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Natural resources and infectious diseases: The case of malaria, 2000–2014☆

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ABSTRACT

Recent discussions on the natural resource curse theory have expanded from looking at economic and sociopolitical developments to focusing on the impact of natural resources on the spread of, and deaths from, infectious diseases. However, consensus on a link between natural resources and infectious diseases rarely exists, and empirical results are mixed at best. This paper attempts to re-explore such a link by focusing on malaria, a major infectious disease. We argue that in resource-rich countries the reluctance of governments to invest in human capital, rampant corruption and weakened state capacity, and inferior hygiene conditions in mining and drilling areas lead to higher numbers of cases of malaria. To provide empirical support, we apply different natural resource measures, and examine their impacts on the number of cases of infection and death from malaria for the period 2000–2014. Statistical results largely confirm our observations that natural resource abundance is positively associated with a higher number of incidences of and deaths from malaria. These results hold with alternative malaria and resource indicators, and model specifications. The results also have policy implications for malaria control, global public health, and natural resource management.

1. Introduction

Recent discussions on the (natural) resource curse theory, where countries with abundant natural resources and rely on resource productions tend to have worse economic and socio-political development (Ross, 2013, 2015; Sachs & Warner, 2001; Wick & Bulte, 2009) than resource-poor ones, have extended to include its impact on the spread of, and deaths from, infectious diseases. However, consensus on the link between natural resources and infectious diseases rarely exists, and empirical results are mixed at best. This inconclusiveness has even triggered a recent scholarly debate (See Section 2) on the link between natural resources and infectious diseases, or public health in general.

This paper aims to join this debate by quantitatively testing the impact of natural resources on malaria during the 2000–2014 period. Malaria is a major threat to public health. It is classified by the United Nations (UN) and the World Health Organization (WHO) as one of the three major infectious diseases. Hence, both organizations hope

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that by the year 2030, they can end the malaria epidemic (WHO, 2016c).

Health experts fighting against infectious diseases usually face additional challenges, such as climate change and environmental degradation, when combating malaria. For instance, it is expected that the East African highland area, which is malaria-resistant due to its high altitude, will become a new site for malaria transmission if global temperatures continue to rise (Niang et al., 2014; 1223). Similarly, unlike two other major communicable diseases, tuberculosis (TB) and human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS), which are transmitted through people, malaria can be transmitted via mosquitoes and people. This paper asks: Does natural resource abundance pose another challenge in combatting malaria?

In addition, though not the deadliest infectious disease, compared to TB and HIV/AIDS, malaria has the most reported cases of infection in the 2010s so far (214 million. TB: 10.4 million; HIV/AIDS: 36.4 million), according to the World Health Organization's (WHO) estimate (WHO, 2017). Children are extremely vulnerable to malaria. In 2015, children younger than 5 years of age accounted for nearly 8% of all malaria deaths. Every tenth child died of malaria in 2016 (Institute for Health Metrics and Evaluation, 2016; WHO, 2016c). Malaria also shows the greatest variation in reported cases among different regions. While, in Europe, no single infected case was reported to the WHO, as of 2015, Africa was, by contrast, home to 87.85% of total cases.[1] Furthermore, malaria is a major mosquito-borne viral infection, and in recent years, there have been more frequent and intense outbreaks of mosquito-borne infectious diseases. The outbreak of the Zika virus scared some participants away from the 2016 Rio Summer Olympics (Caiola, 2016; Gomez, 2016). Dengue fever is another viral infection that has grown substantially in recent decades. Understanding how to tackle malaria may have certain policy implications for other mosquito-borne diseases. All the aforementioned issues justify our selection of malaria as the case in this paper, rather than other communicable diseases.

The natural resource curse thesis states that countries relying on natural resources tend to have worse national development, yet previous studies examining the link between natural resources and national development focus mainly on political transition, economic development, or social stability (See discussions in Section 2). The impact of natural resources on public health and infectious diseases remains unclear. Knowing whether or not natural resources harm malaria control not only helps global communities to formulate appropriate strategies to combat malaria but also provides theoretical development on resource management, malaria control, and public health. In this paper, we argue that resource-rich countries tend to experience more cases of malaria infection and death than resource-poor countries.[2] Resource-rich countries lack strong incentives to combat malaria, since human capital is not the main channel through which the government receives revenues. These resource-rich countries also lack the capability to formulate and implement policies against malaria. Moreover, drilling, deforesting, and mining areas tend to have worse sanitary conditions, and become breeding grounds for malaria infection and death. These observations are empirically confirmed by a series of statistical tests.

In what follows, we begin with a literature review of natural resources and infectious diseases and other health conditions, and argue for why there is a natural resource curse for malaria. Section 3 presents a standard package of statistical tests, including variable and data descriptions, and model selection. Following a discussion of empirical results and the presentation of some robustness checks in Section 4, Section 5 offers a conclusion.

2. Natural resources, infectious diseases and other health conditions

The natural resource curse theory argues that natural resource abundance or dependence has detrimental effects on national development, like stalled democratic transition (Mahdavi, 2015; Ross et al., 2011), lagged economic development (Battaile, Chisik, & Onder, 2014; Sachs & Warner, 2001), and social instability (Collier & Hoeffler, 2005; Lee, 2018; Lujala, Gleditsch, & Gilmore, 2005), among other issues (like gender inequality; Ross, 2008; Simmons, 2015. Also see excellent reviews of the resource curse thesis by Deacon, 2011; Frankel, 2010; Ross, 2015).

Scholars who attempt to make a link between the natural resource curse and public health explore issues such as public health spending, disease, child mortality, and so on. de Soysa and Gizelis' (2013) study revealed that resource wealth is positively associated with the number of HIV/AIDS and TB (as robustness checks) cases. In addition, many papers concentrate on how resource wealth may affect health spending. Klautzer, Becker, & Mattke (2014) examinations of six Gulf Cooperation Council (GCC) member states found that although these oil-rich countries have similar individual income levels to those in the Organisation for Economic Cooperation and Development (OECD) states, their health expenditure per head and medical staff per 10,000 people are significantly lower. In Connell's (2006) explanation of why Nauru became a failed state, in terms of public health issues, the author attributed Nauru's high adult mortality rate, child diabetes, and lack of native medical staff to the over-exploitation of and reliance on phosphate.

