, and indigenous representation bodies point out other variables as well. They are: illegal mining[14], land grabbing and timber lodgers[15], cattle ranching and meat processing plants[16], and transport through the rivers[17]. Moreover, health workers[18] and missionaries[19] pose a potential risk of the spread of COVID-19 among indigenous people considering the imminent contact with their communities.

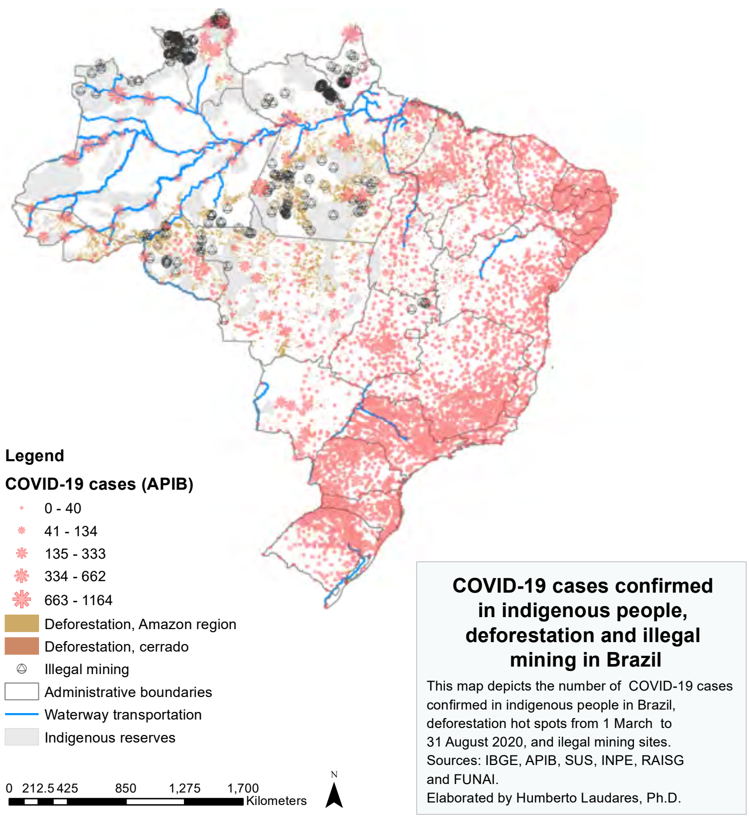
However, the association between deforestation and transmission of COVID-19 is not automatic. COVID-19 is a disease transmitted primarily by droplets from coughing, sneezing, or even talking (WHO (2020)). Therefore, although human proximity is required to transfer the disease, there are still several reasons to believe that deforestation is related to the pathogen's spread.

First, 72% of the deforested lands in 2020 are in conservation areas and indigenous lands[20], which entails some level of – peaceful or violent – social interaction. APIB (2020) reports compelling cases of how deforestation can disentangle in conflicts. Second, whether deforestation targets land grabbing, cattle ranching, illegal mining, or timber extraction, indigenous communities are already exposed to the virus through improper contact with infected people[21]. Socioambiental (2020), for instance, argues the threat imposed by deforestation for the Yanomami people is highly dangerous due

[12] Articulação dos Povos Indígenas do Brasil (APIB)
[13] According data from the Deter system, Terrabrasilis, INPE
[14] Data from Amazonia Socioambiental
[15] G1, 4 August 2020
[16] Globo Rural, 10 June 2020
[17] BBC, 8 May 2020
[18] Instituto Socioambiental, 24 July 2020
[19] The Economist, 9 July 2020
[20] Folha de S. Paulo, Mining and Deforestation, 25 June 2020
[21] O Globo, Ianomami, mining and COVID-19, 2 June 2020

Covid Economics 53, 23 October 2020: 33-71

Figure 1: COVID-19 cases confirmed in indigenous people, deforestation and illegal mining in Brazil



to a greater vulnerability to COVID-19 exposure. The conflicts and close interactions between miners and indigenous have transmitted COVID-19 to about 40% of Yanomami people. Third, deforestation puts pressure on indigenous people to have a forced displacement[22] to regions where the virus may already be present. Finally, Oliveira et al. (2020) and Rocha and Sant'Anna (2020) argue that the fires from the increasing deforestation, combined with the drought and wildfires, worsens respiratory health risks, including the COVID-19 cases, increasing the demand for health services and the locomotion to cities.

Based on the evidence mentioned above, the following section briefly describes the data used in the empirical analysis. It also explains the identification strategy used to show the effects of deforestation on the spread of COVID-19 in indigenous communities.

3 Data

In this section, I describe the different sources and levels of aggregation of the main variables used in the empirical analysis. The Annex details all other variables used as controls.

3.1 Panel data

The panel has 184 days and 5,417 municipalities, totaling 969,728 observations. It starts on 1 March, when the pandemic officially started in Brazil, and ends on 31 August 2020. The two data sources of COVID-19 cases confirmed in indigenous people used in the paper are from the Special Department of Indigenous Health (SESAI)[23] at the Ministry of Health, and the Articulation of Indigenous Peoples of Brazil (APIB).

SESAI is responsible for collecting data from indigenous people, and the reporting is apart from the Brazilian universal health system. The datasets are at Indigenous Special Sanitary Districts (ISSD) level, which are decentralized administrative healthcare units dedicated to the indigenous peoples. There are 34 ISSDs within the borders of 219 municipalities. The APIB's estimates are based on SESAI's statistics, but the organization adds more information collected through the indigenous networks and local governments countrywide and subtracts the duplicated data. APIB's objective,

[22] National Congress, 27 June 2020

[23] In Portuguese, Secretaria Especial de Saúde Indígena

Covid Economics 53, 23 October 2020: 33-71

Covid Economics 53, 23 October 2020: 33-71

in this case, is to reduce the sub-notification of COVID-19 cases in indigenous people (APIB (2020)).

The APIB argues lack of transparency on SESAI statistics – essential to deal with the pandemic – and testing for indigenous peoples. The SESAI's dataset, for instance, does not inform whether the indigenous people that contracted COVID-19 lives in indigenous lands, non-urban settings, or not. It also does not notify which indigenous peoples the diagnosed people belong to. The absence of this information hampers how these communities plan in dealing with the pandemic themselves. It makes the task to match the data of SESAI very challenging with other Ministry of Health's datasets. However, SESAI and APIB databases are the best available information to study the spread of COVID-19 in indigenous populations.

To this end, as a first step, I convert the data from ISSD to municipal level, based on the size of the indigenous population living in each municipality relative to the ISSD total. The Annex section details the data conversion to the municipal level.

For robustness, I also use the COVID-19 hospitalizations of indigenous people from the Ministry of Health's *SIVEP-Gripe* database as a proxy for COVID-19 incidence, and reports the daily data from the Brazilian universal health system (SUS[24]). However, there are fewer indigenous peoples' observations than the other two panels because the *SIVEP-Gripe* does not include data from SESAI. I believe that most of the data is from indigenous living in the cities, even though there seems to be an overlap between the datasets[25]. Besides, the *SIVEP-Gripe* dataset reports COVID-19 hospitalizations by race. The relationship between deforestation and COVID-19 hospitalization tends to be weaker than the cases reported. However, the main advantage of working with this data as proxy is the possibility to compare the results with other ethnic groups, namely black, white, 'pardo' (mixed), and East Asian (yellow) people.

On the right side of the equation, deforestation, the main independent variable, is measured by the warning areas of deforestation in $100km^2$ within the Amazon Forest and the Cerrado (Brazilian Savannah) ecosystems. The data, collected from Brazil's National Institute for Spatial Research, is at the municipal level from 1 March to 31 August 2020.

Table 1 exhibits the summary statistics of the daily data, totaling 996,876 observations.

[24] Sistema Único de Saúde

[25] In the case of deaths reported, APIB (2020) estimates an overlap around 41%, while 10.8% of the total is not clear if it is an overlap or not.

CEPR PRESS

Table 1: Summary statistics: daily panel data

Variables	N	Mean	SD	Min	Max	Sum
COVID-19 confirmed cases of indigenous people (SESAI)	996,876	0.023	0.519	0	90	23,179
COVID-19 confirmed cases of indigenous people (APIB)	996,876	0.0291	.822	0	251	28,985
COVID-19 hospitalizations of indigenous people	996,728	0.001	0.042	0	8	1,163
COVID-19 hospitalizations of black people	996,728	0.016	0.308	0	40	15,527
COVID-19 hospitalizations of white people	996,728	0.109	1.667	0	248	108,942
COVID-19 hospitalizations of 'pardo' people	996,728	0.112	1.378	0	151	111,290
COVID-19 hospitalizations of East Asian people	996,728	0.004	0.096	0	14	3,754
Deforestation (per $100km^2$)	996,728	0.000	0.004	0	0.7	116.2
Log Deforestation (per km^2)	7,053	-0.729	1.453	-8.517	4.324	

Notes to Table 1. Table 1 displays the descriptive statistics of the key variables used in the panel data estimations. The COVID-19 confirmed cases of indigenous peoples' data are published by the Ministry of Health's Special Department of Indigenous Health (SESAI)[26]) and by the Articulation of Indigenous Peoples of Brazil (APIB), the Brazilian indigenous peoples' major representative organization. The COVID-19 hospitalization data from the Ministry of Health's *SIVEP-Gripe* database is used in the robustness check. Deforestation data is extracted from the Real-Time Deforestation Detection System (Deter) of the National Institute for Space Research - INPE.

