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Transversal project report

How is forest disturbance, measured through tree cover loss, associated with zoonotic disease risk across spatial scales and over time?

By Olivia CHEVRAND, Ahmed-zakaria HEDROUG, Louis MALLOT, Lucas SIMATOVIC

Master 2 students in Economics at Aix Marseille School of Economics

Under the supervision of Professor Abdessemed Raouf BOUCEKKINE

Teacher-researcher at Aix-Marseille Université, Faculté d'économie et de gestion (FEG)

Overview of the report

This report is organized as follows: we will first introduce our subject by explaining our motivations and research question, then section 2 reviews the empirical literature, section 3 presents the data used, section 4 provides the empirical method we choose to use, section 5 examines the regression analyses and their key findings, and section 6 concludes our report.

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Introduction

In recent decades, the world has experienced an increasing emergence and severity of zoonotic disease outbreaks. Epidemics such as Ebola, SARS, and, most recently, COVID-19 have not only demonstrated the dramatic impacts of zoonoses on the health sector but have also caused substantial economic disruptions and restricted human mobility across the globe. The emergence and consequences of zoonoses have revived both scientific and political debates on environmental factors that may facilitate the emergence and spread of these diseases. Among these factors, deforestation has received growing attention. By modifying natural ecosystems, forest disturbance, measured through tree cover loss, alters wildlife habitats and changes animal behavior, thereby increasing contact between wildlife, livestock, and humans.

Our initial research interest focused on exploring the potential role of hunting and bushmeat consumption in zoonotic transmission. However, due to the lack of representative and reliable data on hunting practices, we were unable to conduct a meaningful empirical analysis on this topic. Consequently, we shifted our focus to another phenomenon that remains highly relevant and is better documented in the scientific literature: forest disturbance, measured through tree cover loss. Deforestation (meaning in this project forest disturbance) today remains a phenomenon that gets tracked in a consistent and global manner across nations worldwide and therefore enables systematic inquiries into the relationship between environmental degradation and diseases.

Before stating the research question, it is important to define key terms used in this study. Deforestation is generally understood as a permanent conversion of forested land to non-forest uses such as agriculture, mining, or urban expansion. In contrast, forest disturbance is measured using indicators like tree cover loss, which may capture both permanent and temporary changes in forest cover. Zoonotic diseases are those caused by pathogens, viruses, bacteria, or parasites that can be transmitted between animals and humans. Emergence refers to the appearance of a new infection in a human population, which may include the reoccurrence of known diseases in a particular ecosystem. These definitions are essential for understanding the mechanisms through which environmental change may influence disease dynamics.

This research is further motivated by structural considerations. In many developing countries, economic pressures often drive the expansion of farmland or exploitation of forest resources. Understanding how forest disturbance relates to zoonotic disease risk could inform strategies that balance development objectives with disease prevention. Broadly, disease prevention is generally more effective and less costly than outbreak management. Demonstrating a link between forest disturbance and zoonotic risk could therefore highlight habitat protection as a viable component of public health strategy.

From these observations, the guiding question of this project emerges:
How is forest disturbance, measured through tree cover loss, associated with zoonotic disease risk across spatial scales and over time?

This question is relevant on several levels. It not only seeks to determine whether a relationship exists but also explores how this relationship may vary across regions and time periods, highlighting the critical role of environmental context. It also encourages examination of factors that may serve as tipping points in the relationship between forest disturbance and pathogen spillover.

2. Empirical literature

To support our project, we selected three articles directly related to our research question on the relationship between forest disturbance and zoonotic disease risk.

