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Malaria and protective behaviours: is there a malaria trap?

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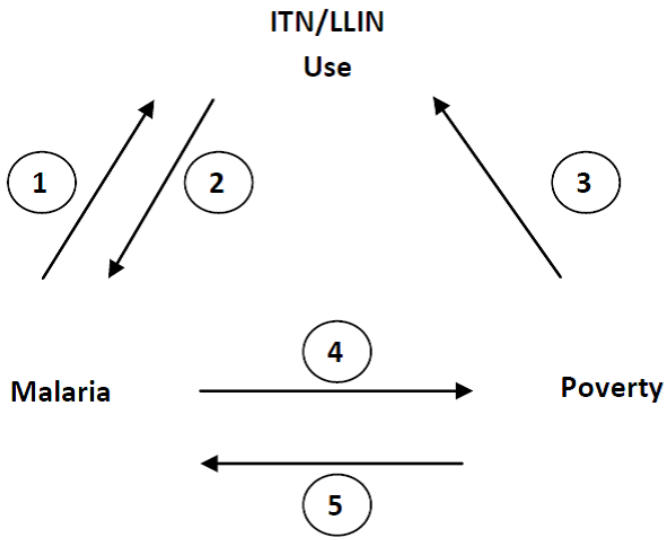
Introduction

- **The relationship between ITN use, malaria and poverty**



(1) Malaria risk should influence the use of an ITN/LLIN: prevalence elastic behavior.

(2) The efficiency of ITN/LLINs to reduce malaria prevalence is established.

(3) Poverty is certainly influencing ITN/LLIN use through costs or opportunity costs. ITN could have an indirect effect on poverty through (2) & (4)

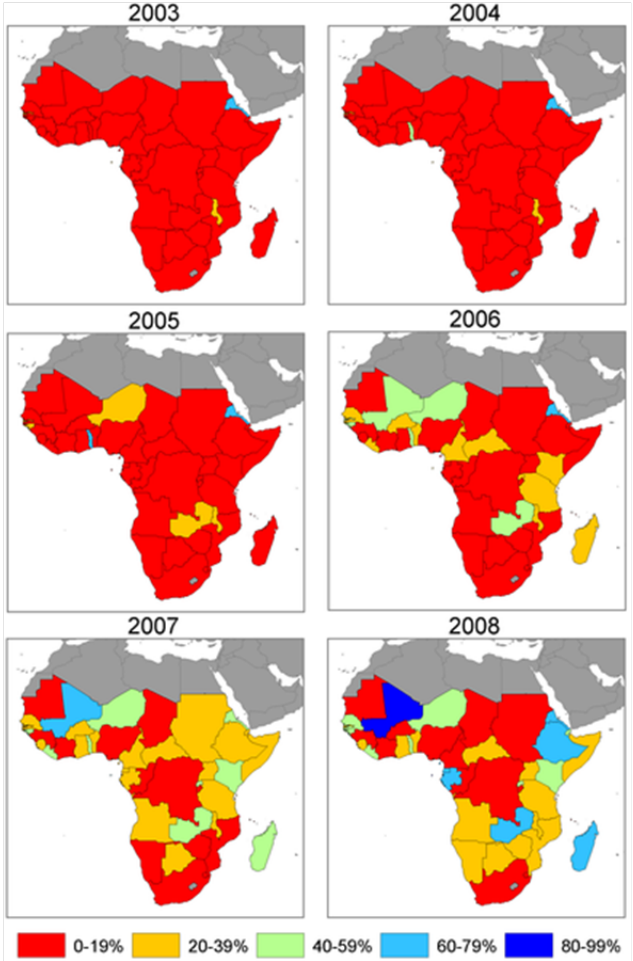
(4) & (5) The relationship between malaria and poverty is certainly bidirectional.

Introduction

- **Motivations:**
  - In spite of large and widespread efforts to distribute ITNs in Africa, they remain poorly used
  - We attempt to propose a theoretical interpretation of this paradox
  - One explanation amongst others could be that there is a "*malaria trap*", i.e. a stable equilibrium with high prevalence and low protection.

Introduction

Figure 6. Annual maps of ITN household ownership coverage at the national level in 44 African countries.