I also collapse the daily data to weekly to smooth the noise. In the case of COVID-19 cases in indigenous people is even more relevant due to potential delays in the reporting because of geographical distances and low access to health equipment. Table 7 displays the summary statistics of the weekly data.

3.2 Cross-section

The main dependent variable used in the cross-section analysis is the accumulated numbers of COVID-19 cases reported by the Special Department of Indigenous Health (SESAI) at the Ministry of Health and the total cases compiled by APIB. The deforestation data, the primary independent variable, is presented in accumulated values from 1 March to 31 August 2020.

The benefit of using a cross-section at the municipal level is adding several other control variables and capturing the mechanisms through which deforestation affects the spread of COVID-19 in indigenous communities. Besides, adding relevant controls also minimizes the potential bias derived from omitted variables.

Covid Economics 53, 23 October 2020: 33-71

CEPR PRESS

Table 2: Summary statistics: cross-section

Variables	N	Mean	SD	Min	Max
COVID-19 cases of indigenous people (SESAI)	5,417	4.286	36.723	0	1,025
COVID-19 cases of indigenous people (APIB)	5,417	5.350	47.176	0	1,164
COVID-19 hospitalizations of indigenous people	5,417	0.215	2.021912	0	64
COVID-19 hospitalizations of black people	5,417	2.867	39.884	0	2,367
COVID-19 hospitalizations of white people	5,417	20.115	255.001	0	17,044
COVID-19 hospitalizations of 'pardo' people	5,417	20.548	181.798	0	9,134
COVID-19 hospitalizations of East Asian people	5,417	0.693	10.889	0	738
Deforestation (per 100km^2)	5,417	0.020	0.172	0	5.552
Population density	5,385	123.405	637.898	0.049	14,208
Illegal mining	5,385	0.008	0.0920	0	1
Conflict involving indigenous people (CPT)	5,417	0.037	0.188	0	1
Conflict involving indigenous people (CIMI)	5,417	0.040	0.197	0	1
Cattle ranching	5,334	31,664	72,910	21	1571,245
Wildfires - Fire Radiative Power (FRP)	5,417	1,179	12,493	0	506,161
GDP	5,385	9.749	0.678	8.097	12.750
Inequality (Gini coefficient)	5,380	0.503	0.066	0.284	0.808
Extreme poverty	5,384	0.279	0.448	0	1
Number of emergency rooms	5,384	0.059	0.366	0	13
Access to public roads	3,503	3.983	1.795	-4.605	12.496
Proximity to waterway	5,385	0.055	0.227	0	1
Proximity to an environmental protection agency (Ibama)	5,385	0.937	0.597	0	4.012
Access to clean water	2,558	0.677	0.240	0	1
Access to treated sewage	2,558	0.350	0.470	0	1
Rainfall	5,040	11.634	5.335	0	33
Distance to the coast	5,084	0.048	0.213	0	1
Distance to the state capital	5,299	251.472	164.103	0	1,476
Altitude	5,299	411.488	293.885	0	1,628
Latitude	5,385	-16.49	8.30	-33.68	4.60
Longitude	5,385	-46.27	6.445	-72.89	-34.81
Types of soil:					
Sglei	5038	0.009	0.096	0	1
Slat	5038	0.338	0.473	0	1
Sluvi	5038	0.038	0.192	0	1
Sneo	5038	0.130	0.336	0	1
Snit	5038	0.030	0.171	0	1
Splan	5038	0.040	0.196	0	1
Splint	5038	0.036	0.188	0	1

Notes to Table 2. Table 2 exhibits all variables included in the cross-section analysis. The Annex brings detailed information about each of them.

Covid Economics 53, 23 October 2020: 33-71

The control variables include access to clean water, public roads and waterways[27], population density, GDP, income inequality, and geographical variables, such as rainfall, altitude, and distance to the state capital (see in the Annex for a detailed description of the variables). I also use illegal mining, conflicts involving indigenous people, wildfires, and cattle ranching as control variables, even if they are also the main mechanisms connecting deforestation with the dissemination of COVID-19 in indigenous communities.

Table 2 exhibits the summary statistics of the variables used in the cross-section estimates.

4 Empirical Strategy

The empirical analysis exploits the relationship between deforestation and COVID-19 cases from 1 March 2020 to 31 August 2020[28]. The following econometric model will be the main reference in analyzing a municipal level and daily panel data. I estimate equations of the form:

$$COVID_{it} = \alpha + \rho COVID_{i(t-l)} + \beta \Gamma_{i(t-l)} + \delta_t + \lambda_i + \upsilon_{it}, \tag{1}$$

where $COVID_{it}$ is the dependent variable that captures the number of COVID-19 cases of indigenous people in the municipality i in period t. The lagged variable of COVID-19 cases in l time units on the right-hand side is included to reflect the disease transmission mechanism's intrinsic persistence. $\Gamma_{i(t-l)}$ is the main explanatory variable, namely the lagged value of deforestation alerts per 100 Km^2. The parameter β measures the causal effect of deforestation on the transmission of COVID-19 in indigenous people. Additionally, λ_i is the set of municipality dummies and δ_t the time effects related to common trends in deforestation. The error term is expressed by $\upsilon_{i(t)}$, absorbing all other omitted effects. Time is expressed by t, and l is the lagged values.

The fixed-effects model measures the municipality within variation over time. The parameter λ_i captures time-invariant municipality unobserved characteristics that affect deforestation, avoiding the potential problem of omitted variables. This is the key difference between the pooled ordinary least squares (OLS) model and the fixed-effects.

I use the lagged values (of 5 and 14 days) of the main independent variables in the estimations. There are two reasons for that. First, the empirical literature on public

[27]Waterways are the main transportation modal in the Amazon region.

[28]The first cases of COVID-19 in indigenous communities started to be reported from 1 April. However, since I use lagged variables for the independent variable, the data starts from 1 March 2020

Covid Economics 53, 23 October 2020: 33-71

Covid Economics 53, 23 October 2020: 33-71

health reports that individuals infected with coronavirus may remain asymptomatic between 5 to 12 days (Lauer et al. (2020)). The authors' findings show that 97.5% of patients develop symptoms within 11.5 days of infection. On the other hand, the WHO states that the incubation period of the coronavirus is, on average, 5 to 6 days, but it can be up to 14 days[29]. Second, as mentioned before, the geographic barriers and difficult access to hospitals by indigenous people delay the reporting of contaminated indigenous people's health status. Also, SESAI reports the COVID-19 cases by the day of the diagnosis, not the contamination day. In the Amazon region, where there is the highest concentration of indigenous peoples, the main transportation system is fluvial. A trip to a medium city can take more than a day. Besides, using lagged variables eliminates any potential contemporaneous effects between Covid-19 reported cases and deforestation.

I also estimate the relationship mentioned above using a cross-section, by accumulating both COVID-19 cases and deforestation values for the whole period analyzed and adding other relevant covariates. The main estimations based on the cross-section data rely on the state-fixed effects model, that captures within-state variation, λ_i, while time dimension δ_t remains constant because $t = 1$. The specification is particularly interesting because the states – together with the municipalities – are the key federal entities that implement policies to combat the COVID-19 in Brazil. There was significant heterogeneity in the policies adopted across the country. Therefore, estimating the state-fixed effect and the other covariates added tend to be more efficient in reducing the omitted variables bias than the OLS.

The cross-section data allow us to investigate the mechanisms that reinforce the relationship between deforestation and the spread of COVID-19 to originary peoples, such as illegal mining, cattle ranching, wildfires, and conflicts involving indigenous people, under the 'bad control' framework (Angrist and Pischke (2008) and Cinelli, Forney, and Pearl (2020)). In this case, the mentioned mechanisms can also be the outcome of deforestation. Controlling for them would introduce bias in the estimation results and lead to the 'bad control' problem. However, 'bad controls' are useful to provide insights about the mechanisms through which the independent variable affects the dependent one, once compared the estimations that contemplate and do not include them (Maccini and Yang (2009).

The next section exhibits the main results of my analysis.

[29]See at WHO COVID-19 Situation Report 73

CEPR PRESS

Covid Economics 53, 23 October 2020: 33-71

5 Results

5.1 Panel data results

Figure 1 exhibits a visual format of the main results. Table 3 reports the main results of the panel data using municipal level fixed-effects estimation. Throughout the paper, the standard errors used are robust against heteroskedasticity and clustered at the municipal level to prevent serial correlation. Columns 1 to 4 have as dependent variable COVID-19 cases reported by the Ministry of Health (SESAI), and columns 5 to 8 exhibit COVID-19 cases reported by the Indigenous Peoples association (APIB). The independent variable, deforestation, is lagged in 14 days. Table 8 reports the same estimation using 5 days lagged independent variables. The first and the fifth columns report pooled OLS results, while the others exhibit fixed effects estimations.

Table 3 implies that one unit increase in deforestation per 100 Km^2 is associated, on average, with the confirmation of 2.1 to 2.4 new daily cases of COVID-19 in indigenous people 14 days after the deforestation warnings. As a reference, the OLS coefficient is 3.9 for the cases reported by SESAI (column 1) and 4.7 when using the cases consolidated by APIB (column 5), both with 14 days lag deforestation as an independent variable. Adding nonlinearity in the model, columns (3) and (7) report one unit increase in deforestation areas per 100 Km^2 explaining 5.1 and 5.5 new COVID-19 cases in indigenous people respectively[30]. Table 3 also shows that deforestation, which takes place in $t = 1$, will increase the COVID-19 cases among indigenous people by 3.5 (column 4) to 9.5% (8) fourteen days later ($t = 15$).