In addition to studies on diseases, scholars also pay attention to how natural resources may affect public health

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[1] Of six WHO regions (Africa, Americas, South-East Asia, Europe, Eastern Mediterranean, and Western Pacific), the average value of malaria infected case is 35,675,000 with a standard deviation of 75,000,779. TB's two respective values are 1,731,667 and 1,740,071, and HIV/AIDS' are 6,110,000 and 9,619,220, respectively (calculated based on WHO, 2017).

[2] In this paper, the terms "resource-rich" and "resource-poor" mean more than just the degree of natural resource abundance. More importantly, they denote the degree to which a country relies on natural resources for economic production. While "resource-rich" means heavier dependence in terms of degree, "resource-poor" means less or even no dependence.

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spending. For example, Hong (2017) demonstrated that a 10-dollar per capita increase in oil led to a 1% decrease in health spending. This finding is consistent with Hong (2018); Zhan, Duan, & Zeng (2015) case study of China, showing that resource-rich prefectures or provinces tend to have lower health spending. Finally, Makhlouf, Kellard, & Vinogradov, 2017, Wigley (2017) found that child motility rates in resource-rich countries tend to be higher.

However, there are still some findings to support the observation that natural resources can contribute to better public health outcomes, or that there is no clear evidence that natural resources cause harm to health. Anshasy and Katsaiti (2015) found that overall, certain resources can lead to better health results, like lower diabetes and obesity rates. Sterck (2016) in his studies did not only refute the findings by de Soysa and Gizelis (2013) but also found that resource dollars provide more funds for public health and lead to better health outcomes. Stijns (2006), after replacing several natural resource indicators, found no affirmative associations between natural resources and public health. Instead, some were essential for the growth of developing countries. Overall, the inconclusiveness of the link to natural resources prevents us from unifying the explanations of the role of natural resources in public health.

We join the debate by arguing that resource-rich countries tend to have worse malaria control and prevention than resource-poor countries. In general, resource-rich countries tend to have worse malaria control and management because these countries tend to have less investment in human capital, rampant rent-seeking or corruption behaviors, and worse hygiene and environmental issues conducive to the outbreak of malaria.

The argument that natural resources may have a negative impact on the spread of, and death from infectious diseases, firstly relies on the reluctance of resource-rich countries to invest in infrastructure that is conducive to human capital accumulation (de Soysa & Gizelis, 2013; Wigley, 2017). One standard theory of political development argues that one goal of the state is to maximize revenues in order to survive politically (Bueno de Mesquita, Smith, Siverson, & Morrow, 2005; Levi, 1989; Chapter 2). Under normal circumstances, this utmost goal of political survival would encourage political leaders to pursue economic, social, and political advancement through the development of human capital, the taxation of people's economic activities, and then the provision of certain services to its people in return. These services include primary education, infrastructure, better living standards, and other public goods conducive to the further accumulation of human capital and the establishment of a larger tax base. Inversely, the general public holds the power to limit government functions by ensuring taxed income is used properly, or only for certain purposes and with their consent.

With respect to public health, the government has the role of keeping its human capital healthy. Therefore, it takes responsibility for monitoring vaccination and immunization, expanding and maintaining health stations, and providing health care to combat infectious diseases and consolidate human capital accumulation, for example. In resource-poor countries, governments tend to take public health more seriously. Table 1 presents descriptive statistics showing the relationship between malaria eradication/elimination and the average resource rents as a proportion of Gross Domestic Product (GDP) (World Bank, 2018c; WHO, 2016a).[3] Evidence shows that 50% (21 out of 42 if we include missing values) or even 70% (21 out of 30 if not) of states that eradicated malaria and reported zero malaria cases have average resource rents of 5% or less.

However, in certain resource-rich countries, government leaders lack strong incentives to invest in human capital, since they are able to receive non-tax revenues from natural resources to sustain their political survival.[4] Most natural resources are state-owned, and national revenues can be levied without taxing people's economic activities (or can be levied at the minimum level). By so doing, there is no urgent need for political leaders to maintain a tax base by generating a healthy environment for their subordinates to live and survive in. Scholarly evidence has proven that resource-rich countries tend to spend less on health (Cockx & Francken, 2014; Kim & Lin 2017). In contrast, without being taxed or taxed properly, the people have less bargaining power against the government when seeking to advance their quest for improved healthcare.[5] Moreover, because the general public has less say in how unearned income is distributed and spent (Busse & Gröning, 2013; Ross, 2001), they depend on the government decision to reallocate resource dollars to the health department, if at all, to support all possible measures against malaria. This dependence increases the uncertainty of efforts against malaria.

The first argument is that resource-rich countries lack incentives to maintain a healthy environment conducive to development. In addition, natural resources may also impede the establishment of the government's capability to formulate, implement, and evaluate health measures, even if they are willing to do so.

Various scholars have stressed the importance of state capacity in national development, and have indicated a variety of state capacity dimensions, such as rule of law, taxation ability, bureaucratic capability, military coercion, and economic development (Arbetman & Kugler, 1998; Besley & Persson, 2009; Hanson & Sigman 2013; Hendrix, 2010). Combating malaria now requires the government to handle more intricate and complicated measures, such as coordinating regional, international, and national actions, monitoring the implementation of vaccination, distribut-

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[3] A further description of total natural resources rents is introduced in Section 3's Independent variable subsection.

[4] There is no denying that in some resource-rich countries, political leaders spend their resource dollars smartly, like in Saudi Arabia and Venezuela, to sustain political life by satisfying people's needs, such as social welfare, free education, and free healthcare. Yet, overall, more resource-poor countries are erased from the malaria list than resource-rich countries, as we have already seen in Table 1.

[5] This is also what Ross (2001 called the "taxation effect," that, by avoiding taxing people or reducing their tax burden intentionally or unintentionally because of oil revenues, the general public will be less likely to request accountability from their government. Levi (1989); McDonald (2007) reach similar observations on taxation and government accountability.

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Table 1
Average total natural resource rents as % of GDP and number of states that eradicated malaria or reported 0 cases, 1955–2015.

	1955–1972	1972–1987	2007–2015	2014–2015
Eradication	✓	✓	✓	
0 Cases				✓
Average Resource Rents				
0.00–5.00%	6	5	3	7
5.01–10.00%	1	0	0	1
10.01–15.00%	0	0	0	1
15.01–20.00%	0	0	0	1
20.01% and above	0	1	2	2
N/A	9	2	0	1
Total	16	8	5	13

Source: World Bank (2018c); WHO (2016a).