Flaxman AD, Fullman N, Otten MW, Menon M, et al. (2010) Rapid Scaling Up of Insecticide-Treated Bed Net Coverage in Africa and Its Relationship with Development Assistance for Health: A Systematic Synthesis of Supply, Distribution, and Household Survey Data. PLoS Med 7(8): e1000328. doi:10.1371/journal.pmed.1000328
http://www.plosmedicine.org/article/info:doi/10.1371/journal.pmed.1000328

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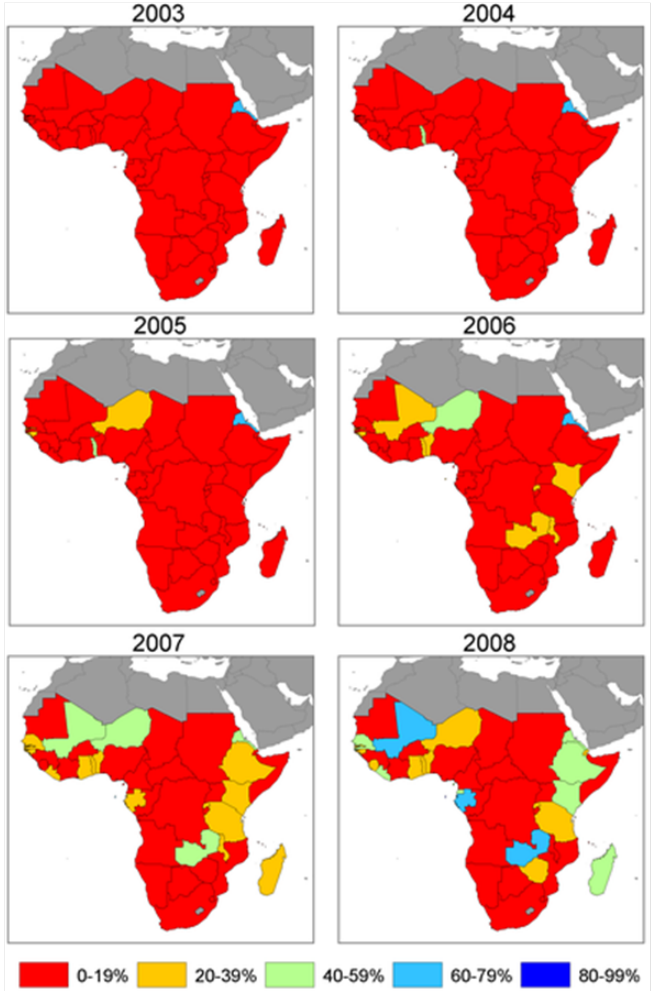
Introduction

Figure 8. Annual maps of ITN use in children under 5 coverage at the national level in 44 African countries.



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Introduction

- **Potential explanations**
  - Differences in the supply side of bednets provision
  - Other behavioral factors amongst those who own nets ?

Introduction

Table 5.6 Reasons for not using mosquito net for sleeping

Percentage of households with at least one mosquito net that was not slept under the previous night, and among those, percentage reporting various reasons for not using a net for sleeping the previous night, by background characteristics, Uganda MIS 2009

Background characteristic	Percentage of households with at least one mosquito net that was not slept under the previous night	Number of households	Too hot	Don't like smell	No mosqui-toes	Net too old/too many holes	Net not hang	Other	Don't know	Number of households with at least one that was not slept under the previous night
Residence										
Urban	13.6	710	19.8	0.0	13.8	3.6	48.4	51.7	0.4	96
Rural	17.5	3,711	15.2	1.9	5.8	12.6	59.1	34.3	1.6	650
Region										
Central 1	14.2	364	14.5	0.0	2.4	18.5	60.0	32.5	1.9	52
Central 2	14.6	439	7.3	0.0	14.4	7.2	36.2	53.2	2.5	64
Kampala	16.5	273	26.5	0.0	11.4	6.9	38.7	57.6	0.8	45
East Central	5.8	557	(13.2)	(0.0)	(7.6)	(7.3)	(47.1)	(37.0)	(1.7)	32
Mid Eastern	20.8	530	6.6	0.9	5.5	9.3	65.1	31.4	0.0	110
North East	24.7	335	7.4	0.0	4.3	7.6	98.8	21.8	0.0	83
Mid Northern	24.6	552	18.0	0.0	7.7	20.3	63.5	25.4	1.0	136
West Nile	14.7	288	1.0	0.0	0.0	6.3	93.2	19.3	0.0	42
Mid Western	12.2	377	21.4	1.1	7.0	10.2	54.7	37.2	3.7	46
South Western	19.2	705	30.2	7.9	7.2	10.4	28.9	52.6	3.0	136
Wealth quintile										
Lowest	14.7	871	2.7	0.4	4.4	22.4	75.6	21.0	0.2	128
Second	16.7	931	5.0	0.5	4.2	11.3	59.5	33.4	2.6	155
Middle	17.4	848	26.8	0.7	0.9	17.5	52.4	34.5	2.3	148
Fourth	17.5	852	18.9	6.6	8.8	3.4	60.2	35.9	0.3	149
Highest	18.1	919	23.1	0.0	14.6	5.0	44.7	53.8	1.5	166
Total	16.9	4,421	15.7	1.6	6.8	11.4	57.7	36.5	1.4	746