The reason to add nonlinearity in columns (3) and (7) is natural and geographical barriers, such as rivers and mountains, and infrastructure. I would expect that the sign of the coefficient of deforestation is positive, while the squared value is negative, as in table 3 holds.

I find that lagged values of COVID-19 cases reported in indigenous people within a given municipality, since the disease is highly contagious (Petersen et al. (2020)), explain 14 to 30% of the new cases of COVID-19 reported in the same ethnic group. The implicit cumulative effect of deforestation on COVID-19 dissemination[31] coefficients is negative and lower than one.

Performing the estimations using weekly data, I lose variability, however, it smooths

[30] For reference, the median is 0.004. The maximum points for deforestation are that up to 0.28 (SESAI) and 0.33 per 100 Km^2 (APIB)

[31] The implicit cumulative effect of deforestation coefficient is estimated by Deforestation per 100 Km^2_{t-l}/(1-COVID-19 cases$_{t-l}$). This variable was based on Acemoglu et al. (2008)

Covid Economics 53, 23 October 2020: 33-71

the data and accounts for potential delays in reporting COVID-19 cases in indigenous peoples. I use lagged independent variables in one and two weeks. Table 9 reports one unit increase in deforestation per 100 Km^2 is associated, on average, with the confirmation of 6.3 to 10.3 new weekly cases of COVID-19 in indigenous people one or two weeks after the deforestation warnings (columns 1, 2, 5 and 6). The quadratic models in columns (3) and (7) show that one unit increase in deforestation areas per 100 Km^2 explains the COVID-19 transmission to 25 (SESAI) to 33 (APIB) indigenous people per week. Alternatively, columns (4) and (8) suggest that one unit increase in deforestation warnings per 100 Km^2 increases the weekly transmission of COVID-19 among indigenous peoples by 15.4% (SESAI) to 30% (APIB).

Table 3: Fixed-effects results: deforestation and COVID-19 cases in indigenous peoples

	COVID-19 cases SESAI				COVID-19 cases APIB			
	Pooled OLS	Fixed effects	Fixed effects	Fixed effects	Pooled OLS	Fixed effects	Fixed effects	Fixed effects
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Deforestation (per 100 Km^2)$_{t-14}$	3.912***	2.400**	5.056***		4.818***	2.076***	5.476***	
	(1.258)	(0.945)	(1.943)		(1.292)	(0.733)	(1.684)	
Log Deforestation (per Km^2)$_{t-14}$				0.0350*				0.0948***
				(0.0197)				(0.0269)
Deforestation (per 100 Km^2)$^2_{t-14}$			-7.657**				-9.804***	
			(3.147)				(3.469)	
COVID-19 cases SESAI$_{t-14}$	0.415***	0.296***	0.296***	0.265***				
	(0.0561)	(0.0522)	(0.0522)	(0.0569)				
COVID-19 cases APIB$_{t-14}$					0.227***	0.140***	0.139***	0.0986
					(0.0330)	(0.0331)	(0.0331)	(0.0731)
Implied cumulative	-0.894	-0.885*	-0.828*	-0.793*	-0.915**	-0.773*	-0.698	-0.794*
effect of deforestation	(0.478)	(0.481)	(0.471)	(0.467)	(0.466)	(0.456)	(0.456)	(0.413)
Constant	0.0159***	-0.00003	-0.00004	0.223**	0.0199***	-0.00007	-0.00008	0.451***
	(0.00210)	(0.00216)	(0.00216)	(0.0938)	(0.00229)	(0.00327)	(0.00327)	(0.139)
Observations	920,874	920,876	920,876	6,495	920,876	920,839	920,839	6,494
R-squared	0.151	0.083	0.083	0.100	0.051	0.021	0.021	0.067
Number of municipalities		5,417	5,417	913		5,417	5,417	913

Notes to Table 3. Columns 1 and 5 present pooled OLS estimations with robust standard errors clustered by municipality in parentheses. The remaining columns are fixed-effects estimation at municipal level with time and municipality dummies and robust standard errors clustered at municipal level in parentheses. The implicit cumulative effect of deforestation coefficient is estimated by Deforestation per 100 $Km^2_{t-l}/(1\text{-COVID-19 cases}_{t-l})$. All the independent variables are lagged in 14 days. The standard errors are in parentheses, where *** p<0.01, ** p<0.05, * p<0.1.

Covid Economics 53, 23 October 2020: 33-71

5.2 Cross-section results

This section presents the results of cross-section data. Table 4 shows the estimations using OLS (columns 1 and 5) and state fixed effects (columns 2, 3, 4, 6, 7 and 8), allowing for within state variation. In columns 4 and 8, I add as controls the main mechanisms that correlate with both the COVID-19 cases and deforestation variables (see table 6). While they can be called 'bad controls', equations' coefficients might be biased when they are included, thus they are important as a reference in the analysis.

The columns (3) and (7) exhibit my main estimations because they include 'good' but not 'bad' controls, which reduces the potential bias found in both OLS equations (columns 1 and 5), and the state fixed-effects estimations without the incorporation of key covariates (columns 2 and 6). Thus, although I opted to include fewer control variables, there are quite relevant controls for the analysis[32].

The main results imply that one unit change in warning areas for deforestation per 100 km^2 within the Amazon Forest and the Cerrado ecosystem in Brazil increases COVID-19 cases by 37.39 (SESAI) to 55.22 (APIB) indigenous people. As expected, the coefficients are smaller than the OLS baseline (columns 1 and 5) but quite similar to the state-fixed effects baseline (columns 2 and 6).

Until the end of August, the warning areas of deforestation totaled 11,622 Km^2. Doing a straightforward linear calculation means that, on average, 4,345 to 6,418 indigenous people could have contracted COVID-19 due to the deforestation, based on SESAI and APIB data, respectively. In other words, deforestation explains at least 18.7 to 22.1% of all COVID-19 cases confirmed in indigenous people until 31 August 2020.

Population density and economic inequality are key variables to explain the spread of COVID-19 in Developing Countries (Ahmed et al. (2020), Pequeno et al. (2020)), which is also the case here. Both variables are positively correlated with COVID-19 cases and statistically significant. One unit hike in the Gini coefficient, which captures income inequality, is associated with an increase of 67 to 86 news cases of COVID-19. The mentioned results are even more concerning in the context of a pandemic that will certainly enlarge income and opportunity gaps between the rich and the poor (Campello, Kankanhalli, and Muthukrishnan (2020) Blundell et al. (2020), Dorn, Cooney, and Sabin (2020), Vahidy et al. (2020)).

There are few mechanisms through which deforestation could enhance human contact and contribute to the spreading of the coronavirus, such as wildfires, cattle ranch-

[32] In the Annex, I present additional regressions with more controls for reference.

Covid Economics 53, 23 October 2020: 33-71

ing, illegal mining, and conflicts. All those variables correlate with both COVID-19 cases and deforestation. Not only they can serve as a transmission mechanism of deforestation, but these mechanisms can also contribute to more COVID-19 contamination independently of deforestation. For instance, illegal mining can be expanded through deforestation in indigenous lands (Sonter et al. (2017)), generating some sort of human contact between indigenous and non-indigenous. Also, COVID-19 can be spread through well established illegal mining activities independently of deforestation.

Columns (4) and (8) include the mentioned variables as 'bad controls'. While I will take a closer look at them in the next section, Table 4 pinpoints their correlation with COVID-19, once controlled for deforestation and remaining covariates. Only illegal mining and conflicts present the expected – and statistically significant at the 99% confidence interval – results. I find that the presence of illegal mining in a given municipality results in 122 to 160 cases of COVID-19.

Since there are 46 municipalities with reported illicit mining activities, I can deduce that, on average, illegal mining explains 22 to 25% of the COVID-19 in indigenous people in Brazil. Similarly, the existence of conflicts involving indigenous people, including land disputes with illegal miners and timber lodgers, in a given municipality is linked with 41 to 53 COVID-19 cases. Doing a similar calculation with the 199 registered, they could explain about 36% of the indigenous people's COVID-19 cases. While the illegal mining and conflict dummies are useful for the analysis, they present limitations. First, as a binary variable, they capture the average effect of the existence of those activities in a given municipality but not of their intensity as a continuous variable such as deforestation. Second, in 23 towns (50% of cities that posse illegal mining activities reported) the data overlaps, and the variables also correlate with each other.

However, even using the 'bad controls' as controls, the effects of deforestation on the transmission of COVID-19 to indigenous people is consistently positive and statistically significant. The magnitude of the coefficients drop by 55 to 61% but remains relatively large, explaining 8.5%, on average, of all COVID-19 cases that indigenous people contracted in Brazil. Nevertheless, an equation that included 'bad controls' is more useful to check how robust the baseline estimation is and understand its transmission mechanisms.

In the following section, I will discuss further the main mechanisms of transmission.

