Are ecosystem health and human health related? An analysis of deforestation and malaria in sub-Saharan Africa

Maddy Butts
ECON 428: Seminar in Environmental and Resource Economics
Colgate University
Advisor: Professor O'Hara

Abstract

Malaria directly affects over 200 million people annually and incidence rates are highly dependent on anthropogenic activities such as land use changes and deforestation. In developing countries, human health is highly dependent on ecosystem health and environmental conditions; however, as countries develop and increase national income, land use changes and environmental degradation are inevitable. This paper explores the inherent tradeoffs between development, disease, and deforestation, using panel regressions with fixed effects to examine the links among malaria, deforestation, and per capita national income for 33 sub-Saharan African countries from 2001-2009. Results of this paper show a significant negative association between forest area and malaria incidence and a significant negative association between malaria and per capita national income. We highlight the significance of the natural insurance of ecosystems on human health and the importance of wildlife conservation and ecosystem health on the growth and prosperity of developing nations.

JEL Classification: Q23, I10
Keywords: Deforestation, malaria, public health, biodiversity conservation

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I
Intro

This paper explores the links among ecosystem health, human health, and national wealth, using deforestation, malaria cases, and per capita GDP as respective proxies. Malaria is expected to double over the next 20 years if left untreated, so it is imperative to develop an understanding how to best mitigate the deleterious pandemic and its effects on public health, labor productivity, and economic development. The results of this paper show a significant, positive association

between deforestation and malaria cases in sub-Saharan Africa and a significant, negative association between malaria cases and per capita GDP.

Deforestation is a malicious and evil deed to environmentalists, yet for developing nations, it can be a sign of economic growth and development. Deforestation provides timber for construction and for export, it creates room for new roads and industrialization, and slash-and-burn techniques can form fertile, arable land to produce cash crops. These practices can help to improve the economies of rural areas in developing countries, help to create vital infrastructure such as roads, and ultimately have a positive spillover effect to the urban sector (Andersen & Reis 1997). Land use changes are inevitable as a country develops, industrializes, and raises its national income, which simultaneously increases the standard of living of the population. However, environmental degradation can also have negative indirect effects on the country, as human health and ecosystem health are inextricably linked. Deforestation, agricultural practices, irrigation, the spread of exotic species, and anthropogenic pollution can all have deleterious effects on ecosystem health, which, in turn, can impact human health. For example, habitat destruction and biodiversity loss are associated with increases in the incidence and distribution of infectious diseases (Pongsiri et al 2009).

One such disease is malaria, which impacts over 100 countries around the world (WHO WMR). Malaria is an infectious disease caused by five species of the *Plasmodium* parasite, *P. falciparum, P. vivax, P. ovale, P. malariae* and *P. knowlesi*, that is spread to humans by 30 vector species of the female *Anopheles* mosquito (WHO 2013; Pongsiri et al 2009). About 3.4 billion people are at risk of malaria globally,

and the WHO estimated 207 million cases of malaria and 627,000 deaths due to malaria in 2012, 80-90% of those occurring in Africa (2013). Symptoms of malaria are flulike, including fever, chills, headache, and nausea, and can progress to seizures, coma, and death if the parasites are left untreated and infect vital organs. The impact of malaria on human health is so serious that humans living in malaria-endemic regions have evolved a potentially deadly genetic mutation that can protect humans against malaria, known as the sickle cell trait. Having one copy of this genetic mutation, from only one parent, is advantageous in preventing and/or mitigating the effects of malaria, but having two copies of the trait, one from each parent, is highly deleterious and deadly.

Deforestation and malaria are both prevalent in sub-Saharan Africa. Two biological factors explain the severity of malaria in Africa; the most efficient malaria vector and the most severe malaria strain are widespread in Africa. In some parts of the continent, 25-30% of the population has the disease, which has resounding effects on the economies of sub-Saharan Africa. For example, there is more than a five-fold difference between GDP PPP in malaria-endemic countries compared to those without malaria (Gallup & Sachs 2001). The effects of malaria are manifested in multiple ways; there are several mechanisms by which malaria can indirectly and directly impact a nations' gross domestic product. The obvious costs of malaria are loss of lives, foregone incomes due to morbidity, and demand for health care, but malaria has much broader impacts on society. Societies with endemic malaria are negatively effected by two other factors resulting from malaria: 1) changes in household behavior and social changes and 2) macroeconomic factors. Changes in

household behavior include increased fertility rates, reduced human capital, absenteeism in schooling, and reduced household savings. Malaria also impacts the macroeconomic situation of a country by inhibiting tourism, trade, and foreign direct investment in the malarious region (Sachs & Malaney 2002).