Note: Numbers in parentheses are based on 25-49 unweighted cases, while an asterisk denotes a figure based on fewer than 25 unweighted cases that has been suppressed.

Introduction

- **Potential explanations**
  - Use also decreases a few months after interventions (Burkina Faso; Toé et al. 2010)

    "LLINs were not used when the perceived benefits of reduction in mosquito nuisance and of malaria were considered not to be worth the inconvenience of daily use."

  - Our model is just one possible explanation

Introduction

- **Definition**
  - A "*malaria trap*" is defined as the result of malaria reinforcing poverty while poverty reduces the ability to deal with malaria.

Introduction

- **Background:**
  - The approach is based on "*economic epidemiology*" (Geoffard Philipson, 1996 amongst others)
  - However the current literature à la Geoffard and Philipson does not study the possibility of "disease traps" related to human behaviours
  - This literature does not focus on malaria but mostly on HIV with a few exceptions (Gersovitz et al. 2005, Momotta et al., 2005 or Laxminarayan et al., 2010).
  - The models used for malaria use general SIR models that are not particularly malaria-specific.

Introduction

- **Background:**
  - In the literature (in ecology), it has been argued that there could exist a poverty trap associated with a dynamic interaction between a disease prevalence and poverty: disease prevalence increases poverty, while poverty increases the susceptibility to infectious diseases (Bonds et al., 2010).
  - However, this approach has been essentially based on empirical estimates of macroeconomic relations between income GDP per capita (Gross Domestic Product) and infectious disease burden (DALYs, Disability Adjusted Life Years).
  - This kind of result has been used to advocate disease protection campaigns, e.g. distribution of ITN/LLINs at subsidized prices (Sachs, 2006).

Epidemiological model

- The time variation of malaria prevalence among humans can be defined in a simplified way as:

$$\dot{X} = mabZ(1 - X) - rX \tag{1}$$

where m is the vector density (ratio of mosquitoes per human), a is the number of bits per unit of time and per mosquito, b is the proportion of infected bites that produce infection among humans, Z is the proportion of infectious mosquitoes, and r is the clearance rate of malaria in humans.

- Similarly, the variation of the proportion of infectious mosquitoes, can be written as:

$$\dot{Z} = acX(e^{-gn} - Z) - gZ \tag{2}$$

where c is the proportion of bites on infectious humans that produce infection among mosqui-toes, g is the death rate of mosquitoes, and n is the length of sporogonic cycle (parasites' multiplication in the mosquito).

Epidemiological model

- Assuming that the time period of life is long enough, malaria prevalence reaches a steady state equilibrium defined by Smith and Mc Kenzie (2004)

$$Q(X) = \frac{bEIR}{r + bEIR} \tag{3}$$

where EIR is the entomological inoculation rate classically defined such as $EIR = maZ$.

- In what follows (after protection through ITN/LLIN), the parameter m will become itself a variable. The function can thus be defined as Q(X, m) and is concave, and characterized by the following properties:

$$\begin{cases} Q(0, m) = 0, \\ Q(1, m) < 1 \end{cases} \tag{4}$$

Epidemiological model

- It can be easily shown that the slope at origin of Q(X, m) is equal to a number, R_0, that is classically called in the McDonald and Ross tradition the "basic reproduction rate".

- If $R_0 \leq 1$, then $Q(X, m)$ converges towards the trivial disease free stable steady state. This case is not considered in what follows, as it does not coincide with the persistence of malaria in large regions of the developing world.