Table 4: State-fixed effects (accumulated): deforestation and COVID-19 cases in indigenous peoples

	COVID-19 cases SESAI				COVID-19 cases APIB			
	OLS	State fixed effects	State fixed effects	State fixed effects	OLS	State fixed effects	State fixed effects	State fixed effects
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Deforestation (100km^2)	46.58***	37.20***	37.39***	16.67***	65.64***	55.09***	55.22***	21.46***
	(10.27)	(2.853)	(2.943)	(4.285)	(17.02)	(3.695)	(3.835)	(5.586)
Population density			0.00139*	0.00298***			0.00235**	0.00523***
			(0.000768)	(0.00113)			(0.00100)	(0.00147)
GDP			-0.479	-1.275			0.348	-0.713
			(1.016)	(0.963)			(1.324)	(1.255)
Inequality (Gini coefficient)			67.23***	48.05***			86.13***	62.09***
			(9.099)	(8.623)			(11.86)	(11.24)
Wildfires				-0.116**				-0.0257
				(0.0566)				(0.0737)
Cattle ranching				0.00290				-0.00174
				(0.00810)				(0.0106)
Illegal mining				121.7***				159.9***
				(5.961)				(7.772)
Conflict				41.63***				53.11***
				(2.720)				(3.546)
Constant	3.327***	3.519***	-35.18***	-18.55*	4.009***	4.225***	-55.37***	-33.89**
	(0.487)	(0.466)	(10.82)	(10.29)	(0.629)	(0.603)	(14.10)	(13.42)
Observations	5,417	5,417	5,040	4,992	5,417	5,417	5,040	4,992
R-squared	0.048	0.147	0.146	0.254	0.057	0.133	0.141	0.251
Geographical controls	No	No	Yes	Yes	No	No	Yes	Yes

Notes to Table 4. Columns 1 and 5 present OLS estimations with robust standard errors in parentheses. The remaining columns are fixed-effects estimation at state level and robust standard errors clustered at state level in parentheses. The geographical variables included are rainfall, distance to the coast, distance to the state capital, and altitude. The standard errors are in parentheses, where *** p<0.01, ** p<0.05, * p<0.1.

6 Mechanisms

This section focus on the transmission channels of the main effect. To this end, I use the cross-section data. Columns (4) and (8) of Tables 4 function as a reference for this section as well, since it estimates the effects of the set of main mechanisms – wildfires, illegal mining, cattle ranching, and conflicts – on COVID-19 cases reported in indigenous communities. I rely on the same type of estimations applied in the prior section: OLS and state-fixed effects.

Table 11 regresses the mechanisms variables on deforestation to estimate their joint

Covid Economics 53, 23 October 2020: 33-71

Covid Economics 53, 23 October 2020: 33-71

relationship with the main independent variable of the model. I consistently find a positive correlation between the mechanisms and deforestation. The coefficients of cattle ranching lose their statistical significance when other control variables are added to the model. Taking column (2) as a reference, I find that one percent change in wildfires and cattle ranching are associate with a 7.15% and 4.6% change in deforestation, and a municipality that posses illegal mining and conflict is associated, respectively, with 179.3% and 63.1%[33] change in deforestation.

On the other hand, table 12 exhibits the reversed calculation, estimating the effects of deforestation on the mechanisms. I confirm that the relationship between them is positive and statistically significant. Tables 13 and 14 exhibit the results of each mechanism regressed on COVID-19 cases without deforestation as an independent variable. I find positive and statistically significant values only for wildfires, illegal mining, and conflicts.

The evidence suggests that the two strongest mechanisms through which deforestation affects the spread of COVID-19 in indigenous communities are illegal mining and conflicts. In the subsections below, I comment on each of those two mechanisms separately, based on the 'bad controls' framework (Angrist and Pischke (2008)).

6.1 Illegal mining

Table 11 implies a high correlation between deforestation and illegal mining. Column (6) in table 14 shows that the existence of illegal mining in a given municipality is associated with 189 (column (6)) or 174.5 (column (9)) cases of COVID for indigenous people. The estimated coefficient for illegal mining in column (8) at table 4, which controls for deforestation, is 159.9.

I interpret this as an indication that deforestation contributes to the transmission of COVID-19 to originary peoples through illegal mining ($\approx$ 84 to 91%) and other potential mechanisms aside deforestation.

6.2 Conflicts

In the Brazilian setting, conflict is an intuitive mechanism through which deforestation can disseminate COVID-19 among indigenous communities. Simultaneously, it is intertwined with other mechanisms such as illegal mining, wildfires, or forced displacements[34]

[33] I followed the standard calculation: (exp(B) - 1)*100%

[34] I have not found data to test these mechanisms.

CEPR PRESS

Covid Economics 53, 23 October 2020: 33-71

Table 11 shows that conflicts is correlated with deforestation. Column (8) in table 14 implies that the occurrence of conflicts involving indigenous peoples within the borders of a municipality is associated with 65.8 (column (8)) or 54.6 (column (9)) cases of COVID. Table 4, controlling for deforestation, estimates this parameter in 53.11.

My understanding is that deforestation explains a large part through which conflicts contribute to new COVID-19 cases of indigenous people (81 to 97%), but, as a bad control, I also recognize that it affects the spread of COVID-19 through other channels as well.

7 Robustness check

The available databases report COVID-19 cases by the 34 Indigenous Special Sanitary Districts (ISSD). According to Saúde Indígena) (2020), until 29 August 2020, 54.1% of the the notified COVID-19 cases were confirmed. 95% of the confirmed cases were based on laboratory tests[35], while the remaining cases were clinically diagnosed. About 378 (1.6%) of the cases resulted in death. SESAI's data does not report hospitalization rates.

Alternatively, the Ministry of Health's *SIVEP-Gripe* database reports COVID-19 hospitalizations by race. However, as mentioned before, there are very few indigenous peoples' observations compared to the other two panels used in this paper. Based on a shred of evidence, I believe that the Ministry of Health's *SIVEP-Gripe* dataset mostly contains information from indigenous living in the cities, although it is not certain how much both datasets overlap.

The effect of deforestation on COVID-19 hospitalizations is not as direct as is the case of COVID-19 transmission. Besides, the clinical development of the patient requires to take into consideration additional individual characteristics. In light of those circumstances, I use the hospitalization data as a proxy for COVID-19 incidence. Therefore, I rely on this data to check for robustness and compare the effect of deforestation on COVID-19 hospitalization among races, namely indigenous, black, white, 'pardo' (mixed), and East Asian (yellow) people.

Table 5 reports the main results of deforestation on hospitalizations by race, based on a daily and municipal level panel data, and on a fixed-effects model. The independent variables are lagged in 14 days, reproducing the same approach used in the table

[35] APIB (2020) argues that SESAI only uses the serological test (rapid tests), and not the gold standard COVID-19 real-time reverse transcription polymerase chain reaction (rRT-PCR) test.

Covid Economics 53, 23 October 2020: 33-71

3. I note that deforestation is only positively correlated – and statistically significant – with COVID-19 hospitalization in indigenous people. Column (2) implies that one unit increase in deforestation areas per 100 Km^2 at $t-14$ is associated with 0.05 COVID-19 hospitalizations of indigenous people.

Table 5: Fixed-effects results: deforestation and COVID-19 hospitalizations by race

	Indigenous		Black	White	'Pardo'	East Asian
	OLS	Fixed effects	Fixed effects	Fixed effects	Fixed effects	Fixed effects
	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable is COVID-19 hospitalizations by race					
Deforestation (per 100 Km^2)$_{t-14}$	0.120***	0.0525***	0.0151	0.0200	0.184	-0.0102
	(0.0459)	(0.0112)	(0.0521)	(0.199)	(0.211)	(0.0206)
Indigenous$_{t-14}$	0.137***	0.0661***				
	(0.0160)	(0.0010)				
Black$_{t-14}$			0.487***			
			(0.0009)			
White$_{t-14}$				0.568***		
			(0.0008)			
'Pardo'$_{t-14}$					0.576***	
					(0.0008)	
East Asian$_{t-14}$						0.170***
						(0.0010)
	0.0011***	-0.0000	0.0008	0.0253**	0.0071	0.0011
	(0.00004)	(0.0005)	(0.0026)	(0.0100)	(0.0106)	(0.0010)
Observations	920,890	920,890	920,890	920,890	920,890	920,890
R-squared	0.019	0.005	0.237	0.322	0.337	0.030
Number of municipalities	5,417	5,417	5,417	5,417	5,417	5,417
5,417	5,417					

Notes to Table 3. Columns 1 exhibits a pooled OLS estimation with robust standard errors in parentheses. The remaining columns are fixed-effects estimation at the municipal level with time and municipality dummies and robust standard errors in parentheses. All the independent variables are lagged in 14 days. Columns 1 and 2 have as dependent variable COVID-19 hospitalizations of indigenous people, column 3, black, 4, white, 5, 'pardo' (mixed), and 6, East Asian ('yellow'). Following the Brazilian Institute of Geography and Statistics' classification and guidelines, the race self-declared by the patients. The standard errors are in parentheses, where *** p<0.01, ** p<0.05, * p<0.1.

Table 15 exhibits the accumulated data in a cross-section format. Columns (1) and (2) confirm the finding of table 5, where deforestation only presents a positive and statistically significant causal effect on COVID-19 of indigenous people, but not of the other races.

Until the end of August, the warning areas of deforestation totaled 11,622 Km^2. Based on the deforestation parameter estimated in column (2), I can infer that, on

Covid Economics 53, 23 October 2020: 33-71

average, 106 indigenous people are hospitalized because of COVID-19 due to deforestation. In other words, it represents 9.14% of all COVID-19 hospitalizations of indigenous people until 31 August 2020. The percentage is about half the magnitude found using SESAI and APIB's data.

At the same time, population density and inequality associate with COVID-19 hospitalizations across all ethnic groups. But the magnitude of the coefficients differs substantially for each race. Table 15 show that white people's coefficients are, one average, 422 times higher than for the indigenous people, 4.8 than for black people, and 0.15 than for 'pardos'. While richer municipalities tend to have, on average, a higher number of COVID-19 hospitalizations across all races, except for indigenous people, inequality of income is consistently correlated with COVID-19 hospitalizations.