Studies have shown that deforestation is associated with increases in per capita GDP, yet the indirect effects of deforestation on the economy are generally omitted (Andersen & Reis 1997). Deforestation impacts the *natural insurance* of healthy ecosystems, which can negatively impact human health and labor productivity. For example, Vittor et al found that deforested sites in the Peruvian Amazon had mosquito biting rates 278 times higher than in forested areas (2006). This is mainly because cutting trees generates additional suitable breeding sites for the *Anopheles* mosquito through increasing surface water availability on land previously covered by trees. Deforestation can also decrease abundance of *Anopheles* predators and can result in increased human interaction with malaria vectors, contributing to increased transmission rates (Pattanayak et al 2010; Vittor 2006). Studies have shown that forest degradation is positively associated with malaria cases, and the number of malaria cases is negatively associated with a nations' GDP (Gallup & Sachs 2001, Pattanayak et al 2010). So could policies or strategies to reduce deforestation help to reduce malaria cases and boost the economy of a developing nation?

Public concern regarding deforestation is generally attributed to the Amazon River Basin; however rates of clear cutting in Africa are currently more than twice the world average (UNEP). While deforestation in the Amazon is driven by cattle

ranching, exporting hardwoods, and road creation—often backed by government policies and subsidies—tree cutting in Africa is largely caused by individual human activity. About 70% of deforestation in Africa is attributed to wood fuel demand because 81% of sub-Saharan African households use wood fuel for daily energy demands such as cooking and heating (Subedi et al 2014; World Bank). Burning wood fuel for energy consumption is harmful to human health, so reducing deforestation could have additional indirect benefits. However, this also highlights the need to assess the impacts of reducing deforestation and changing land use practices on the people and society of sub-Saharan Africa.

II
Literature Review

Literature about malaria, deforestation, and development has predominately focused on the biophysical links between malaria and deforestation or the individual economic impacts of either malaria or deforestation. Few studies have studied the associations between ecosystem health, human health, and national wealth, and there is scarce literature that uses econometric models to empirically estimate correlations and causality.

2.1 *Malaria and Poverty*

The relationship between malaria and poverty has been long established and there has been significant focus on malaria and economic development in Africa. Gallup and Sachs provide a theoretical framework for analyzing the effects malaria on a nation's per capita GDP and economic growth rate (2001). They take into account economic policy, geographic factors, and human capital stock to analyze the effect of a malaria index on both per capita GDP and GDP growth rate. The results of

their study indicate that countries with intensive malaria grew 1.3 less per person per year compared to countries without malaria (Gallup & Sachs 2000). This study concludes that changes in malaria are mainly attributed to climate and ecology of a region and not by poverty. Gallup & Sachs state that malaria is not a proxy for poverty, but there are several mechanisms through which malaria impacts a country's productivity (2001).

However, other studies highlight the inherent endogeneity between poverty and malaria, suggesting that Gallup & Sachs omit the reverse causation in their model. For example, Datta & Reimer analyze the endogenous relationship between malaria and GDP for 100 malaria-endemic countries over a 17-year period (2013). They explore whether malarious countries that have raised GDP and decreased malaria have done so by first reducing malaria or by first rising income: which came first? Their empirical framework follows Gallup & Sachs, but they include another model with malaria as the dependent variable in order to explore the reverse causality between malaria and income. Datta & Reimer conclude that income growth has been the main factor in reducing malaria, but boosting economic growth of an impoverished nation requires a greater impetus than only eradicating malaria (2013). While the associations between income and malaria have been long established, there is debate regarding the direction of causation.