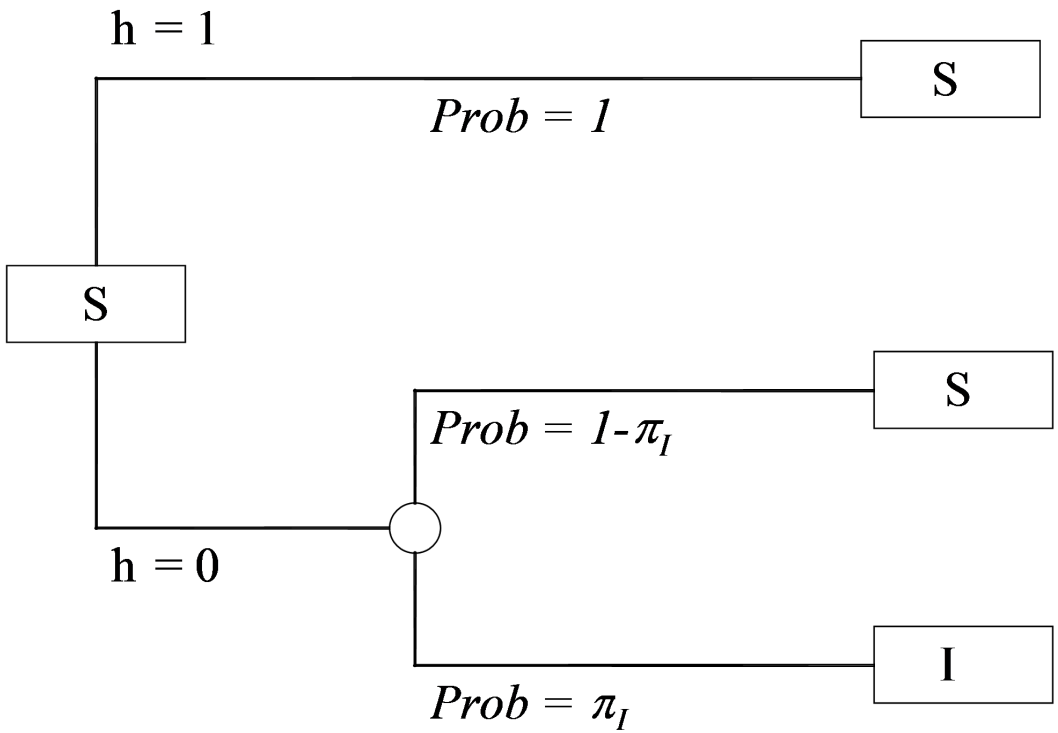
- Conversely, if $R_0 > 1$, then $Q(X, m)$ converges towards a stable steady state characterized by a strictly positive prevalence of malaria.

Epidemiological model with protection

- When $R_0 > 1$, using protection tools could nevertheless reduce malaria transmission, and then, the trivial disease free stable steady state could be reached.
- This is the rationale of ITN/LLINs dissemination policies.
- In order to assess this possibility, a model of protection behavior has been added to the previous epidemiological model.
- It is supposed that the only means by which a person can prevent himself from parasitic infection is to sleep under an ITN/LLIN (even if a person can be infected during the first part of the night). The use of an ITN/LLIN was also considered to provide complete protection from malaria infection.

Epidemiological model with protection

- **Decision tree**



Epidemiological model with protection

- The probability of being infected at any time, conditionally to the absence of protection before, can then be written as:

$$\pi_I = P(\sigma(h) = I | h = 0) \tag{5}$$

where $\sigma(h)$ is the value of the health status of the individual: susceptible, $\sigma(h) = S$, or infected, $\sigma(h) = I$

- π_I is equal to the value of the $Q(X, m)$ function defined in the epidemiological model in absence of protection. If H is the proportion of population using ITN/LLIN, among the $(1 - X)$ uninfected persons, the proportion of infected persons can be simply written as:

$$X = (1 - H)\pi_I \tag{6}$$

Epidemiological model with protection

- Furthermore the density of mosquitoes in contact to humans, m, which was a parameter in the pure epidemiological model,is affected by the presence of ITN/LLIN used by a proportion H of the population:

$$m(H) = \frac{m(0)}{1-H}(1-\gamma(H)) \tag{7}$$

where $\gamma(H)$ is the proportion of mosquitoes killed by the use of ITN/LLINs, an increasing function of H.

- It follows that, at the steady state :

$$\pi_I = Q(X, m(H)) \tag{8}$$

Epidemiological model with protection

- Let's now focus on the determinants of H, that are based on microeconomic decisions.