Note: Periods are defined by WHO (2016a; Table 1, pp. 4–5). The average resource rents, when eradicating malaria or reporting 0 cases, are taken from each period. No states were certified by the WHO on malaria eradication between 1987 and 2007. Countries must report 0 cases for 3 consecutive years to be qualified as malaria-free. N/A denotes that no resource rents data were available for the corresponding period. A detailed list of countries is provided in Appendix.

ing health expenditure and foreign aid properly, and so on, as detailed in WHO (2015; 11–21). Without a strong commitment to combating malaria, political leaders with affluent natural resources may put their people in danger.

Saudi Arabia and Equatorial Guinea can be taken as examples. The Kingdom's spending on malaria is the highest within the Middle East, and relies exclusively on their own domestic funding, while the Republic is ranked second highest in Western Africa, and foreign assistance only constitutes a tiny portion of it (WHO, 2016b, 72, 79). However, in 2013, Equatorial Guinea's infection rate doubled compared to 2012 (14% —>28%), and Saudi Arabia witnessed a 100% increase in the rate of infection between 2010 and 2015 (Asquino, 2015; WHO, 2016b, 79). In other words, if health expenditure largely comes from natural resources, then spending alone on malaria does not make these two societies healthier.

What causes deeper concern here is that, in these countries, natural resources are more likely to strengthen rent-seeking and corruption behaviors, and weaken state capability or the quality of governance. For example, using pesticide is a direct way to kill mosquitoes and larvae, but it also causes damage to humans and animals if they inhale it or touch pesticide-sprayed items. Mosquitoes may also become pesticide-resistant if these chemicals are used too often. Does the government set aside sufficient funding to conduct relevant research into these issues? Do they convene individuals and national, regional, and international agencies to coordinate anti-malaria programs, and evaluate them on a regular basis? These all require a government to undertake efficient action. Yet, in addition to a series of studies already proving that natural resources undermine capacity establishment and strengthen rent-seeking behaviors (Beblawi, 1987; Oskenbayev, Yilmaz, & Abdulla, 2013; Sala-i-Martin & Subramanian, 2013), empirical evidence (see Fig. 1) also shows a negative relationship between a series of governance indicators (Kraay et al., 2010; Marshall & Elzinga-Marshall, 2017; Transparency International, 2017)[6] and resource rents as a fraction of GDP (World Bank, 2018c) during the period 2000–2015. Uganda is involved in a series of funding scandals, including selling anti-malaria drugs at higher prices (5,000 Ugandan shillings) than the recommended 3,500 Ugandan shillings, the theft of at least 1.6 million US dollars from the 45.3 million disbursed by The Global Fund to Fight AIDS, Tuberculosis, and Malaria (Global Fund) by government officials and community workers through "misappropriation, forgeries, nepotism, and lack of accountability" (Ainebyoona, 2016; Cohen, 2008; Mackey and Liang, 2012;). Similar actions, like fund embezzlement, fraud, and the sale of drugs on the black market were also found in other resource-rich African countries, such as Nigeria, Mauritania, Zambia, and Mali (Boseley, 2011; Ogundipe, Obinna, & Olawale, 2016), leading to grant suspensions, or even cancellations.[7]

Third, mining, deforesting, and oil drilling activities can also cause serious outbreaks of malaria in resource-rich countries. These activities usually lead to environmental degradation, such as deforestation, air pollution, greenhouse gas emissions, and water pollution, which are conducive to the survival and adaptation of mosquitoes (Kweka et al., 2016; Nkya, Akhouayri, Kisinza, & David, 2013; Vittor et al., 2009). Labor-intensive mining activities increase migration to, and population density around, mining areas (Castellanos et al., 2016; Knoblauch et al., 2014). Dense population provides access to disease transmission and higher mortality rates. This rapid expansion of population also leads to poor hygiene conditions, which may

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[6] We use three governance indicators: WorldGovernance Indicators(WGI, Kraay et al., 2010), Corruption Perceptions Index (CPI, Transparency International, 2017), and State Fragility Index (SFI, Marshall & Elzinga-Marshall 2017). For WGI, this is a score between ±2:5, and higher values denote more political capability. We take the average value of six subcategories of WGI: political accountability, political stability, regulatory quality, rule of law, control of corruption, and government effectiveness to generate the overall WGI score. SFI uses a 0–25 ordinal scale, and higher values denote more fragility. Finally, CPI uses a scale of 0–100, and higher values show less corruption. Because higher CPI and WGI values denote more cleanliness, and more political capability, respectively, to make interpretations consistent, we converted the SFI score to make higher SFI values denote less fragile.

[7] The rationale behind widespread embezzlement and fraud with foreign aid happening in Africa is that most global funding goes to Africa. In other regions, like Asia and South and Central America, central governments take the main responsibility for funding malaria elimination programs (Pigott, Atun, Moyes, Hay, & Gething, 2012).