The first article, *Outbreaks of Vector-Borne and Zoonotic Diseases Are Associated With Changes in Forest Cover and Oil Palm Expansion at Global Scale* by Serge Morand and Claire Lajaunie, provides empirical evidence linking forest cover changes to outbreaks of zoonotic and vector-borne diseases at the global level. The authors construct a country-level panel dataset covering 1990–2016, combining forest cover and population data from the World Bank, oil palm plantation areas from FAOSTAT, and disease outbreak data from the GIDEON database. Disease outbreaks are classified following established epidemiological criteria. Using Generalized Additive Models (GAMs) with a negative binomial specification, they account for over-dispersion, population size, time trends, and spatial autocorrelation, while allowing for flexible non-linear relationships. The study finds that changes in forest cover are statistically associated with increases in zoonotic and vector-borne disease outbreaks, demonstrating the role of land-use change in disease emergence. However, their analysis is limited to country-level aggregates, potentially masking local heterogeneity, and does not examine subnational variation or temporal lags in forest disturbance impacts—gaps addressed in our project through subnational panel analysis and dynamic specifications.

The second article, *Zoonotic Spillover in an Era of Rapid Deforestation of Tropical Areas and Unprecedented Wildlife Trafficking: Into the Wild* by Yusuf Amuda Tajudeen, Iyiola Olatunji Oladunjoye, Ousman Bajinka, and Habeebullah Jayeola Oladipo, offers a conceptual framework for understanding how deforestation and anthropogenic activities facilitate zoonotic spillover. The authors conduct a narrative review of 35 peer-reviewed studies published between 2001 and 2022, using databases such as PubMed, ScienceDirect, Wiley, and Google Scholar, with keywords related to zoonotic spillover, deforestation, land-use change, biodiversity loss, and wildlife trafficking. Their synthesis shows that deforestation and wildlife trafficking are major drivers of zoonotic spillover by increasing contact between humans and wildlife reservoirs and by reducing biodiversity through the dilution effect. While this review clarifies the biological and ecological mechanisms linking forest loss to zoonotic risk, it does not provide quantitative estimates or explore spatial heterogeneity at subnational levels, which our empirical analysis explicitly addresses.

The third article, *Looking Beyond Land-Use and Land-Cover Change: Zoonoses Emerge in the Agricultural Matrix* by Ivette Perfecto, Luis Fernando Chaves, Gordon M. Fitch, and colleagues, extends the conceptual understanding of how human-dominated landscapes influence zoonotic disease emergence. Drawing on over 300 studies in ecology, epidemiology, evolutionary biology, and socio-economics, the authors develop a framework called the agricultural matrix and landscape immunity. They highlight how the structure and diversity of agricultural matrices shape pathogen evolution, host–pathogen dynamics, and human–wildlife interactions. High-diversity and complex matrices may enhance landscape immunity, whereas intensive matrices may facilitate zoonotic emergence. This work emphasizes the importance of socio-ecological context, but it remains conceptual and does not quantify the association between forest disturbance and disease risk, nor does it examine temporal dynamics—both of which are key components of our study.

Collectively, these articles provide a strong conceptual and methodological foundation, highlighting the links between forest cover change, biodiversity loss, and zoonotic spillover. Building on this literature, our project contributes by estimating the association at multiple spatial scales (global, regional, and subnational), incorporating temporal lags, and using a panel data framework that controls for fixed spatial and temporal effects. This approach allows us to capture both local and short-term dynamics of forest disturbance on zoonotic disease risk, addressing gaps left by the previous studies.

3. Data presentation

3.1. Deforestation dataset

The deforestation data used in this study comes from Global Forest Watch (GFW), a global forest monitoring platform that compiles satellite-based forest change information. The dataset provides several indicators that allow us to capture forest dynamics over time, including:

- tree cover extent (2000, 2010)
- primary forest extent
- aboveground live woody biomass (AGB) stocks and densities (2000)
- annual tree cover loss (2001–2024)
- annual tree cover loss by dominant driver (2001–2024)
- annual primary forest loss (2002–2024)

These data were produced by the GLAD (Global Land Analysis and Discovery) laboratory at the University of Maryland in partnership with Google using Landsat satellite imagery (Hansen et al., 2013). Tree cover loss is defined as a “stand-replacement disturbance”, meaning the removal of at least 50% of tree cover within a 30-meter Landsat pixel. This measure captures a wide range of disturbances—such as agricultural expansion, selective or industrial logging, fire, storms, and disease outbreaks.