2.2 *Deforestation and development*

As deforestation and development have inherent tradeoffs, Andersen & Reis examine how different government policies in Brazil have most effectively encouraged economic development in the Amazon (1997). Using a panel data set

between 1970-85, the authors estimate that every hectare of land cleared was associated with a $466 increase in GDP and suggest that the benefits associated with deforestation exceeded the costs. Finally, the authors state the subsidized credit was the most cost effective strategy to encourage deforestation, yet there is no mention of the indirect effects of deforestation, i.e. on human health. The authors describe the costs of deforestation to be loss of sustainable logging, lost ecological services, biodiversity loss, and carbon release into the atmosphere. However, Andersen & Reis omit how deforestation can impact human health, which, in turn, affects labor productivity and a nation's GDP (1997).

2.3 *Malaria and Deforestation*

There are few studies that econometrically examine the relationship between malaria and deforestation, as most analyses of this link focus on ecological effects. Pattanayak et al. test the relationship between childhood malaria cases and forest degradation by comparing households in protected and unprotected regions in Flores, Indonesia (2010). They use multivariate probit regressions, with child malaria infection data from household surveys as the dependent variable, and control for demographic, ecological, and public health variables. They focus on child malaria for several reasons; children are most vulnerable to health risks, child health status is mainly attributed to parental decisions and external factors rather than personal decisions, and finally children are unlikely to have acquired immunity to malaria at a young age. Results of their regressions show a statistically significant negative relationship between malaria infection and primary forest area and a statistically significant positive relationship between malaria infection and

secondary forests, emphasizing the natural insurance value of protected forests for human health.

A similar paper by Bauch et al uses municipality level data from the Brazilian Amazon to investigate how government policies, ecological factors, and social variables are associated with confirmed cases of malaria between 2003-2006 (2009). Key policy variables include the creation of roads and protected ecological areas, both of which can affect the frequency of malaria cases, and land use variables include deforestation and land area used for agriculture. Results from clustered quantile regressions and a time-series cross section analysis indicated that policies that disperse the population into areas of active deforestation as well as land use changes are associated on average with higher levels of malaria. The Brazilian government has encouraged the development of the Amazon basin through road building and subsidized credits, thus the authors conclude that the government needs to take human health into consideration when establishing these policies (Andersen & Reis 1997; Bauch et al 2009).

III
Empirical Framework

This paper uses fixed effects regressions with panel data for two models. and Datta & Reimer (2013). For the first model, the dependent variable is malaria cases from the World Health Organization and the independent variables control for human capital, land use changes, and government policies. This model is from Bauch et al (2009) and is described below:

$$Malaria_{it} = \beta forest_{it} + \beta irrigation_{it} + \beta protected_{it} + \beta ag_{it} + \beta cement_{it} + \beta cereal_{it} + \beta population_{it}\ \beta life_{it} + \beta rural_{it} + \beta young_{it} + \beta health_{it} + \beta GDP_{it} + \delta Year + \mu$$

The second model is taken from Datta & Reimer (2013), with per capita GDP as the dependent variable, with government indicators, financial savings, labor rates, and malaria cases on the right hand side. The model is shown below:

$$GDP_{it} = \beta labor_{it} + \beta Investment_{it-1} + \beta Govteffectiveness_{it} + \beta Regulatory_{it} + \beta Coast_{it} + \beta Malaria_{it} + \delta Malaria*Labor_{it} + \delta Malaria*Investment_{it} + \delta Year + \mu$$

IV

Data

The two models use country level data for 33 sub-Saharan African countries between 2001 and 2009. The dependent variable in model 1 $\boldsymbol{lmal_{it}}$, which is an independent variable in model 2, is logged total reported cases of malaria per year per thousand people. These data were obtained from the World Health Organization's (WHO) 2013 World Malaria Report and are based on household surveys and rapid diagnostic tests (RDT) at health facilities. These are the same data used by Datta & Reimer (2013), which they use as both dependent and independent variables in their models.