- The choice of protection at individual level, is determined by maximizing the expected utility of each individual through two channels: (i) an expected positive impact on his/her health status in case of protection and (ii) a private cost, called κ. **This cost include the opportunity cost of protection and depends on the marginal utility of income.**
- Hence protection decision is described through the following maximization program:

$$max_h E[u(\sigma(h))] - \kappa W(\omega)h \tag{9}$$

where $u(S)$ or $u(I)$ are the utility levels attached to the health status, with $0 < u(I) < u(S)$; ω is the individual income; $W(\omega)$ is the marginal utility of the income, supposed as usual to decrease with income. κ being the private cost.

Epidemiological model with protection

- **How is poverty taken into account?**
- It is assumed that there exists a minimum subsistence level such as in the case a Stone-Geary utility function. This implies that the marginal utility of income, $W(\omega)$, goes to infinity for all individuals at (or below) the minimum subsistence level, which is classically called the extreme poverty line Ω (i.e. the minimum level of income deemed adequate in a given country for an individual or a household).
- In other words, the extreme poverty line is an income level below which nobody can afford an ITN/LLIN, i.e. $h = 0$.

Epidemiological model with protection

- **Decision to protect**
- the individual will use protective tools when $\kappa W(\omega)$ is lower than the expected utility loss associated with the risk of infection that occurs in the absence of protection:

$$E[u(\sigma(1)) - u(\sigma(0))] \geq \kappa W(\omega) \tag{10}$$

Epidemiological model with protection

- According to equation (10) and the 3 probabilities in the previous decision tree it follows that:

  $h = 1$ if and only if $u(S) - (1 - \pi_I)u(S) - \pi_I u(I) \geq \kappa W(\omega)$ (11)

  A person will use ITN/LLIN if the utility of being non-infected is greater than the utility of paying for a protective tool, according to the income and the probability of being infected without using any protection. Hence, protection occurs if and only if:

$$\pi_I \geq \frac{\kappa W(\omega)}{u(S) - u(I)} \tag{12}$$

Epidemiological model with protection

- This equation shows that there is a **threshold probability of infection** above which a person engages in protection.
- The key point in this approach is that the threshold probability of infection depends on the marginal income utility loss associated with using the ITN/LLIN, $\kappa W(\omega)$, with respect to the net value attached to susceptible health status, $u(S) - u(I)$.
- This threshold depends on the individual income ω. The threshold function, linking π_I to ω, termed $C(\omega)$, is monotonic and $C'(\omega) < 0$, as the function $W()$ is monotonic and $W'(\omega) < 0$. In addition, the function $C()$ is increasing with κ. Consequently:

$$\begin{cases} h = 1 \text{ if } \omega \geq C^{-1}(\pi_I), \\ h = 0 \text{ else} \end{cases} \tag{13}$$

Epidemiological model with protection

- Consequently, the income threshold conditioning protection, $C^{-1}(\pi_I)$, decreases with κ. Knowing individual protection behaviors, the aggregated level of protection (the percentage of protected persons) can be computed by integration as follows:

$$H = \int_{C^{-1}(\pi_I)}^{+\infty} f(\omega) d\omega = 1 - F(C^{-1}(\pi_I)) \qquad (14)$$

where f is the probability density function of ω (F the cumulative density function), describing the income distribution of the population.

- Equations (6) , (8) and (14) fully describes the dynamics of H and π_I as a function of X.

Prevalence elastic behaviors

- Nearby the steady-state, the dynamics corresponds to a standard prevalence-elastic behaviour of protection (positive malaria prevalence elasticity), where H is an increasing function of X, because it is increasing with π_I
- The main question to be solved, concerning the long-term properties of this model at the steady-state, is whether a malaria trap can persist in the long run, in spite of the availability of ITN/LLINs as protection tools since the higher the unit cost κ of ITN/LLINs, the lower the protection.

Long term properties: conditions of persistence of a malaria trap

- This is why ITN/LLINs programs are usually based on subsidized ITN/LLINs prices. Let us then consider the best case of almost full subsidization ($\kappa \to 0$)
- $\forall \kappa$ when $\kappa \to 0$ the long term equilibrium corresponds to a malaria trap, if and only if:

$$R_0 > \frac{1}{F(\Omega)(1 - mF(\Omega))} \tag{15}$$

where $F(\Omega)$ is the proportion of persons under the extreme poverty line in a population, also called the extreme poverty incidence. Note that m depends on H, the proportion of protected persons, which depends itself on income, and, thus, on the extreme poverty incidence.