GFW additionally provides information on the drivers of tree cover loss, identifying the dominant cause for each pixel, and reports indicators related to forest carbon flux, such as:

- annual forest greenhouse gas (GHG) emissions (2001–2024)
- average annual forest CO_2 removals (2001–2024)
- net GHG flux at the national and first sub-national (state/province) levels (2001–2024)

For our analysis, we rely specifically on the “Subnational Tree Cover Loss” sheet of the dataset, which reports annual tree cover loss at the first administrative level (e.g., states, provinces). We use the annual tree-cover-loss variable as our key indicator of forest disturbance.

A crucial methodological note is that tree cover loss is not equivalent to deforestation. Tree cover loss measures the removal or mortality of vegetation taller than 5 meters—including both natural forests and plantations—and does not differentiate between temporary disturbances (e.g., rotational harvesting, post-fire regrowth) and permanent conversion to non-forest land. Therefore, in this study, tree cover loss should be interpreted as a proxy for forest disturbance intensity rather than strict deforestation.

Forest disturbance is expressed in logarithmic form in the econometric models in order to:

- reduce the influence of extreme values,
- allow coefficients to be interpreted as semi-elasticities,
- and account for potential non-linearities in the relationship between forest loss and health outcomes.

3.2. Measuring zoonotic disease risk

The empirical analysis relies on a proxy for zoonotic disease risk constructed from internationally comparable panel data. Due to the absence of harmonized, long-run time series on the incidence of strictly zoonotic diseases at a fine spatial scale, the dependent variable does not directly measure confirmed cases of specific zoonoses. Instead, it captures a broader indicator of transmissible disease risk that is plausibly related to zoonotic spillover dynamics.

The data are primarily drawn from the World Development Indicators (WDI) database compiled by the World Bank, which provides standardized country-level information over time. The proxy incorporates reported cases of transmissible diseases alongside key demographic and environmental indicators, allowing for consistent cross-country and temporal comparisons.

Several assumptions underlie this measurement strategy. First, it is assumed that variations in the proxy reflect, at least partially, underlying changes in exposure to pathogens of animal origin. Second, any measurement error associated with the proxy is assumed to be uncorrelated with local forest disturbance once spatial and temporal fixed effects are included. Third, changes in disease surveillance capacity and reporting practices are assumed to affect all observational units relatively uniformly within a given year, which motivates the inclusion of year fixed effects.

In addition to the dependent variable, the WDI database provides a set of control variables commonly used in the epidemiological and environmental economics literature. These include population density, the urbanization rate, poverty indicators, and GDP per capita, which capture demographic pressure, settlement patterns, socio-economic conditions, and access to health infrastructure. Including these controls helps isolate the association between forest disturbance and zoonotic disease risk from other structural determinants of disease transmission.

While this approach is standard in the empirical literature, it implies that the estimated coefficients should be interpreted as statistical associations rather than strict causal effects.

4. Empirical method

Our empirical strategy relies on panel-data econometric models to examine the association between forest disturbance and zoonotic disease risk across spatial and temporal scales.

4.1. Fixed-effects panel models

The analysis is based on panel-data regressions with spatial and temporal fixed effects. This specification controls for:

- all time-invariant characteristics specific to each spatial unit (country or region), such as baseline climate, ecosystem structure, long-term biodiversity, or institutional features of health systems;
- common shocks affecting all units in a given year, including global epidemics, improvements in diagnostic technologies, or changes in data collection methodologies.

Standard errors are systematically clustered at the relevant spatial level to account for serial correlation within units over time.

This fixed-effects framework reduces bias from omitted variables that are constant over time and improves the credibility of the estimated associations relative to cross-sectional or pooled specifications. However, it does not fully eliminate concerns related to reverse causality or time-varying unobservables, which reinforces the need for cautious interpretation.