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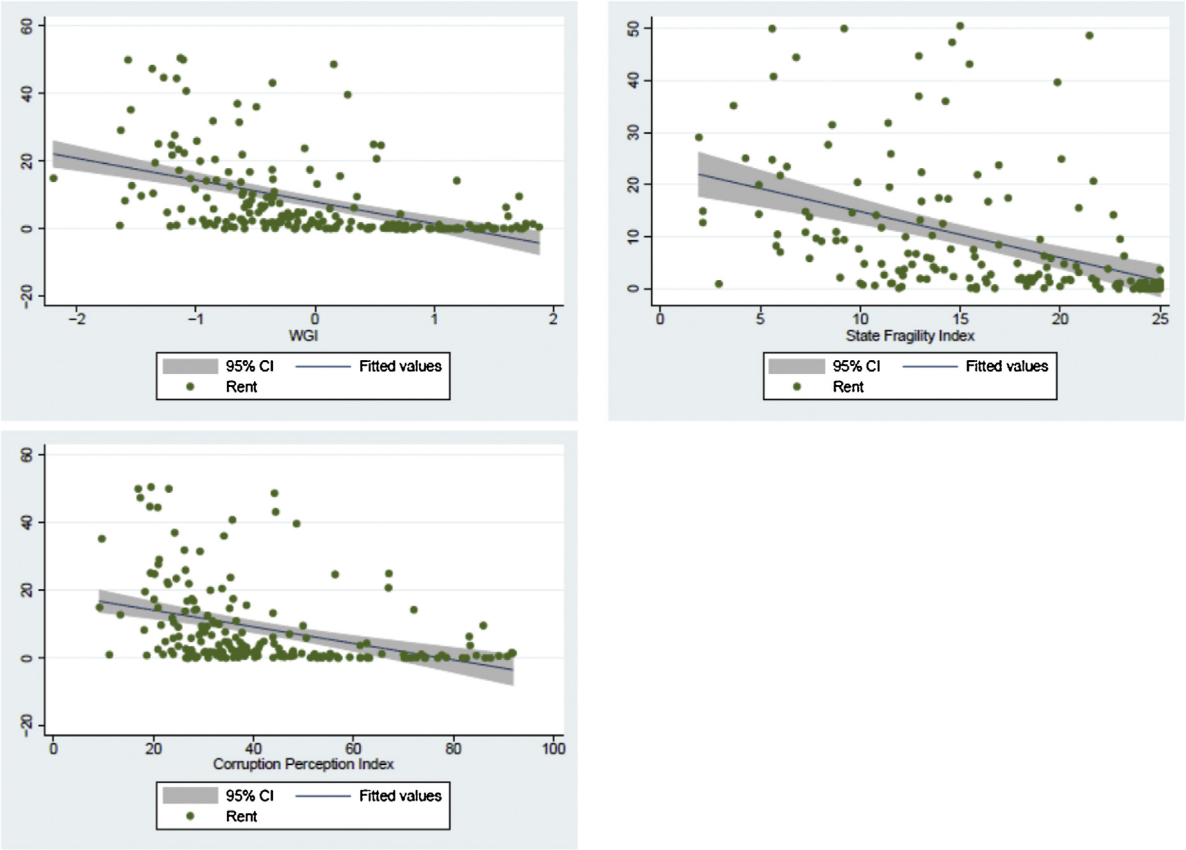

Fig. 1. The link between total resource rents and WGI (upper left), SFI (upper right), and CPI (bottom left), 2000–2014.
Source: Kraay et al. (2010); Marshall, & Elzinga-Marshall (2017); Transparency International (2017); World Bank (2018c)

in turn bring up malaria, if the government is not well prepared and is unable to provide adequate health measures to combat infectious diseases. In Sub-Saharan Africa and Southeast Asia, a substantial proportion of malaria cases are found in resource-rich countries. Oil-rich Nigeria alone contributed 55% of estimated cases of infection to the region of 48 states, followed by Côte d'Ivore and Mali, both of which have lucrative extractive industries. Indonesia and Myanmar, with their abundance of natural resources, also accounted for most of the malaria cases in Southeast Asia (WHO, 2016c; Annex 2). In Latin America, nearly all malaria cases reported by Brazil, Venezuela, and French Guiana were found in the Amazonian gold mining area, where economic opportunities attract poor people to migrate and dwell, in order to dig gold, legally or illegally (de Oliveira, dos Santos, Zeilhofer, Souza-Santos, & Atanaka-Santos, 2013; Douine et al., 2018; Eisler, 2003; Nobrega, 2014).

In short, in resource-rich countries, governments' reluctance to deal with malaria, rampant rent-seeking behavior, low institutional quality in formulating and implementing malaria-related policies, and lack of sufficient infrastructure, health stations, and equipment to improve sanitary conditions in mining areas all contribute to larger numbers of cases of malaria infection and death. In the next section, the authors will conduct empirical analysis to identify the relationship between malaria and natural resources. We further illustrate the effects of natural resources on malaria by showing the aforementioned flows in Fig. 2.

Finally, the core hypotheses of this paper are stated below:

H1. If countries rely more on natural resources for economic production, then they tend to have a higher number of infected cases of malaria. (1)

H2. If countries rely more on natural resources for economic production, then they tend to have a higher number of deaths from malaria. (2)

3. Variables, data, and methods

3.1. Dependent variables: infected and death cases from malaria

The dependent variables examined in this paper are the (logged) number of reported infected (ln Case) and death (ln Death) cases from malaria. Data are retrieved from WHO's Global Health Observatory (GHO) data repository, and cover the 2000–2014 period.[8]

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[8] World Bank (2018c) also reports malaria data, namely incidence of malaria per 1,000 people at risk. Yet this dataset only has 258 data points,

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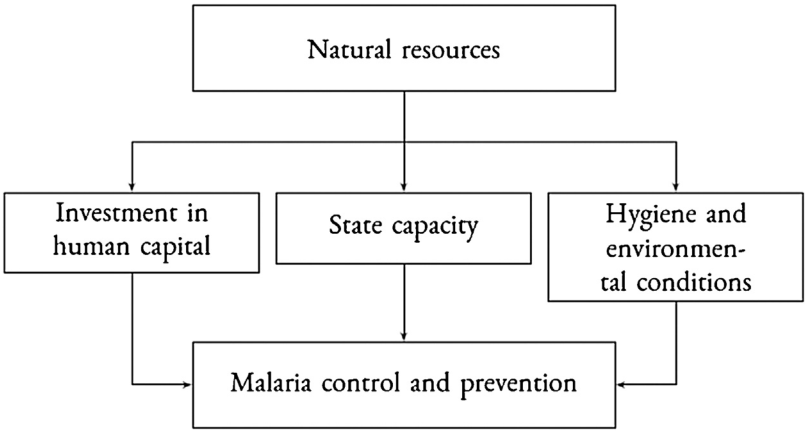

Fig. 2. The flow chart of the effects of natural resources on malaria control and prevention.

A total of 107 political entities are reported by WHO (2017) as having at least one malaria infection and/or death case within this period, but there are great variations among these states. While since 2000 Azerbaijan, El Salvador, and Uzbekistan have no reported death cases, the Democratic Republic of Congo (DR Congo) is the only country that reported more than 12,000 cases every year from 2004 to 2014. In addition, Mozambique alone recorded nearly 7.2 million infected cases in 2014, but its population size was only roughly one-third of DR Congo (which reported 9.96 million cases), and one-seventh of Nigeria (7.82 million) in the same year. Finally, most infected and death cases are concentrated in Africa.