Long term properties: conditions of persistence of a malaria trap

- Given $\kappa \to 0$ and $H \to 1 - F(\Omega)$, as the vector density m is a decreasing function of H, the higher the incidence of extreme poverty, $F(\Omega)$, the higher the risk of persistence of a malaria trap.
- Consequently, even if the ITNs are highly subsidized, the malaria trap will persist for high enough values of R_0 and of extreme poverty incidence.
- If all the population is below the poverty line, a subsidization policy is truly ineffective.

Empirical test

- The previous model describes protection behaviours and the existence of theoretical conditions under which a malaria trap persists. As stated above, protection should
  - increase with prevalence of malaria (i.e. positive malaria prevalence elasticity),
  - decrease with an increase of economic cost of protection and
  - decrease with an increase of the incidence of extreme poverty.

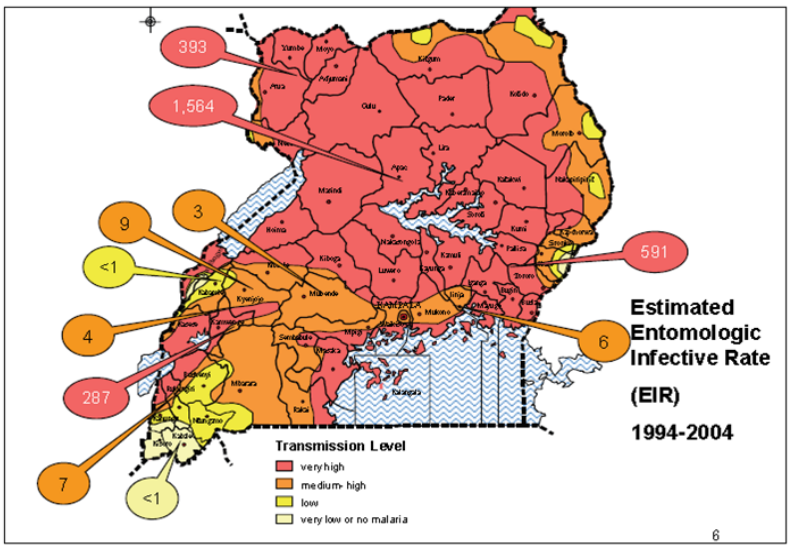
Empirical test

- Therefore we test the following structural equation on a cross-sectional survey:

$$\begin{cases} F(\Omega) = \alpha_1 + \beta_{1a} X + \beta_{1b} IVs_{PovertyIncidence} + \beta_{1c} Regions + \epsilon_1 \\ X = \alpha_2 + \beta_{2a} F(\Omega) + \beta_{2b} H + \beta_{2c} IVs_{Malaria} + \beta_{2c} Regions + \epsilon_2 \\ H = \alpha_3 + \beta_{3a} X + \beta_{3b} F(\Omega) + \beta_{3c} IVs_{Protection} + \beta_{3c} Regions + \epsilon_3 \end{cases} \tag{16}$$

- The complete system of structural equations was estimated with a heteroskedastic-efficient 3SLS two step generalized method of moments.

Empirical test: Uganda



Source: Malaria Control Program, Ministry of Health, Uganda. Available at http://www.health.go.ug/mcp/distmaps.html