8 Final considerations

This paper documents a positive and statistically significant relationship between deforestation and the transmission of COVID-19 in indigenous communities. This correlation, when using hospitalization as a proxy of COVID-19 incidence, was not found in other ethnic groups. Even in the context of the COVID-19 pandemic, deforestation and the intertwined expansion of illegal mining have been growing in Brazil – especially in the Amazon region and within the indigenous reserves – with the consent of the current central government. Consequential conflicts involving indigenous peoples, also within indigenous reserves, boost the transmission of COVID-19 in this vulnerable ethnic group.

Using new datasets, I find that deforestation explains about 22% 0f all COVID-19 cases confirmed in indigenous populations. One Km^2 deforested today results in 9.5% more new COVID-19 cases in two weeks.

I do not have the presumption to state that deforestation causes the growth of COVID-19 cases in native populations. Further work is necessary to reach that conclusion; however, I believe this paper brings a stepping-stone for additional work on this topic. Also, the fact that COVID-19 related statistics of indigenous peoples and data from private health system are not included in a common reporting system it is a problem in itself. The data harmonization on COVID-19 would be vital to track the disease's development on a more realistic base and better evaluate the effects of the pandemic on society.

I believe the presented results are policy-relevant. The evidence suggests that ending deforestation is an optimal environmental policy. Still, it is also a health and economic key issue given the importance to curb the spread of the COVID-19 and decrease the intensity of the economic shocks the pandemic has been causing at micro and macro levels.

Covid Economics 53, 23 October 2020: 33-71

References

Acemoglu, Daron et al. (June 2008). "Income and Democracy". In: *American Economic Review* 98(3), pp. 808–42. DOI: 10.1257/aer.98.3.808. URL: https://www.aeaweb.org/articles?id=10.1257/aer.98.3.808.

Ahmed, Faheem et al. (May 2020). "Why inequality could spread COVID-19." In: *The Lancet. Public health* 5 (5), e240. ISSN: 2468-2667. DOI: 10.1016/S2468-2667(20)30085-2. ppublish.

Alon, Titan et al. (Apr. 2020). *The Impact of COVID-19 on Gender Equality*. COVID Economics, Working Paper 4. Center for Economic Policy Research. URL: https://cepr.org/sites/default/files/CovidEconomics4.pdf.

Angrist, Joshua D and Jörn-Steffen Pischke (2008). *Mostly harmless econometrics: An empiricist's companion*. Princeton university press.

APIB (2020). *Vidas Indígenas Importam! COVID-19 e Povos Indígenas, o enfrentamento das violências durante a pandemia*. Tech. rep. Articulação dos Povos Indígenas do Brasil (APIB).

Assunção, Juliano et al. (2019). *Optimal environmental targeting in the amazon rainforest*. Tech. rep. National Bureau of Economic Research.

Azevedo, M. et al. (2020). "Análise de Vulnerabilidade Demográfica e Infraestrutural das Terras Indígenas à Covid-19".

Bacher-Hicks, Andrew, Joshua Goodman, and Christine Mulhern (July 2020). *Inequality in Household Adaptation to Schooling Shocks: Covid-Induced Online Learning Engagement in Real Time*. Working Paper 27555. National Bureau of Economic Research. DOI: 10.3386/w27555. URL: http://www.nber.org/papers/w27555.

Baqui, Pedro et al. (2020). "Ethnic and regional variations in hospital mortality from COVID-19 in Brazil: a cross-sectional observational study". In: *The Lancet Global Health*.

Baragwanath, Kathryn and Ella Bayi (2020). "Collective property rights reduce deforestation in the Brazilian Amazon". In: *PNAS (University of Michigan, Ann Arbor,USA)* 117, pp. 20495–20502. ISSN: 0027-8424. DOI: 10.1073/pnas.1917874117.

Bertocchi, Graziela and Arcangelo Dimico (July 2020). *COVID-19, Race, and Redlining*. COVID Economics, Working Paper 38. Center for Economic Policy Research. URL: https://cepr.org/sites/default/files/CovidEconomics38.pdf#Paper4.

Blundell, Richard et al. (2020). "COVID-19 and Inequalities*". In: *Fiscal Studies* 41(2), pp. 291–319. DOI: 10.1111/1475-5890.12232. eprint: https://onlinelibrary.

wiley.com/doi/pdf/10.1111/1475-5890.12232. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/1475-5890.12232.

Bruce, Raphael et al. (2020). "Racial Inequality in Health Care During a Pandemic". In: *Available at SSRN: https://ssrn.com/abstract=3691313*.

Burgess, Robin, Francisco Costa, and Benjamin A Olken (2019). "The Brazilian Amazon's Double Reversal of Fortune". In: *SocArXiv*.

Campello, Murillo, Gaurav Kankanhalli, and Pradeep Muthukrishnan (May 2020). *Corporate Hiring under COVID-19: Labor Market Concentration, Downskilling, and Income Inequality*. Working Paper 27208. National Bureau of Economic Research. DOI: 10.3386/w27208. URL: http://www.nber.org/papers/w27208.

Castro, Marcia C et al. (2019). "Development, environmental degradation, and disease spread in the Brazilian Amazon". In: *PLoS biology* 17(11), e3000526.

Chimeli, Ariaster B and Rodrigo R Soares (2017). "The use of violence in illegal markets: Evidence from mahogany trade in the Brazilian Amazon". In: *American Economic Journal: Applied Economics* 9(4), pp. 30–57.

Cinelli, Carlos, Andrew Forney, and Judea Pearl (2020). *A Crash Course in Good and Bad Controls*. Tech. rep.

Dorn, Aaron van, Rebecca E. Cooney, and Miriam L. Sabin (Apr. 2020). "COVID-19 exacerbating inequalities in the US." In: *Lancet (London, England)* 395 (10232), pp. 1243–1244. ISSN: 1474-547X. DOI: 10.1016/S0140-6736(20)30893-X. ppublish.

Fellows, M. et al. (2020). *Não são números, são vidas! A ameaça da covid-19 aos povos indígenas da Amazônia brasileira*. Tech. rep. Instituto de Pesquisa Ambiental da Amazônia (IPAM) and Coordenação das Organizações Indígenas da Amazônia Brasileira (COIAB).

Laudares, Humberto (2016). *From Telegraphs to Space: TransportInfrastructure, Development and Deforestation inthe Amazon*. Tech. rep. The Graduate Institute of International and Development Studies.

Lauer, Stephen A. et al. (May 2020). "The Incubation Period of Coronavirus Disease 2019 (COVID-19) From Publicly Reported Confirmed Cases: Estimation and Application." In: *Annals of internal medicine* 172 (9), pp. 577–582. ISSN: 1539-3704. DOI: 10.7326/M20-0504. ppublish.

Maccini, Sharon and Dean Yang (June 2009). "Under the Weather: Health, Schooling, and Economic Consequences of Early-Life Rainfall". In: *American Economic Review* 99(3), pp. 1006–26. DOI: 10.1257/aer.99.3.1006. URL: https://www.aeaweb.org/articles?id=10.1257/aer.99.3.1006.

Covid Economics 53, 23 October 2020: 33-71

Malhi, Y. et al. (2008). "Climate Change, Deforestation, and the Fate of the Amazon". In: *Science* 319, pp. 169–172. ISSN: 0036-8075. DOI: 10.1126/science.1146961.

McLaren, John (June 2020). *Racial Disparity in COVID-19 Deaths: Seeking Economic Roots with Census data.* Working Paper 27407. National Bureau of Economic Research. DOI: 10.3386/w27407. URL: http://www.nber.org/papers/w27407.

Moutinho, P. et al. (2020). *The Amazon in flames: deforestations and fire during the COVID-19 pandemic". Tech. rep. Amazon Environmental Research Institute.*

Nordhaus, William (2019). "Climate Change: The Ultimate Challenge for Economics". In: *American Economic Review* 109, pp. 1991–2014. ISSN: 0002-8282. DOI: 10.1257/aer.109.6.1991.

Oliveira, Gabriel de et al. (2020). "Smoke pollution's impacts in Amazonia". In: *Science* 369(6504). Ed. by Jennifer Sills, pp. 634–635. ISSN: 0036-8075. DOI: 10.1126/science.abd5942. eprint: https://science.sciencemag.org/content/369/6504/634.2.full.pdf. URL: https://science.sciencemag.org/content/369/6504/634.2.

Oviedo, A.F. et al. (2020). "Povos indígenas e Covid-19: relato emergencial". In: ed. by R. Pacheco. Editora Primata. Chap. A vulnerabilidade socioambiental dos povos indígenas no Brasil ao Covid-19.

Pailler, Sharon (2018). "Re-election incentives and deforestation cycles in the Brazilian Amazon". In: *Journal of Environmental Economics and Management* 88, pp. 345–365. ISSN: 0095-0696. DOI: 10.1016/j.jeem.2018.01.008.

Pequeno, Pedro et al. (2020). "Air transportation, population density and temperature predict the spread of COVID-19 in Brazil". In: 8, e9322. ISSN: 2167-8359. DOI: 10.7717/peerj.9322.

Petersen, Eskild et al. (Sept. 2020). "Comparing SARS-CoV-2 with SARS-CoV and influenza pandemics." In: *The Lancet. Infectious diseases* 20 (9), e238–e244. ISSN: 1474-4457. DOI: 10.1016/S1473-3099(20)30484-9. ppublish.

Rocha, Rudi and André Sant'Anna (2020). *Winds of Fire and Smoke: Air Pollution and Health in the Brazilian Amazon.* Tech. rep. Instituto de Estudos para Políticas de Saúde (IEPS).

Saúde Indígena), SESAI (Secretaria Especial de (2020). *Informe Epidemiológico 17: Doença por Coronavírus (COVID-19) em populações indígenas.* Tech. rep. Ministério da Saúde, Secretaria Especial de Saúde Indígena.