Table 1: Summary Statistics of Variables

Variable	Obs	Mean	Std. Dev.	Min	Max
lmal	230	6.476045	1.80368	1.846563	9.39088
lfor	231	8.481964	1.624136	5.178407	11.9636
lnirr	231	3.582476	1.649809	0	6.990256
lnterrha	231	7.923533	1.835627	2.851458	10.2083
agr	231	9.3879	1.281128	6.204558	11.26446
sqcement	231	13.35739	15.85025	0	88.99843
cer	231	1.151849	.4611741	.158229	2.589796
lnpop	231	16.05237	1.204019	13.82755	18.80561
life	231	52.27647	6.149159	40.57768	72.1509
rural	231	65.87837	16.17785	15.5684	91.5282
young	231	43.30522	3.695957	28.4004	48.97488
sqhealth	231	1.542371	.3640659	.4780961	2.525892
lngdp	231	7.192804	.8694742	5.569924	9.496856
mallab	230	482.6552	165.8905	106.362	852.4716
labor	231	73.52381	11.30037	45.3	90.8
laginv	184	7.144608	3.743385	.1203258	26.25196
govt	198	-.7640383	.504844	-1.768885	.7272412
malinv	183	44.97791	25.75772	.9479987	133.2319
reg	198	-.6352091	.5036921	-2.117973	.7914705
perpopcoast	231	.3013986	.3255677	0	1.113264

On the right hand side of model 1, variables control for ecological and land use practices, human capital and demography, and wealth & policies that might affect malaria. Summary statistics of all variables are shown above.

Ecology & land use:

Deforestation $\boldsymbol{lfor_{it}}$ is the logged forest area of a country in hectares and was obtained from the Food and Agriculture Organization of the UN (FAO). Logged total area equipped for irrigation per 1000 ha, $\boldsymbol{lnirr_{it}}$, total agricultural area, $\boldsymbol{agr_{it}}$, and total cereal yield in tons per hectare $\boldsymbol{cer_{it}}$, were also obtained from the FAO. Other land use practices include logged area of protected terrestrial land in hectares, $\boldsymbol{lnterr_{it}}$, and square rooted CO_2 emissions from cement production in thousand metric tons, $\boldsymbol{sqcement_{it}}$. $\boldsymbol{Cer_{it}}$ measures the total yield of cereal production in tons/hectare and acts as a proxy for precipitation and climate, as cereal yields are

highly sensitive to droughts, floods, and annual temperature fluctuations, and was obtained from FAO. Similarly, $\boldsymbol{sqcement_{it}}$ measures the annual emissions from cement production, in $MTeCO_2$ and acts a proxy for road production, modeled after Bauch et al (2009), and obtained from the World Bank.

Human capital & demography

Variables that control for human capital and demographic factors are also included in the model. $\boldsymbol{Lnpop_{it}}$ is the logged total national population over time, $\boldsymbol{rural_{it}}$ measures the percent of the population that lives in rural areas, and $\boldsymbol{young_{it}}$ measures the total percent of the population under 14 years old. $\boldsymbol{Life_{it}}$ is the life expectancy at birth in total years, which acts as a proxy for human capital. All human capital & demography data were obtained from the World Bank.

Wealth & government policies

$\boldsymbol{Lngdp_{it}}$ is logged per capita GDP PPP in constant 2005 international $ was and was obtained from the World Bank, as the relationship between malaria and income levels have been established (Sachs & Malaney 2000, Datta & Reimer 2013). $\boldsymbol{Sqhealth_{it}}$ is the square root of public health expenditure as a percentage of total GDP; both GDP and health expenditure data were obtained from the World Bank.

Additional variables in model 2

Model 2 comes from Datta & Reimer (2013) and has $\boldsymbol{lngdp_{it}}$ as the dependent variable. Dependent variables include $\boldsymbol{labor_{it}}$ which is the labor force participation rate as a % of the total population, and $\boldsymbol{laginv_{it-1}}$ which is gross public investment as a percent of GDP, both from the World Bank. $\boldsymbol{Laginv_{it-1}}$ is lagged one year, following Datta & Reimer (2013) and is a proxy for capital productivity, while $\boldsymbol{labor_{it}}$ is a

proxy for labor productivity. Government indicators include $\boldsymbol{Govt_{it}}$ is a measure of government effectiveness and reflects the quality of public services and $\boldsymbol{reg_{it}}$ measures a government's ability to implement and regulate sound policies, both come from the World Bank's Worldwide Governance Indicators. $\boldsymbol{Percoast_{it}}$ is the population living within 100 miles of the coast, as coastal regions are more vulnerable to malaria, from the UNEP. The final three variables are $\boldsymbol{lmal_{it}}$ as well interactions between malaria and labor and malaria and investment, $\boldsymbol{mallab_{it}}$ and $\boldsymbol{malinv_{it}}$.