3.2. Independent variables: natural resource rents and depletion

To test the impact of natural resources on malaria infection and death cases, we apply The World Bank's two natural resource measures in the World Development Indicators (WDI), namely total natural resource rents as a fraction of GDP (Rents), and natural resource depletion as a fraction of adjusted Gross National Income (GNI) (Depletion).[9]

By definition, total natural resource rents are the total differences between commodity prices and production costs. These natural resource commodities include oil, gas, mineral, coal, and forest. This indicator is very often used as a proxy for natural resource abundance, if not otherwise noted. Moreover, resource rents also capture the concept of the "rentier state," that the country relies heavily on external rents, is the only recipient of such rents, and plays a decisive role in distributing such rents (Beblawi, 1987). We can also view this indicator as proxy for resource abundance.

We also examine how natural resource depletion may shape the malaria landscape. Natural resource depletion is the combination of unit forest rents times the excess of roundwood harvest, the ratio of energy (coal, oil, and gas) and mineral stock of values to the remaining reserve lifetime. This is an indicator of how fast countries consume their natural resource endowment to generate national income. Yet this depletion also increases the difficulty for states to meet sustainable development goals, since most natural resources are non-renewable in nature. We consider this as an alternative proxy measure for natural resource dependence.

3.3. Control variables

We also include a set of control variables to test how these variables affect malaria infection and death rates, including economic, demographic, political, health, and geographical variables. We briefly describe each variable in turn.

The first four variables are all retrieved from The WHO's (2018c) WDI to account for how economic and demographic factors influence cases of malaria infection and death. In general, economic development or wealth is positively associated with better health conditions and infectious disease control, as argued in Nundy et al. (2011); Tusting et al. (2016); Wood, McInturff, Young, Kim, & Lafferty, (2017). GDP per capita is measured in current US$ (ln GDP pc), and trade as a percentage of GDP is also referred to as trade openness (to the world) (Openness). While dense population should be associated positively with our dependent variables, having more people residing in urban areas may provide a method to eliminate malaria as cities generally have more access to the public health system and knowledge of malaria. We select population density and the people residing in urban areas as a proportion of total population to test demographic factors of malaria incidence and death (Density, Urbanization).

Moreover, politics plays a role in determining a state's overall health status by allowing the possibility of provid-

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which is roughly one-fifth of the datasets we used in this paper. We decided not to use this dataset.

[9] As renowned resource expert Ross (2015) mentioned, there is no single best indicator that can measure or approximate natural resources directly. Therefore, we have natural resource depletion as an alternative indicator of natural resources to examine the relationship between malaria cases and natural resources.

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ing public health goods, as some scholars argued (Bueno de Mesquita et al., 2005; Gizelis, 2009; Hanson 2014). For political institutions, we select Freedom House (2017)' *Freedom in the World*, which evaluates a political entity's annual overall political performance within the 1973–2017 period. We simply take the average value of Freedom House's two major categories, political rights and civil liberties, to generate a polity score (Polity) of 1–7. To interpret results consistently, as with other variables, we subtract all average values from 8 to make the score of 1 the least free, and 7 the freest.

Two health-related variables are health expenditure as a fraction of GDP (Expenditure), and foreign resources for health as a fraction of total health expenditure (Foreign). Both variables are taken from the World Bank (2018c). As increasing health expenditure is, so far, one of the most straightforward routes to eliminating malaria, we wonder if foreign aid also plays a critical role in doing so.

Finally, data for three climate and geographical variables (Tropical, Latitude, ln Altitude) are reached from Geiger and Pohl (1954); Matthews (1983); Nunn and Puga (2012). Evidence from natural science has proven that geographical location, elevation, and climate are the main channels of malaria transmission (Niang et al., 2014 Niang et al., 2014; 1222–1223; Sachs, Mellinger, & Gallup, 2001). We add these three variables together to see how they impact malaria transmission and death. Tropical denotes the proportion of a country that is tropical climate, and Altitude (logged) is the mean elevation measured in meters above sea level.

3.4. Model selection

There are two major statistical methods applied in this paper, based on the data structure and the different types of dependent variables. First, with regard to the data structure, because the datasets we retrieved for our dependent variables cover 107 political entities' malaria data during the 2000–2014 period, our data structure is time-series cross-sectional in nature. We apply the time-series cross-sectional model with random effects (RE) to test the relationships between different natural resource indicators and cases of malaria infection and death. The choice of the RE model is based on a variety of methodological reasons.

First, the RE model allows us to model variables "measured at the higher level" (Bell & Jones, 2015; 135–136), and in this paper "the higher level" is the country.[10] Second, the RE model makes predictions about out-of-sample observations possible, and when the sample size is relatively small, the RE model is preferable (Clark & Linzer, 2014). Finally, geographical and climate variables are time-invariant, and the RE model allows us to estimate these time-invariant variables' effects on our dependent variables (Baltagi, 2008; Bell & Jones, 2015; 136).

In addition, we take the issues of endogeneity and reverse causality into consideration. To avoid these issues, we lag all dependent variables by one year. All things combined, the RE model in this paper is:

$$Malaria_{it+1} = \alpha + X'_{it}\beta + \varepsilon_{it} \tag{3}$$

where i stands for country and t time here, and X' denotes all explanatory and control variables. $\varepsilon_{it} = \mu_i + \lambda_t + \nu_{it}$, that μ_i is unobservable individual effects, λ_t unobservable time effects and ν_{it} is the remainder disturbance.[11]

We also apply the ordinary least squares (OLS) model for comparison, since our dependent variables are continuous after logging.[12] It is:

$$\mathrm{Malaria_i} = \alpha_i + \sum_{i=1}^{n} \beta_i x_i + \varepsilon_i \tag{4}$$

where the subscript i, t stands for country and year respectively, x stands for all independent and control variables, α is the intercept, and ε is the error term. Both models are conducted with robust standard errors.

4. Statistical results

Before we discuss statistical results, Table A1 in the Appendix (Supplementary data) provides summary statistics, including mean values, standard deviations, maximal and minimal values, and the number of observations. Now we turn to discuss Tables 2 and 3, in which all statistical results are reported.