Socioambiental, Instituto (2020). *The impacts of the pandemic on the yanomami indigenous territory.* Tech. rep. Instituto Socioambiental.

Covid Economics 53, 23 October 2020: 33-71

Sonter, Laura J. et al. (2017). "Mining drives extensive deforestation in the Brazilian Amazon". In: *Science* 8. ISSN: 2041-1723. DOI: 10.1038/s41467-017-00557-w.

Souza-Rodrigues, Eduardo (2019). "Deforestation in the Amazon: A unified framework for estimation and policy analysis". In: *The Review of Economic Studies* 86(6), pp. 2713–2744.

Vahidy, Farhaan S. et al. (Aug. 2020). "Racial and ethnic disparities in SARS-CoV-2 pandemic: analysis of a COVID-19 observational registry for a diverse US metropolitan population." In: *BMJ open* 10 (8), e039849. ISSN: 2044-6055. DOI: 10.1136/bmjopen-2020-039849. epublish.

WHO (2020). *Transmission of SARS-CoV-2: implications for infection prevention precautions - Scientific brief*. Tech. rep. World Health Organization.

Covid Economics 53, 23 October 2020: 33-71

Annex

Description of the variables

The main variables are described as follows:

Dependent Variables

- **Number of weekly COVID-19 hospitalizations(Panel Data)** by race (Indigenous, Black, White, 'Pardos', East Asian people) at municipal level - From March 1^{st} to August 31^{th}, 2020.

- **Number COVID-19 infections (Covid-19 Cases SESAI)** for indigenous people recognized by the Special Secretariat for Indigenous Health (SESAI) within the Brazilian Unified Health System (SUS) - From April 1^{st} to August 31^{th}, 2020.

    * The obtained database counted the number of infections throughout the 34 Special Indigenous Health Districts (ISSD) located in the country. Since the analysis was executed at the municipal level, I needed to proportionally distribute the number of cases reported by the SESAI for each municipality that is located at least in one of these ISSDs (The distribution among ISSDs and municipalities can be found here).

    * I applied a *relative frequency* based on the estimates for the indigenous population in each of theses municipalities (IBGE, 2019) to find the corresponding proportion and, thus, determine the number of cases of infected from the ISSDs at the municipal level, as follow:

    $$Sesai(x, y) = y_{i,d} \frac{x_i}{\sum_{n=j} x_j}$$

    * Where (y) is the daily number (d) of infected on a certain ISSD in which contains a determined municipality (i); (x) is the indigenous population of this particular municipality; and (j) is the set of all municipalities that are found on this specific ISSD.

- **Number of COVID-19 infections (Covid-19 Cases APIB)** for indigenous people recognized by the Articulation of the Indigenous Peoples of Brazil (APIB) - From April 1^{st} to August 31^{th}, 2020.

Covid Economics 53, 23 October 2020: 33-71

Covid Economics 53, 23 October 2020: 33-71

- The APIB granted us access to their database, which counted the daily number of the indigenous people infected not considered by the SESAI-SUS. As mentioned previously, the organization claims that the Brazilian Government (through SESAI) is under-notifying the actual number of indigenous infected by COVID-19. Although they gave us information at the municipal level, some instances did not have the municipality for the cases recognized and only the state in a respective day. Another point was that this database only accounted for a surplus of cases that SESAI did not consider in its reports.

- Similar to the estimated number of cases at the municipal level from the SESAI database (*Sesai(x,y)*), I needed to proportionally distribute the number of cases reported by the APIB for the instances that did not have municipalities, but only the states mentioned. Likewise, I did not account for all municipalities inside a state, but only those located inside in at least one Special Indigenous Health District (ISSD).

- I then applied a *Relative Frequency* based on the estimates for the indigenous population (IBGE, 2019) in each of theses municipalities to find the corresponding proportion and, thus, determine the number of cases of infected from the States at the municipal level, as follow:

$$Apib(x,y,z) = y_{i,d}\frac{x_i}{\sum_{n=j} x_j} + z_{i,d}\frac{x_i}{\sum_{n=s} x_s}$$

- Where (y) is the daily number (d) of infected on a certain ISSD in which contains a determined municipality (i); (x) is the indigenous population of this particular municipality; and (j) is the set of all municipalities that are found on this specific ISSD. Also, (z) is the daily number (d) of infected on a certain State in which contains a determined municipality (i); and (s) is the set of municipalities that are found on this specific State which are also located in at least one of the ISSDs.

- **Accumulated number of COVID-19 hospitalizations** by race (Indigenous, Black, White,'Pardos', East Asian people) at municipal level - From March 1^{st} to August 31^{th}, 2020. Data collected from DataSUS - SRAS database and retrieved at September 7^{th}, 2020.

Independent Variable of Interest

- **Deforestation**: Accumulated warning areas for deforestation (in 100 km^2) within the Amazon Forest and the Cerrado ecosystem at the municipal level - From March 1 to August 31, 2020. I also use the data in the natural log format. Data collected from Brazil's National Institute for Space Research - Deter database and retrieved at September 7 20^{th} 2020.

- **Deforestation (Panel data)**: Daily and weekly evolution to warning areas for deforestation (per 100 km^2) within the Amazon Forest and the Cerrado ecosystem at the municipal level - From March 1 to August 31, 2020.

- **Log deforestation**: Natural log of daily data of warning areas for deforestation (per km^2) within the Amazon Forest and the Cerrado ecosystem at the municipal level - From March 1 to August 31, 2020.

Other variables used as a control in the analysis at municipal level were:

1. Population data by race and total estimate of the Brazilian population. Data collected from Brazilian Institute of Geography and Statistics (IBGE) - 2010 Census and 2019 population estimates respectively;

   - **Indigenous population (% Total)**: Proportion of indigenous people at municipal level.
   - **'Pardos' population (% Total)**: Proportion of 'pardos' people at municipal level.
   - **Black population (% Total)**: Proportion of black people at municipal level.
   - **White population (% Total)**: Proportion of white people at municipal level.
   - **Yellow population (% Total)**: Proportion of yellow people at municipal level.

2. Access to multidisciplinary indigenous health care teams (EMSI). Data observed from March to June 2020 and retrieved at DataSUS - CNES Equipes de Saude.

   - **Average of multidisciplinary indigenous health care teams** outside and inside the Legal Amazon by municipality.

3. Data from the National Sanitation Information System (SNIS): (1) Water and Sewage [2018]; (2) Solid Waste [2018]; (3) Rainwater [2018];

Covid Economics 53, 23 October 2020: 33-71

CEPR PRESS

Covid Economics 53, 23 October 2020: 33-71

- **Access to clean water**: Proportion of municipal population that have access to clean water in 2018.
- **Access to treated sewage**: Proportion of municipal population that have access to treated Sewage in 2018.
- **Access to public roads**: Extension of public roads inside the municipality (km) in 2018.
- **Urban density**: Proportion of urban population over the urban area of a municipality in 2018.
- **Urban density**: Total population of the municipality per Km^2.

4. Gini Index and GDP by municipality in Brazil. Data collected from SUS - Tabnet and Brazilian Institute of Geography and Statistics (IBGE), 2017 respectively;

   - **Inequality (Gini coefficient)**: Gini index based on GDP at municipal level in 2010.
   - **GDP**: Municipal GDP in 2017.

5. Cities with isolated indigenous populations. Data collected by the Instituto Socioambiental, COVID-19 and retrieved at August 14^{th}, 2020;

   - **Existence of uncontacted tribes**: Binary variable for municipalities that have uncontacted tribes (confirmed and not confirmed) in their territory in 2020. Source of the data: Instituto Socioambiental, 2020.

6. Geographical variables produced with the software GIS based on shapefiles from the Brazilian Institute of Geography and Statistics (IBGE);

   - **Rainfall**: Average of rainfall at the municipal level in millimeters per hour (mm).
   - **Waterway**: Binary variable for municipalities in which their centroids are at least 100 km distance to the nearest waterway.
   - **Distance to the coast**: Distance of the municipal capital until the closest cost area (km).
   - **Distance to the state capital**: Distance of the municipal capital until its state capital (km).
   - **Altitude**: Municipality altitude (m).

7. Illegal mining

    - **Illegal mining**: Binary variable for municipalities that have an illegal mining activity. The data was compiled by the Amazon Geo-Referenced Socio-Environmental Information Network (RAISG), Ilegal Mining Map and retrieved on August 14^{th} 2020.

8. Land conflicts;

    - **Number of land conflicts**: Total number of land conflicts involving Indigenous people in Brazil in 2019. Data collected by the 'Commissão Pastoral da Terra'.
    - **Land Conflicts - CACI**: Conflicts occurred involving indigenous people at the municipal level until 2019 (Dummy Variable). Created by the Fundação Rosa Luxemburgo, in partnership with Armazém Memória and InfoAmazonia, the database was collected at the Cartography of the Attacks against (CACI) website.

9. Cattle ranching;

    - **Cattle ranching**: The total number of bovine cattle by municipality per $1{,}000 Km^2$. Also used in natural logarithmic form. Data from IBGE, *Censo Agropecuário* 2017.

10. Wildfire: Fire Radiative Power (FRP);

    - **Wildfire: Fire Radiative Power (FRP)**: Measurement of the radiant energy released per time unit by burning vegetation per $1{,}000 Km^2$. Also used in natural logarithmic form. Data from INPE, Burning Program, for the Amazon and Cerrado regions.