- A country with extreme poverty
- We have data on malaria and net use

Empirical test

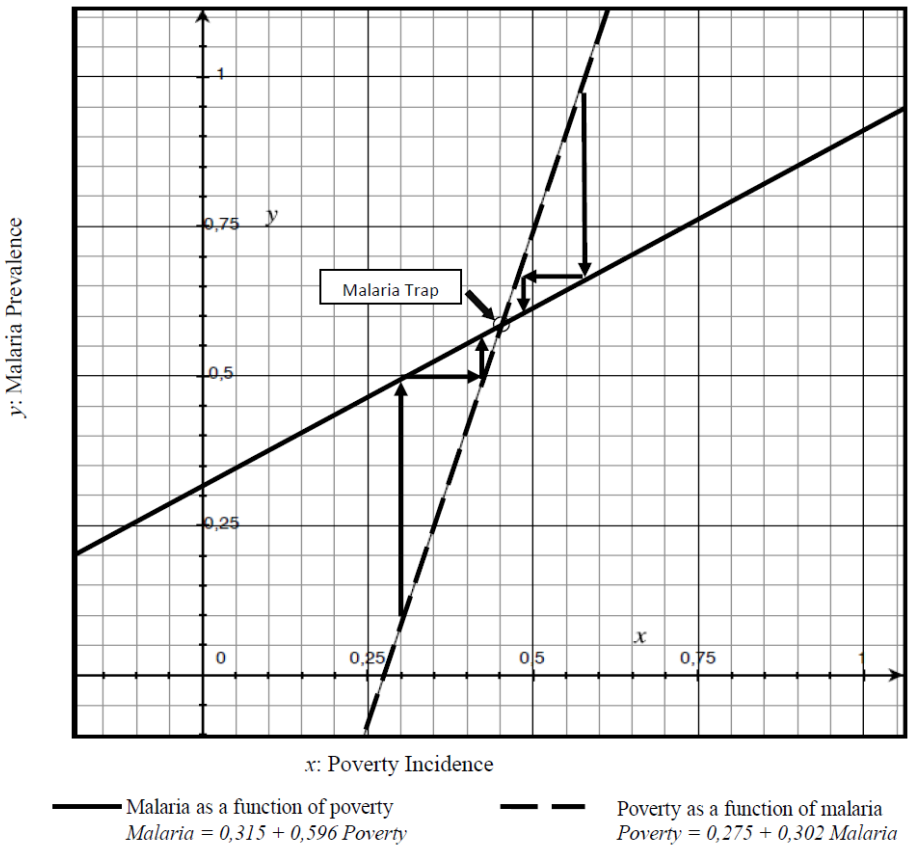
Table 2 Prevention, malaria and poverty in Uganda: OLS and 3SLS GMM regressions results

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	3SLS GMM		
	Dep Var is % using an ever treated net last night in the village	Dep var is malaria prevalence in the village	Dep var is poverty incidence in the village	Dep Var is % using an ever treated net last night in the village	Dep var is malaria prevalence in the village	Dep var is poverty incidence in the village
Malaria	-	−0.044	-	-	−0.862***	-
Prevention		(0.130)			(0.308)	
Poverty	−0.046	0.376***	-	−0.323*	0.543***	-
Incidence	(0.078)	(0.096)		(0.194)	(0.132)	
Malaria	−0.022	-	0.242***	0.438**	-	0.302**
Prevalence	(0.063)		(0.067)	(0.175)		(0.124)
Intercept	0.208***	0.400***	−0.013	0.062	1.364***	−0.290***
	(0.044)	(0.058)	(0.047)	(0.078)	(0.174)	(0.064)
Observations	170	170	170	170	170	170
R-squared	0.379	0.550	0.668	-	-	-

The coefficients attached to each variable are presented (standard errors, adjusted for heteroscedasticity in parentheses). All regressions include regional dummies. ***denotes statistical significance at the 1% level, ** at the 5% level, * at the 10% level. The Hansen J Test of overidentifying restrictions shows that the instruments are well identified in 3SLS GMM regressions (Hansen's J chi2= 12.247; *p* value = 0.140). A rejection of the null hypothesis implies that the instruments are not satisfying the orthogonality conditions required for their employment (i.e. that they are uncorrelated with the error term of the estimated Equation).

Empirical test

- This figure illustrates the linear predictions of the relationship between malaria and poverty from Uganda dataset, solving partially the three-equations system.



Conclusions

- Until now, we have focused on the dynamics without the presence of a treatment choice. It can be shown that the trap is reinforced when treatment is introduced, and in this case the trade-off between prevention and intervention is interesting to analyze.
- Social influences on individuals' decisions may lead to malaria trap.
- Particularly, the use of ITNs by the very poor should be subsidized, i.e. the very poor people should not only be provided highly subsidized ITNs, but they should be given incentive for protection use (including financial award) to keep and use their ITNs as suggested for immunization coverage in other empirical randomized studies.

Conclusions

- Otherwise, they may rationally resell their ITNs on a parallel market (or use them for other purposes) and then malaria prevalence may stay high at equilibrium.
- It could be relevant to implement this policy at the community level in collaboration with community health workers, insofar as the origin of the issue is related to the presence of externalities that emerge at this community level.

Thank you for your attention!