4.2. Multi-level comparison across spatial scales

The empirical strategy explicitly compares results across multiple spatial scales in order to assess whether the relationship between forest disturbance and zoonotic disease risk depends on the level of aggregation. Three levels of analysis are considered: (i) a global country-level panel, (ii) a restricted country-level sample focusing on Asia and Africa, and (iii) subnational panels exploiting within-country variation.

Although the underlying dataset is global in scope, particular attention is devoted to Asia and Africa. These regions are characterized by some of the highest rates of forest loss worldwide, exceptionally high levels of biodiversity, and a historical concentration of zoonotic spillover events. Focusing on these regions therefore increases the substantive relevance of the analysis and improves the likelihood of detecting meaningful associations between forest disturbance and zoonotic disease risk.

Comparing estimates across global, regional, and subnational samples allows the analysis to evaluate whether national-level aggregation masks important local heterogeneity. This approach is especially relevant in a context where the biological mechanisms underlying zoonotic spillover—such as habitat disruption, changes in wildlife populations, and increased human–animal contact—are inherently local and may not scale linearly to broader spatial units.

4.3. Dynamic specifications and temporal lags

The health impacts of forest disturbance are not necessarily immediate and may materialize with a delay, depending on ecological, epidemiological, and social processes. To account for this temporal dimension, the analysis estimates models that include lagged values of forest disturbance at one-year and three-year horizons at the subnational level.

These dynamic specifications allow for an examination of the timing of the association between forest disturbance and zoonotic disease risk, distinguishing contemporaneous effects from delayed impacts in the short and medium term. The inclusion of lags is intended to assess whether the association persists over time or attenuates following the initial environmental shock.

This approach is consistent with the epidemiological literature, which emphasizes that zoonotic spillover events are often triggered by recent ecological disruptions, while longer-term effects may be moderated by ecological adaptation, land-use reconfiguration, or public health responses

5. Key findings

Table 1 reports the estimated coefficients from the fixed-effects panel regressions at the national and subnational levels, including contemporaneous and lagged specifications.

Table 1. Fixed-effects estimates of the association between forest disturbance (Deforestation) and zoonotic disease risk

Deforestation and Zoonotic Disease Risk: Global, Regional and Subnational Evidence

	World (Country FE)	Asia & Africa (Country FE)	Subnational – contemporaneous	Subnational – lag 1 year	Subnational – lag 3 years
Deforestation (log)	0.000	-0.007	0.015+		
	(0.007)	(0.009)	(0.008)		
Deforestation (log), t−1				0.015+	
				(0.008)	
Deforestation (log), t−3					0.013
					(0.008)
Population density (log)	-27.428***	-21.689***	-19.143***	-19.143***	-19.143***
	(3.730)	(5.761)	(0.948)	(0.948)	(0.948)
Urbanization rate	-0.017	0.079	0.088***	0.088***	0.088***
	(0.097)	(0.099)	(0.019)	(0.019)	(0.019)
Poverty rate	-0.030	-0.007	-0.016***	-0.016***	-0.016***
	(0.043)	(0.028)	(0.004)	(0.004)	(0.004)
GDP per capita (log)	-2.106*	-1.059	-2.168***	-2.168***	-2.168***
	(0.898)	(1.409)	(0.209)	(0.209)	(0.209)
Num.Obs.	61040	35432	180224	180224	180224

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Dependent variable: zoonotic disease proxy.
All specifications include unit (country or subnational region) and year fixed effects.
Standard errors are clustered at the relevant spatial level.
Subnational models are estimated at the first administrative level using Global Forest Watch data.

At the national level, the estimates show no statistically significant association between forest disturbance and the proxy for zoonotic disease risk. As reported in Table 1, column (1), the coefficient associated with Deforestation in the global sample is close to zero (β = 0.000, standard deviation = 0.007) and remains insignificant after including fixed country and year effects. This result is confirmed in the Asia–Africa subsample (Table 1, column (2)), where the estimated coefficient remains insignificant and slightly negative ($\beta = -0.007$, standard deviation = 0.009). These findings suggest that aggregating data at the national level may mask local dynamics linking forest disturbance and health risk.