Models 1–4 within Table 2 estimate the RE model that controls all predictors for economic, demographic, political, geographical and climate, and, finally, health expenditure. Models 1 and 3 have results when we apply Rents as the main explanatory variable, and Models 2 and 4 when Depletion is applied. In the first two models, the respective logged number of reported infected cases of malaria is 0.0202 and 0.0327 higher when natural resource rents and natural resource depletion are 1% higher, respectively. In the second half of the models, both natural resource indicators drive higher number of death cases (logged) by 0.0238 and 0.0272, if Rents and Depletion are 1% higher, respectively. All of these statistical results are statistically significant at the 0.05 significance level or above.

We now turn to Table 3. Four OLS models, from Model 5–8, lend further support to our findings in Table 2. In general, all these results are statistically significant at the 0.001 level, and have similar negative impacts on infection and death cases from malaria, holding all other variables con-

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[10] Conventional practice suggests the application of the Hausman test to decide the choice between the RE and the fixed effects (FE) model. Yet scholars do not suggest this test as they simply view it as the standard selection of models, or as the endorsement of the FE model if failing to reject the null hypothesis (Baltagi, 2008; Clark & Linzer, 2014).

[11] We also took the issue of serial correlation into consideration. Yet, as Baltagi (2013) argues, this is only the case when the time period is sufficiently long, around 20 years or more. Since our investigation period is 15 years, the influence of autocorrelation should not be a serious issue.

[12] We conducted the Breusch-Pagan Lagrange Multiplier (LM) test to decide whether the RE or OLS model should be selected as the main one. The null hypothesis of the LM test is that no variances exist across observations. The test result gave us the probability > chibar(01) =0.0000. Therefore, we can reject the null hypothesis that there is no variance across units, and therefore the selection of the RE model is preferred.

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Table 2
Natural Resources and (Logged) Infection and Death Cases from Malaria, 2000–2014 (RE).

	(1) ln Case	(2) ln Case	(3) ln Death	(4) ln Death
Rents	0.0202* (2.24)		0.0238*** (3.67)	
Depletion		0.0327** (2.99)		0.0272*** (3.55)
ln GDP pc	−0.911***(−7.60)	−0.920***(−7.47)	−0.698***(−8.20)	−0.704***(−8.02)
Openness	0.00231 (0.89)	−0.000266 (−0.10)	−0.00760***(−4.13)	−0.00714***(−3.84)
Density	0.00321 (1.86)	0.00289 (1.65)	−0.00167 (−1.35)	−0.00193 (−1.53)
Urbanization	0.00723 (0.54)	0.00635 (0.46)	−0.0353*** (−3.43)	−0.0332**(−3.11)
Polity	−0.00629 (−0.07)	0.0180 (0.20)	−0.00808 (−0.14)	−0.0159 (−0.27)
Expenditure	-0.141* (-2.93)	−0.158*(−3.12)	−0.02841 (−0.90)	−0.0352 (−1.05)
Foreign	0.0601*** (8.58)	0.0597*** (8.16)	0.0172*** (4.07)	0.0157*** (3.53)
Tropical	0.0268*** (3.78)	0.0256*** (3.56)	0.00762 (1.35)	0.00714 (1.24)
Latitude	−0.0559*** (−3.64)	−0.0556*** (−3.57)	−0.0575*** (−4.33)	−0.0574*** (−4.26)
ln Altitude	0.854** (2.67)	0.770* (2.38)	−0.461 (−1.66)	−0.480 (−1.70)
Constant	8.708*** (3.66)	9.621*** (3.95)	14.36*** (7.16)	14.61*** (7.16)
Observations	1,108	1,075	926	899
No. of States	96	96	84	84
Wald χ^2	221.21***	212.66***	275.36***	263.33***
R2(between)	0.4804	0.4818	0.5939	0.5852

t statistics in parentheses.
* p < 0:05.
** p < 0:01.
*** p < 0:001.

Table 3
Natural Resources and (Logged) Infection and Death Cases from Malaria, 2000–2014 (OLS).

	(1) ln Case	(2) ln Case	(3) ln Death	(4) ln Death
Rents	0.0327*** (4.66)		0.0705*** (12.27)	
Depletion		0.0389** (4.34)		0.0806*** (11.27)
ln GDP pc	−0.508*** (−4.46)	−0.521*** (−4.46)	−0.780*** (−8.57)	−0.862*** (−9.22)
Openness	−0.0212*** (−9.23)	−0.0192*** (−8.16)	−0.0189*** (−10.84)	−0.0163*** (−9.27)
Density	−0.00000446 (−0.01)	0.000135 (0.23)	−0.00148*** (−3.50)	−0.00179** (−4.18)
Urbanization	−0.0348*** (−5.40)	−0.0278*** (−4.30)	−0.0385*** (−7.54)	−0.0295** (−5.65)
Polity	0.130* (1.98)	0.164* (2.48)	0.152** (3.17)	0.175*** (3.50)
Expenditure	−0.140** (−3.14)	−0.172*** (−3.81)	−0.174*** (−5.22)	−0.221*** (−6.44)
Foreign	0.0361*** (4.87)	0.0426*** (5.58)	0.0133** (2.67)	0.0190*** (3.64)
Tropical	0.0263*** (11.26)	0.0255*** (10.80)	0.00538*** (3.00)	0.00478** (2.58)
Latitude	−0.0399*** (−7.54)	−0.0380*** (−7.11)	−0.0527*** (−11.48)	−0.0503*** (−10.69)
ln Altitude	0.447*** (4.30)	0.463*** (4.35)	−0.523*** (−6.11)	−0.504*** (−5.72)
Constant	11.89*** (11.18)	11.43***(10.55)	16.34***(20.20)	16.57***(19.69)
Observations	1,108	1,075	926	899
R^2	0.4254	0.4239	0.5650	0.5588
Adjusted-R^2	0.4197	0.4179	0.5597	0.5534
F	73.78***	71.11***	107.91***	102.15***

t statistics in parentheses.
* p < 0:05.
** p < 0:01.
*** p < 0:001.

stant. Therefore, statistical results in both tables confirm that a "natural resource curse" does exist for malaria cases.

By using either the RE or OLS model, statistical results have shown that they are consistent with de Soysa and Gizelis (2013, 2016), that natural resources tend to have a negative impact on the spread of communicable diseases. In addition, they also extend to the study of death cases, and find similar associations.

Now we turn to the statistical results of all control variables, and explain each in turn. With regard to the first set of economic variables, ln GDP pc and Openness, coefficient signs generally show a negative association between economy and malaria. Higher personal income (logged) drives lower numbers of infection and death cases (logged) at the 0.001 error level when holding other variables at their means.