11. Indigenous Territories

    - **Indigenous Territories**: Municipalities that have Indigenous lands officially recognized in Brazil (Updated in 2019). Data retrieved from IBGE - Indigenous and 'Quilombola' peoples database.

12. IBAMA - Environmental protection agency

    - **IBAMA**: Distance of centroid of a given municipalities to the nearest environmental protection agency (IBAMA) local office. The variable was calculated by the authors using GIS. Data retrieved from IBAMA.

Covid Economics 53, 23 October 2020: 33-71

Additional figures and tables

Figure 2: COVID-19 cases confirmed in Brazil, in the Developing and Developed countries

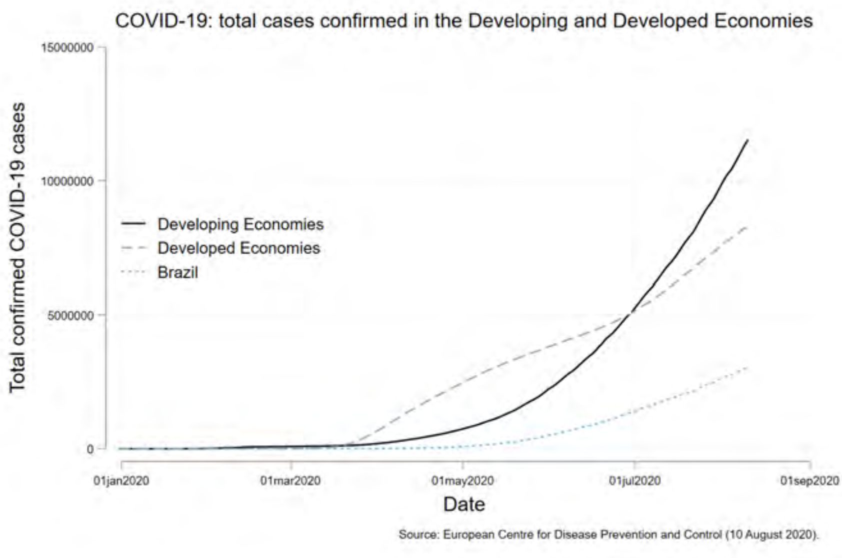


Table 6: Correlation matrix of selected (correlated) variables

Correlation matrix	COVID-19 (SESAI)	COVID-19 (APIB)	COVID-19 hospitalizations	Deforestation	Wildfires	Cattle ranching	Illegal mining	Conflicts
COVID-19 (SESAI)	1							
COVID-19 (APIB)	0.9724	1						
COVID-19 hospitalizations	0.5241	0.4997	1					
Deforestation	0.2198	0.2408	0.1153	1				
Wildfires	0.2023	0.2294	0.1107	0.7618	1			
Cattle ranching	0.1406	0.1388	0.1257	0.3696	0.2927	1		
Illegal mining	0.3745	0.3837	0.2026	0.3709	0.3924	0.2228	1	
Conflicts	0.3170	0.3108	0.2039	0.2529	0.1688	0.2085	0.2319	1

Covid Economics 53, 23 October 2020: 33-71

Figure 3: COVID-19 cases in indigenous peoples and deforestation

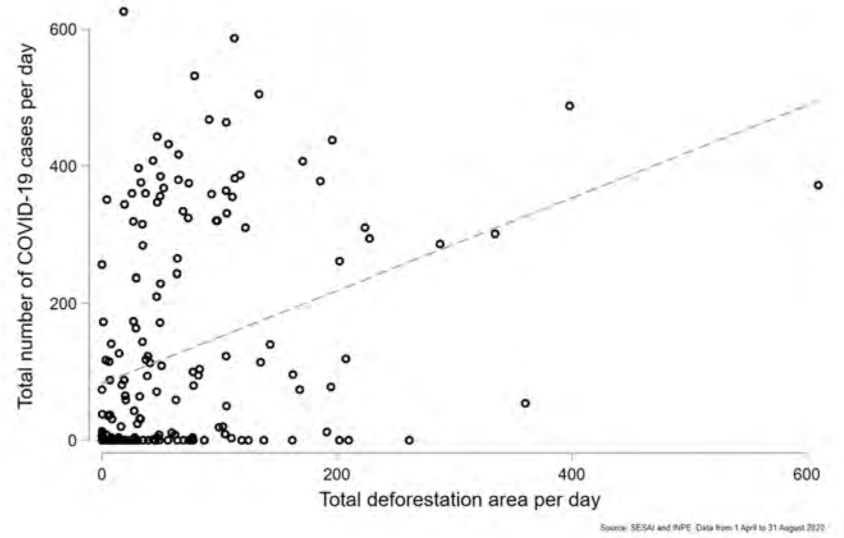


Table 7: Summary statistics: weekly panel data

Variables	N	Mean	SD	Min	Max	Sum
COVID-19 confirmed cases of indigenous people (SESAI)	146,260	0.158	2.299	0	136	23,179
COVID-19 confirmed cases of indigenous people (APIB)	146,260	0.198	3.188	0	294	28,985
COVID-19 hospitalizations of indigenous people	146,260	0.008	0.167	0	26	1,163
COVID-19 hospitalizations of black people	146,260	0.106	1.958	0	212	15,527
COVID-19 hospitalizations of white people	146,260	0.745	11.192	0	1,170	108,942
COVID-19 hospitalizations of 'pardo' people	146,260	0.761	9.117	0	738	111,290
COVID-19 hospitalizations of East Asian people	146,260	0.0257	0.527	0 ^{5}7	3,754	
Deforestation (per 100km^2)	146,260	0.001	.0131	0	1.3	116.2

Covid Economics 53, 23 October 2020: 33-71

CEPR PRESS

Covid Economics 53, 23 October 2020: 33-71

Table 8: Fixed-effects results: deforestation and COVID-19 cases in indigenous peoples

	COVID-19 cases SESAI				COVID-19 cases APIB			
	Pooled OLS	Fixed effects	Fixed effects	Fixed effects	Pooled OLS	Fixed effects	Fixed effects	Fixed effects
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Deforestation (per 100 $Km^2)_{t-5}$	3.247***	1.440**	4.739***		3.695***	1.641**	4.209***	
	(1.078)	(0.635)	(1.548)		(1.174)	(0.820)	(1.428)	
Log Deforestation (per $Km^2)_{t-5}$				0.0451**				0.0453*
				(0.0178)				(0.0260)
Deforestation (per 100 $Km^2)^2_{t-5}$			-9.446***				-7.350***	
			(2.933)				(2.580)	
COVID-19 cases SESAI$_{t-5}$	0.292***	0.164***	0.164***	0.100***				
	(0.0212)	(0.0166)	(0.0167)	(0.0294)				
COVID-19 cases APIB$_{t-5}$					0.138***	0.109***	0.109***	0.0431
					(0.0194)	(0.0220)	(0.0220)	(0.0459)
Implied cumulative	-0.699	-0.666	-0.569	-0.688	-0.877	-0.763	-0.687	-0.592
effect of deforestation	(0.577)	(0.562)	(0.518)	(0.561)	(0.651)	(0.639)	(0.600)	(0.631)
Constant	0.0168***	-0.00003	-0.00005	0.204***	0.0195***	-0.00008	-0.00009	0.285**
	(0.00198)	(0.00234)	(0.00234)	(0.0764)	(0.00222)	(0.00320)	(0.00320)	(0.113)
Observations	969,627	969,627	969,627	6,971	969,627	969,590	969,590	6,970
R-squared	0.083	0.030	0.030	0.067	0.048	0.014	0.014	0.080
Number of municipalities		5,417	5,417	913		5,417	5,417	913

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 9: Weekly fixed-effects results: deforestation and COVID-19 cases in indigenous peoples

	COVID-19 cases SESAI				COVID-19 cases APIB			
	Fixed effects				Fixed effects			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Deforestation (per 100 $Km^2)_{t-1}$	6.370***				10.30***			
	(1.314)				(3.337)			
Deforestation (per 100 $Km^2)_{t-2}$		7.852***	25.61***			8.976***	33.53**	
		(2.293)	(8.420)			(2.999)	(13.03)	
Log deforestation (per 100 $Km^2)_{t-2}$				0.154**				0.300***
				(0.0668)				(0.110)
Deforestation (per 100 $Km^2)^2_{t-2}$			-32.97***				-45.59**	
			(12.31)				(19.33)	
Constant	-0.0003	-0.0004	-0.0013	0.671**	-0.0005	-0.0005	-0.0017	1.076***
	(0.0191)	(0.0199)	(0.0199)	(0.285)	(0.0245)	(0.0255)	(0.0256)	(0.299)
Observations	140,842	135,425	135,425	5,112	140,842	135,425	135,425	5,112
R-squared	0.009	0.009	0.012	0.044	0.007	0.006	0.009	0.033
Number of municipalities	5,417	5,417	5,417	914	5,417	5,417	5,417	914

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

CEPR PRESS

Covid Economics 53, 23 October 2020: 33-71

Table 10: State-fixed effects (accumulated): deforestation and COVID-19 cases in indigenous peoples