V
Results

Model 1

Results from the fixed effects panel regression for model 1 are shown in table 2, and include three different regressions.

The first model in Figure 2 includes only ecological and land use factors. The results of the time series regressions with fixed effects show several statistically significant association with malaria cases. A one percent increase in forest cover is associated on average with a 1.45% fewer malaria cases per thousand people, and is significant at the 10% level. Additionally, a one percent increase in area equipped for irrigation per 1000 ha is associated on average with a 0.976% increase in malaria cases per thousand people and is significant at the 10% level. Finally, a one ton/hectare increase in cereal production is associated on average with 0.358% decrease in malaria cases and is significant at the 1% level.

The second model adds human capital and demographic variables. This makes the irrigation variable not significant, but there is still a statistically significant association between forest cover and malaria cases at the 10% level. This model also shows that a one percentage point increase in the population under 14 years old is associated on average with 0.187% increase in malaria cases per 1000 people.

The final model adds wealth and government variables, and the only statistically significant variable is sqhealth*.* A one percentage point increase in the proportion of GDP used for public health expenditure is associated on average with a 0.102 percent increase in malaria cases, as this variable was square-rooted for normality.

Table 2: Model 1 panel regression results

	(1) lmal	(2) lmal	(3) lmal
lfor	-1.451+	-1.373+	-1.449*
	(0.742)	(0.711)	(0.706)
lnirr	0.976+	0.594	0.486
	(0.535)	(0.510)	(0.507)
lnterrha	0.342	0.623	0.672
	(0.456)	(0.430)	(0.427)
agr	1.792+	-0.425	-0.508
	(1.015)	(1.038)	(1.031)
sqcement	0.000175	0.00112	0.00277
	(0.00794)	(0.00783)	(0.00805)
cer	-0.358**	-0.525***	-0.492***
	(0.133)	(0.128)	(0.127)
year	-0.000923	-0.0444	-0.0599
	(0.0139)	(0.0481)	(0.0487)
lnpop		2.035	2.293
		(1.469)	(1.465)
life		0.0878*	0.0919*
		(0.0430)	(0.0430)
rural		-0.0240	-0.0185
		(0.0337)	(0.0335)
young		0.187***	0.189***
		(0.0444)	(0.0446)
sqhealth			0.319*
			(0.126)
lngdp			-0.0311
			(0.319)
_cons	-2.006	60.72	88.23
	(29.53)	(81.34)	(82.37)
N	295	295	295
R-sq	0.089	0.217	0.237

Standard errors in parentheses
+ p<0.10, * p<0.05, ** p<0.01, *** p<0.001

Model 2

Results from the fixed effects panel regression results for model 2 are shown in table 3.

The first regression in table 3 omits variables related to malaria, and shows a statistically significant, negative association between labor force and GDP and a statistically significant, positive association between regulatory quality and GDP.

The second regression in column 2 of table 3 includes malaria variables to analyze the relationship between malaria and national income. Looking at labor by itself, holding constant its effect in the interaction terms, a one percent increase in the labor force is associated on average with a 0.025% decrease in per capita GDP. This model shows a negative association between malaria cases and GDP when looking at malaria by itself, and is significant at the 10% level. A one percent increase in malaria cases per 1000 people is associated on average with a 0.164 % decrease in per capita GDP, holding constant its effect in the interaction terms. In this regression, malaria is affecting total factor productivity shown though its association with GDP, but the additional effects on labor and capital productivity are also significant and are captured in the interaction terms. The corresponding coefficients for the interaction terms between malaria and labor and malaria and capital are 0.002 and -0.002 and are significant at the 5% and 10% levels, respectively.