On the other hand, trade openness is also negatively correlated with malaria, except in the case of the first model. In other words, economic well-being, and to a lesser degree trade openness, help contain malaria transmission and death. The latter finding may also contribute to the debate around globalization and infectious diseases about whether openness to the world is detrimental to public health management within sovereign territories (Ollila, 2005; Pang & Guindon, 2004; Perrings, 2015).

Density and Urbanization reach mixed results in contrast to those of economic variables, and with less strength of statistical significance. Having more people dwelling in cities does not necessarily eliminate the transmission of malaria and death from it. This inconclusiveness is even more apparent when we shift to population density, holding all other variables constant. This pattern is also seen

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in the Polity variable. For political institutions, results are only statistically significant at the 0.05 level or higher when the relationship is negatively correlated (Models 5–8). Yet, these results are consistent with de Soysa and Gizelis (2013 findings that regime type alone does not explain public goods provision and better malaria management. Thus, a further investigation of the two is merited.

Results for health expenditure and foreign assistance are highly contrasting. While higher expenditure on health as a proportion of GDP generally lowers infected and death cases of malaria, foreign assistance tends to worsen efforts at malaria eradication. By contributing 1% more to health expenditure, states can lower their infected cases in a range from 0.140 to 0.72 (Models 1, 2, 5, and 6), and death cases from 0.0281 to 0.221 (All other models) when holding remaining variables constant. Most results reach at least the significance level of 0.01 or higher, with the only exceptions being Models 7 and 8. In contrast, receiving foreign assistance for malaria prevention and control has negative consequences at the 0.01 significance level and above. This finding perhaps sheds new light on whether foreign aid can remove malaria, while the scenarios listed in Section 2 are commonly seen in certain resource-rich countries.

Finally, while tropical climate and latitude generally gain the expected results and signs that most scholars found in prior research, the average (logged) elevation has distinctive results for infection and death. Living at higher altitudes increases the logged number of malaria infections, but reduces that of deaths when the average elevation is increased by one unit.

We also noticed that because coefficients depend largely on the mean and variance of independent and control variables, statistical results in both Tables 2 and 3 are not directly comparable. To remedy this issue, we standardized all coefficients and presented results in Tables A3 and A4 in the Appendix (Supplementary data). Here, we focus exclusively on the effects of two natural resource indicators. Summary statistics for all standardized variables are presented in Table A2 in the Appendix (Supplementary data).

We found that in Table A3, if we increase Rents and Depletion by 1 standard deviation, the logged infected rate from malaria will increase by 0.081 and 0.095, respectively, while the logged death rate from malaria will increase by 0.118 and 0.098, respectively. In Table A4, if we follow the same step, the logged infected rate from malaria will increase by 0.130 and 0.115, respectively. Similarly, if we increase both of these natural resource indicators by 1 standard deviation, the logged death rate from malaria will increase by 0.307 and 0.280, respectively.

Overall, the effects of two alternative natural resources on malaria indicators are roughly the same. These findings largely confirm the argument that natural resources have negative effects on malaria control and management.

4.1. Robustness checks

We also conduct robustness checks to see if our estimation results hold up after substituting certain alternative indicators. In so doing, we firstly replace the main explanatory variable with natural resource exports as the proxy for natural resource dependence (Exports). This indicator is the combination of two variables within the WDI dataset, namely fuel exports, and ore and metal exports as proportions of merchandize exports (World Bank, 2018c). Summary statistics are presented in Table A5 (Supplementary data), and empirical results are presented in Table A6 in the Appendix (Supplementary data).

As results have demonstrated, countries tend to have more cases of infection and death from malaria if their merchandize exports depend more on natural resource commodities (Though failing to reach statistical significance at least at the 0.05 level, Model 3's p-value is as low as 0.067). This finding is consistent with those natural resource variables' results in Section 4. Similar results are also found in economic, health expenditure, and two geographical and climate sets of variables, while demographic, political, and elevation variables remain inconclusive.

Second, we replaced the number of death cases with Murray et al. (2012)' global mortality data (ln DeathM). This dataset was released in 2012 and covers the data from 1980 to 2010, though it does not report infection cases. We make the starting year of investigation consistent with this paper (2000) and the end year 2010, and also lag all independent and control variables by one year. Results are listed in the Appendix's Table A8 (Supplementary data).

Statistical results largely confirmed that, after replacing the original malaria dataset, overall various natural resource indicators still have their negative impacts on the number of death cases from malaria, with the only exception being Model 3. Though the first three models fail to attain statistical significance, and in Model 3 the coefficient sign is negative, Models 4–6 have statistically significant results at the 0.001 level, holding all other variables constant.

With regard to control variables, the degree to which people reside in urban areas is negatively associated with death cases from malaria. A one percent increase in urbanization can have 0.0271–0.0727 (logged) number of death cases fewer at the significance level of 0.001, holding all other variables constant. In addition, while the effects of health expenditure become inconclusive, higher elevation can mean fewer deaths from malaria.

Third, we also consider if our estimation results are affected by any influential data point. To minimize the influence of outliers without dropping observations, which may raise the concern of selection bias, we apply the cluster-robust Huber–White standard errors. Statistical results with robust standard errors are presented in Tables A9 and A10 in the Appendix (Supplementary data). We mainly focus on explaining three natural resource indicators.

As we can see, by judging their coefficient signs, countries tend to experience higher numbers of infection and death cases from malaria across all different models with different natural resource indicators. In Tables A9 and A10, natural resources lose their statistical significance in some models because their p-values are greater than 0.100, but others remain statistically significant at the 0.05 level or above.

We also wondered if the reduction in malaria deaths and transmission is the product of better living conditions.

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Individual countries may be able to tackle malaria issues because they are more advanced than other countries. To test this, we separated all states by their Gross National Income (GNI) per capita based on the World Bank (2018b)'s Atlas Method and divided them into high-income and non-high-income groups, keeping the first as high-income economies. This is a dummy variable (Emerging). Countries are coded as 1 if they were defined as high-income economies by the World Bank (2018b) and 0 otherwise. The results are presented in the Appendix (Table A11) (Supplementary data). Summary statistics of this dummy variable (frequency distribution) are presented in Table A5 in the Appendix.