	COVID-19 cases SESAI				COVID-19 cases APIB			
	OLS	State fixed effects	State fixed effects	State fixed effects	OLS	State fixed effects	State fixed effects	State fixed effects
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Deforestation ($100km^2$)	41.59**	69.60***	69.31***	22.95***	59.25**	83.55***	80.84***	30.17***
	(15.18)	(10.88)	(4.067)	(4.728)	(25.21)	(12.26)	(5.579)	(5.931)
Population density	0.000221	0.00153*	0.000135	0.00128	0.000762	0.00284**	0.000412	0.00247
	(0.000700)	(0.000836)	(0.000595)	(0.00120)	(0.00107)	(0.00136)	(0.000817)	(0.00151)
Inequality (Gini coefficient)	103.5**	32.01**	21.28**	34.30***	131.0**	44.97**	33.10***	45.30***
	(43.09)	(12.82)	(8.328)	(10.06)	(50.26)	(17.04)	(11.42)	(12.62)
Extreme poverty			-1.645	-1.967			-2.493	-2.575
			(1.195)	(1.475)			(1.640)	(1.850)
Access to roads		1.042***	0.769***	0.0123		1.336***	0.913**	-0.0415
		(0.341)	(0.272)	(0.322)		(0.413)	(0.374)	(0.404)
Access to treated water		-4.393*	-1.520			-7.540**	-3.840	
		(2.434)	(2.355)			(3.619)	(3.230)	
Proximity to waterways		10.80	2.826	-0.00426		15.05	6.049*	0.757
		(6.706)	(2.478)	(2.772)		(9.140)	(3.399)	(3.477)
Number emergency rooms			6.749***	7.322***			12.01***	12.93***
			(0.979)	(1.452)			(1.343)	(1.821)
Constant	-48.64**	-19.80	-13.80***	-19.35***	-75.31**	-34.23	-20.05***	-26.71***
	(20.78)	(14.27)	(4.633)	(5.190)	(32.81)	(21.51)	(6.356)	(6.511)
Observations	5,380	2,414	2,413	3,261	5,380	2,414	2,413	3,261
R-squared	0.082	0.163	0.301	0.329	0.089	0.148	0.257	0.359
'Bad controls'	No	No	No	Yes	No	No	No	Yes
Geographical controls	No	Yes	Yes	Yes	No	Yes	Yes	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

CEPR PRESS

Covid Economics 53, 23 October 2020: 33-71

Table 11: State-fixed effects (accumulated): deforestation and mechanisms

	Log deforestation per $100Km^2$				
	OLS	State fixed effects	State fixed effects	State fixed effects	State fixed effects
	(1)	(2)	(3)	(4)	(5)
Log wildfires	0.0715***	0.0715***	0.0323***	0.0159*	0.0209**
	(0.00710)	(0.00568)	(0.00825)	(0.00842)	(0.00862)
Log cattle ranching	0.0425***	0.0457***	0.00225	-0.0117	-0.0123
	(0.00750)	(0.00694)	(0.00973)	(0.0106)	(0.0106)
Illegal mining	1.097***	1.027***	1.252***	1.234***	1.204***
	(0.348)	(0.121)	(0.229)	(0.228)	(0.228)
Conflict	0.658***	0.489***	0.545***	0.472***	0.488***
	(0.122)	(0.0582)	(0.0933)	(0.0939)	(0.0962)
Log local government			-0.0107	-0.00819	-0.00843
total revenues			(0.00951)	(0.00987)	(0.00988)
Distance to environmental protection			0.00744	-0.0336	-0.0382
agency's (IBAMA) nearest office			(0.0305)	(0.0338)	(0.0339)
Indigenous population/Total					-0.669
					(0.599)
Constant	-0.475***	-0.497***	0.144	0.0839	0.943
	(0.0673)	(0.0631)	(0.196)	(0.205)	(0.619)
Observations	5,385	5,385	1,801	1,698	1,698
R-squared	0.160	0.267	0.316	0.331	0.334
Geographical controls	No	No	No	Yes	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 12: Mechanisms: effects of deforestation on wildfires, cattle ranching, illegal mining, and conflicts

	Log wildfires		Log cattle ranching		Illegal Mining		Conflicts	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log deforestation (km^2)	0.494***	0.407***	0.276***	0.166***	0.0159***	0.0148***	0.0326***	0.0321***
	(0.0318)	(0.0335)	(0.0265)	(0.0256)	(0.00148)	(0.00154)	(0.00307)	(0.00313)
Constant	1.706***	0.917***	9.141***	8.221***	0.00733***	-0.00778	0.0343***	0.0205**
	(0.0245)	(0.107)	(0.0203)	(0.0820)	(0.00114)	(0.00492)	(0.00236)	(0.0100)
Observations	5,417	4,994	5,417	4,994	5,385	4,994	5,417	4,994
R-squared	0.635	0.634	0.363	0.380	0.183	0.175	0.161	0.173
Geographical controls	No	Yes	No	Yes	No	Yes	No	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 13: Mechanisms: effects of wildfires, cattle ranching, illegal mining, and conflicts on the transmission of COVID-19 cases in indigenous people

	COVID-19 cases reported in indigenous people (SESAI)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log wildfires	1.028***	0.656**							0.318
	(0.257)	(0.276)							(0.257)
Log cattle ranching			0.444	-1.044***					-1.595***
			(1.062)	(0.386)					(0.360)
Illegal mining					153.7***	140.8***			129.3***
					(33.87)	(5.528)			(5.440)
Conflicts							61.15***	50.61***	42.58***
							(9.680)	(2.787)	(2.668)
Population density		0.00156**		0.000587		0.00137*		0.00142*	0.00002
		(0.000781)		(0.000846)		(0.000734)		(0.000756)	(0.000776)
GDP		-0.312		0.477		-0.574		-0.384	-0.994
		(1.058)		(1.033)		(0.971)		(0.999)	(0.972)
Inequality (Gini coefficient)		68.61***		74.02***		56.36***		61.47***	54.71***
		(9.268)		(9.334)		(8.714)		(8.966)	(8.596)
Proximity to waterways (100 km)		-3.263		-3.128		-0.300		-1.830	0.122
		(2.568)		(2.565)		(2.417)		(2.487)	(2.359)
Constant	2.486***	-38.25***	0.206	-39.03***	2.991***	-28.20***	2.032***	-34.42***	-10.97
	(0.648)	(11.24)	(10.09)	(11.12)	(0.995)	(10.35)	(0.325)	(10.64)	(10.54)
Observations	5,417	5,040	5,417	5,040	5,385	5,040	5,417	5,040	5,040
R-squared	0.123	0.120	0.001	0.120	0.148	0.220	0.098	0.173	0.260
Geographical controls	No	Yes	No	Yes	No	Yes	No	Yes	Yes

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 14: Mechanisms: effects of wildfires, cattle ranching, illegal mining, and conflicts on the transmission of COVID-19 cases in indigenous people

	COVID-19 cases reported in indigenous people (APIB)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log wildfires	1.581***	1.048***							0.520
	(0.334)	(0.361)							(0.336)
Log cattle ranching			0.735	-0.702					-1.448***
			(1.311)	(0.505)					(0.469)
Illegal mining					201.4***	189.5***			174.5***
					(48.93)	(7.207)			(7.102)
Conflicts							77.14***	65.78***	54.59***
							(12.59)	(3.649)	(3.483)
Population density		0.00261**		0.00187*		0.00233**		0.00239**	0.00112
		(0.00102)		(0.00111)		(0.000957)		(0.000990)	(0.00101)
GDP		0.528		1.588		0.319		0.605	-0.440
		(1.384)		(1.353)		(1.265)		(1.308)	(1.269)
Inequality (Gini coefficient)		87.96***		93.24***		71.92***		79.21***	67.44***
		(12.13)		(12.22)		(11.36)		(11.74)	(11.22)
Proximity to waterways (100 km)		-5.022		-4.682		-0.965		-3.079	-0.398
		(3.359)		(3.359)		(3.151)		(3.256)	(3.080)
Constant	2.594***	-59.22***	-1.385	-65.09***	3.662***	-47.14***	2.517***	-55.96***	-26.95*
	(0.842)	(14.70)	(12.09)	(14.56)	(1.208)	(13.49)	(0.413)	(13.94)	(13.76)
Observations	5,417	5,040	5,417	5,040	5,385	5,040	5,417	5,040	5,040
R-squared	0.101	0.107	0.001	0.106	0.153	0.214	0.095	0.160	0.252
Geographical controls	No	Yes	No	Yes	No	Yes	No	Yes	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 15: Cross-section: state fixed-effect estimates of the effect of deforestation on COVID-19 hospitalizations by race

	COVID-19 hospitalizations									
	Indigenous		Black		White		'Pardo'		East Asian	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Deforestation ($100km^2$)	0.825***	0.915***	-0.378	-0.596	-1.476	-3.380	13.27	14.87	0.210	0.0629
	(0.160)	(0.152)	(3.336)	(3.331)	(21.34)	(21.55)	(15.19)	(14.59)	(0.914)	(0.934)
Population density		0.0003***		0.0219***		0.127***		0.110***		0.0046***
		(0.00004)		(0.0008)		(0.0056)		(0.0038)		(0.0002)
PIB		0.000591		3.249***		23.43***		26.26***		0.930***
		(0.0524)		(1.150)		(7.440)		(5.037)		(0.323)
Inequality (Gini coefficient)		3.155***		54.07***		379.7***		259.6***		12.74***
		(0.469)		(10.30)		(66.63)		(45.11)		(2.889)
Constant	0.198***	-1.629***	2.875***	-57.31***	20.14***	-401.8***	20.28***	-371.7***	0.689***	-15.36***
	(0.0260)	(0.558)	(0.544)	(12.25)	(3.482)	(79.26)	(2.479)	(53.66)	(0.149)	(3.436)
Observations	5,417	5,040	5,417	5,040	5,417	5,040	5,417	5,040	5,417	5,040
R-squared	0.120	0.137	0.011	0.142	0.011	0.122	0.014	0.189	0.005	0.087
Geographical controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Covid Economics 53, 23 October 2020: 33-71