Table 3: Model 2 panel regression results

	(1) lngdp	(2) lngdp
labor	-0.0118*	-0.0254*
	(0.00589)	(0.00974)
laginv	0.00501+	0.0182*
	(0.00263)	(0.00883)
govt	-0.0479	-0.0378
	(0.0360)	(0.0354)
reg	0.107*	0.0984*
	(0.0419)	(0.0420)
perpopcoast	-3.274	-3.783+
	(2.286)	(2.257)
year	0.0294***	0.0294***
	(0.00264)	(0.00263)
lmal		-0.164+
		(0.0871)
mallab		0.00209*
		(0.00104)
malinv		-0.00223+
		(0.00135)
_cons	-49.95***	-48.83***
	(5.400)	(5.440)
N	184	183
R-sq	0.509	0.544

Standard errors in parentheses
+ p<0.10, * p<0.05, ** p<0.01, *** p<0.001

Discussion & Conclusion

This study analyzed the links between ecosystem health, human health, and economic development. While most previous studies of this type have focused on the Amazon River basin, this study explored deforestation in sub-Saharan Africa, excluding South Africa. Results of panel regressions indicated a statistically significant, negative relationship between forest area and malaria cases. This suggests that deforested areas of sub-Saharan Africa are associated on average with higher incidence of malaria. Cereal production, which was a proxy for precipitation

and temperature fluctuations also showed a statistically significant negative relationship with malaria cases, though the coefficient is quite small. This was expected, as previous studies have concluded that malaria is highly dependent on geography and ecological factors (Gallup & Sachs 2001). Finally, as suggested by Pattanayak et al (2010), the proportion of the population under 14 years old has a statistically significant, positive association with malaria cases, as children are much more vulnerable to malaria than adults. Public health expenditure as a proportion of GDP is associated with a higher incidence in malaria cases, picking up the reverse causality of this relationship, as countries with more malaria cases must spend more money on healthcare. However, this might also bring up the question whether NGOs are more effective at increasing the health status of an impoverished nation. It was also interesting that per capita GDP was not statistically significant in this model.

Results of this study indicate a statistically significant negative relationship between forest area and malaria cases in sub-Saharan Africa. This was expected, as the ecology literature states the cutting down forests increases availability of breeding sites for the mosquitos that transmit malaria. Therefore, we can make the assumption that policies that protect forests may help to decrease the malaria pandemic. However, the majority of deforestation in Africa, as previously mentioned, is attributed to individual human activity, generally for cooking and heating from wood fuel combustion. This is a lifestyle behavior that is unlikely to change with government policies regarding deforestation. Therefore, could the use of alternative fuel sources help to reduce deforestation, and, in turn reduce malaria? This brings up additional environmental justice issues, yet the link between

deforestation and malaria is clear and should not be omitted when analyzing forest cutting and economic development.

The second regression model in this paper explores the link between ecosystem health and economic development, using malaria and per capita GDP as respective proxies. Results of this regression show that, omitting its involvement in interaction terms, an increase in malaria incidence is associated with a reduction in per capita GDP. This is in accordance with the literature, as malaria increases demand for health care, increases absenteeism at work and school, changes household behaviors and savings, and can have broader macroeconomic effects that inhibit economic growth (Sachs & Malaney 2002). Forest area and malaria incidence were shown to be significantly associated in the first model and malaria incidence and national income were significantly associated in the second model. This suggests that deforestation may lead to a reduction in the *natural insurance* of ecosystems, which may, in turn, have an impact on human health and total factor productivity.

Malaria is a serious pandemic and has been shown to be associated with lower per capita national income and can hinder economic growth. Therefore, it is important to understand its causes and to develop possible eradication strategies. This paper shows significant links between deforestation, malaria incidence, and per capita GDP, suggesting that the indirect effects on human health of anthropogenic activities that cause land use changes should be considered. This paper cannot describe causation, but only correlations between the main variables of interest; however, we highlight the importance of biodiversity and ecosystem

health. The significance of ecosystems is often overlooked, but human health and environmental conditions are inextricably linked, as demonstrated in this paper.

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