However, a different relationship emerges when the analysis is conducted at a finer spatial scale. In the subnational–contemporaneous specification (Table 1, column (3)), Deforestation is associated with a modest increase in zoonotic risk at the regional level. The estimated coefficient is positive and marginally significant ($\beta = 0.015$, standard deviation = 0.008, $p < 0.1$), indicating that the potential effects of forest cover loss are observable locally but not detectable at more aggregated levels. This result highlights the fundamentally local nature of zoonotic disease transmission mechanisms.

Dynamic analysis reinforces this interpretation. When forest disturbance is introduced with a one-year lag (Table 1, column (4)), the coefficient remains positive, of similar magnitude, and marginally significant ($\beta = 0.015$, standard deviation = 0.008, $p < 0.1$). However, the effect weakens when a three-year lag is considered (Table 1, column (5)), with the coefficient remaining positive but becoming statistically insignificant ($\beta = 0.013$, standard deviation = 0.008). This temporal profile suggests that the potential health effects of tree cover loss are mainly short-term, before gradually dissipating.

Finally, the results reported in Table 1 highlight the structuring role of socioeconomic factors in explaining the zoonotic risk proxy. In all subnational models, population density is negatively associated with risk ($\beta \approx -19.1$, $p < 0.001$), while the urbanization rate shows a positive and significant correlation ($\beta \approx 0.088$, $p < 0.001$). Per capita GDP is also negatively correlated with zoonotic risk ($\beta \approx -2.17$, $p < 0.001$), suggesting that economic and health capacities contribute to mitigating the risks associated with communicable diseases. These results indicate that forest disturbance does not act in isolation, but is part of specific demographic and economic configurations.

Conclusion

The objective of this project was to examine the existence and nature of the link between forest disturbance and the risk of zoonotic diseases, taking into account both data constraints and the spatial dimension of transmission mechanisms. Using international data from Global Forest Watch and World Development Indicators, and relying on fixed-effects panel models, the analysis explored this relationship at different geographical scales and over several time horizons.

The empirical results show that no statistically significant association is observable between tree cover loss and the proxy for zoonotic risk when the analysis is conducted at the national level, even in the most exposed regions such as Asia and Africa. This absence of effect at the aggregate level suggests that the dynamics linking forest ecosystem disturbance and disease transmission do not necessarily translate into detectable variations in average health risk at the macroeconomic level.

However, analysis conducted at the subnational level reveals a positive, albeit modest, association between forest disturbance and zoonotic risk. This effect appears in contemporary specifications and with a one-year lag, before diminishing and becoming insignificant in the longer term. This spatial and temporal profile is consistent with epidemiological and ecological literature, which highlights the local and often transient nature of zoonotic spillover mechanisms following recent environmental disturbances.

Beyond deforestation itself, the results highlight the central role of socioeconomic and demographic factors in shaping zoonotic risk. Population density, urbanization dynamics, and the level of economic development appear to be major determinants of the variations observed, suggesting that forest disturbance does not act in isolation but is part of specific territorial configurations that condition exposure, transmission, and detection of diseases.
However, several limitations should be noted. The use of a proxy for zoonotic risk, rather than direct data on the incidence of strictly zoonotic diseases, introduces uncertainty into the measurement of the phenomenon under study. Furthermore, despite the inclusion of fixed spatial and temporal effects, the empirical approach adopted does not allow a strict causal relationship to be established between forest disturbance and health risk. The results should therefore be interpreted as statistical associations rather than causal effects.

Finally, these limitations do not detract from the main significance of this work, which lies in highlighting the decisive role of the spatial scale of analysis. The results suggest that policies for the prevention of zoonotic diseases and forest management would benefit from being designed and implemented at the local or regional level, where interactions between humans, wildlife, and the environment are most direct. As such, this project highlights the importance of integrated approaches combining environmental policies, land use planning, and health capacities in order to better anticipate and limit the risks associated with the emergence of zoonotic diseases.

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