The statistical results showed that the effects of resource indicators on malaria were still negative and statistically significantly different from 0. Though the effects of Emerging are not significant, all coefficients carried the expected signs without influencing the effects of resources on malaria. In other words, statistical results further confirm the impact of natural resource rents on malaria deaths and infected cases.

Finally, we also considered the effects of climate factors on malaria, adding two additional factors to the model-annual average temperature (Celsius) and rainfall (mm). Data are taken from the World Bank (2018a)'s Climate Change Knowledge Portal. Since this portal offers monthly but not annual data, we simply took the average value for each country-year. Summary statistics of these two variables are presented in Table A12 in the Appendix (Supplementary data).

The statistical results further confirmed that the effects of resource indicators remain statistically significant after adding climate variables in the model. However, these two variables demonstrate opposite effects on malaria. While higher precipitation is associated with lower malaria death and infected cases, higher average temperature leads to more serious consequences on malaria management. Though only some results are significant statistically, this finding provide us further policy implications on examining the associations between climate change and malaria management.

Overall, statistical results as presented in this Section all confirm that a country's dependence on natural resources is positively associated with the number of infected cases and deaths from malaria. These results further confirm that a natural resource curse does exist in the public health field.

In conclusion, we found that by replacing our indicators of main explanatory and outcome variables, or by suppressing the influence of influential points, the negative relationship between natural resources and malaria infection and death still holds. Overall, these confirm that either natural resource abundance or domestic dependence, or export dependence, has deeper and more negative impacts on malaria prevention and control.

5. Conclusion

The recent discussions of natural resources and their possible impact on infectious diseases has triggered scholarly attentions, yet the consensus on such an impact rarely exists, and results are mixed at best. In this paper, we aim to join the debate by examining malaria, the most infectious disease in recent years. We argue that natural resources lead to more cases of infection and death from malaria. Countries which rely heavily on abundant natural resources tend to experience malaria transmission and death. Within these countries, political leaders' reluctance to invest in infrastructure conducive to human capital, widespread rent-seeking behaviors, and worse hygiene conditions in mining, drilling, and deforesting locations all contribute to the spread of, and death from, malaria. In other words, a natural resource curse does exist for communicable diseases.

To gain empirical support for the argument above, we conducted several quantitative analyses by applying the data of malaria death and infection cases, natural resource indicators, and other variables of the 2000–2014 period, covering 107 countries. Evidence shows that, when countries rely on natural resources' contributions to national wealth, they tend to experience more cases of malaria. Initial findings also gained further support when we substituted original indicators with different ones, for both outcome and explanatory variables, such as resource exports and the malaria mortality dataset. Our findings are largely consistent with previous studies, that resource endowment is negatively associated with public health-related issues, like HIV/AIDS, infant mortality, and health expenditures (de Soysa & Gizelis, 2013, 2016; Cockx & Francken, 2014; Kim & Lin 2017; Wigley, 2017).

Additionally, higher per person income is positively associated with better malaria management. This is possibly because individuals may have more financial resources for healthcare. However, there is no conclusive link between political institutions and malaria control and prevention. The argument that democracy is superior to dictatorship in providing public goods, at least, is not seen in this paper. Public health expenditures alone, though not statistically significant in this paper, can still be an important contribution; however, this does not align well with foreign medical assistance, since medical goods and grants may be misallocated. Climatic and geographical factors affect malaria management in different ways, and these results have practical policy suggestions when facing global warming and climate change.

However, this does not mention that resource-rich countries cannot escape the "malaria trap." Instead, as Table 1 has already demonstrated, nine countries that reached the malaria eradication goal, the last stage of malaria control, had a resource rent of 5% or more. In addition, according to the WHO, there were 21 countries that may have the potential to eliminate malaria by 2020 (WHO, 2016b, 12, Table 2). Among them, four countries' (Saudi Arabia, Suriname, Algeria, and Bhutan) resource rents as a portion of GDP were also higher than 5% as of 2015 (World Bank, 2018c). However, since they account for a minority of malaria eradication countries, it requires more effort to combat this mosquito-borne disease. Below, we will offer theoretical, policy and practical implications from this paper's arguments and findings.

Firstly, the negative effects of natural resources on malaria transmission and death as found in this paper support the existence of the resource curse in infectious

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disease management. Moreover, these findings, along with what previous studies have already revealed (as discussed in Section 2), clearly demonstrate that the resource curse does not only apply to political, economic and social issues, but also to the field of public health. In other words, with a variety of theoretical development, discussions and empirical tests, the resource curse thesis now seems more generalizable. If not handled properly, natural resources certainly pose substantial challenges to national development.

Secondly, though the existence of the resource curse in malaria management is somewhat less encouraging, it may also provide certain policy implications for natural resource and malaria management, if resource-rich countries wish to be free from both illnesses. With regard to natural resources, countries should strengthen their management of natural resources and the degree of transparency in resource wealth management. The Extractive Industry Transparency Initiative (EITI) launched in 2003 may be a solution. The Initiative aims to increase transparency and governance of the extractive sector by disclosing information about every activity between countries and the mining corporations. As of February 2018, 51 countries have joined the EITI to promote openness and accountability of the natural resource management (Extractive Industries Transparency Initiative, 2018). Other proposals like private ownership (Luong & Weinthal, 2006) of natural resources, direct deposit of resources revenues to citizens (Diamond & Mosbacher, 2013) may also be workable if implemented appropriately.

Thirdly, policy practitioners who want to unhook the link between natural resources and malaria should consider paying attention to human capital accumulation, rather than government revenues from natural resources. They can also reduce the risk of malaria by diversifying industries. Industrial diversification can reduce reliance on natural resources as the main source of the national economy and prevent populations from being concentrated in mining and drilling areas (Ahmadov, 2014; Cuberes & Jerzmanowski, 2009; Luong & Weinthal, 2006). This encourages the government to pay more attention to human capital in both quantity and quality dimensions. The former requires countries to increase the pool of human capital, while the latter asks them to keep human resources healthy. This explains why industrial diversification is merited in combating malaria.

Finally, though this paper focuses on malaria, a similar research design should apply well to other mosquito-borne viral infections, such as dengue fever and Zika. However, we need to be more confident that there is a link between natural resources and infectious diseases, and only when we can better handle the resource curse can we improve the public health of the world and individual countries.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.soscij.2018.08.009.

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