Health and Wealth: An endogenous growth model with infectious diseases

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Abstract

This paper studies the effect of infectious diseases on human and health capital accumulation and on growth. We show there is empirical evidence of clustering relationships between incidence of infectious diseases, human capital and income. To explain the clustering we study a model where human capital accumulation is the engine of growth. There is also an infectious diseases prevalent whose transmission is given by SIS dynamics. Infective individuals are too ill to either work or accumulate human capital. Society can also choose to spend resources on health capital which will reduce the incidence of the disease. We show that prevalence of infectious diseases can affect the incentives to invest both in health and human capital. There can be a poverty trap due to incidence of incidence of diseases, with no expenditure on human or health capital. We show that decrease in mortality (demographic transition) will have differential effects on countries - with the poorest countries having a Malthusian effect, and poor countries can undergo a “take-off” effect where there is expenditure to control the disease as well as positive investment in human capital. Thus, the demographic transition (which is exogenous in the model) may lead (but not necessarily) to an epidemiological transition.

Outline

- **Introduction**
- SIS Epidemiology Model
- Endogenous Growth Model with Exogenous Disease Dynamics
- Endogenous Growth Model with Endogenous Disease Dynamics
- Conclusion

Infectious Diseases

- Recent outbreaks of infectious diseases - H1N1, SARS, Avian Flu, Dengue, Malaria, HIV/AIDS, Tuberculosis...
- Increasing awareness and push for controlling infectious diseases - i.e. Millenium Development Goals.
- Is this an economic argument or a humanitarian argument?

Infectious Diseases

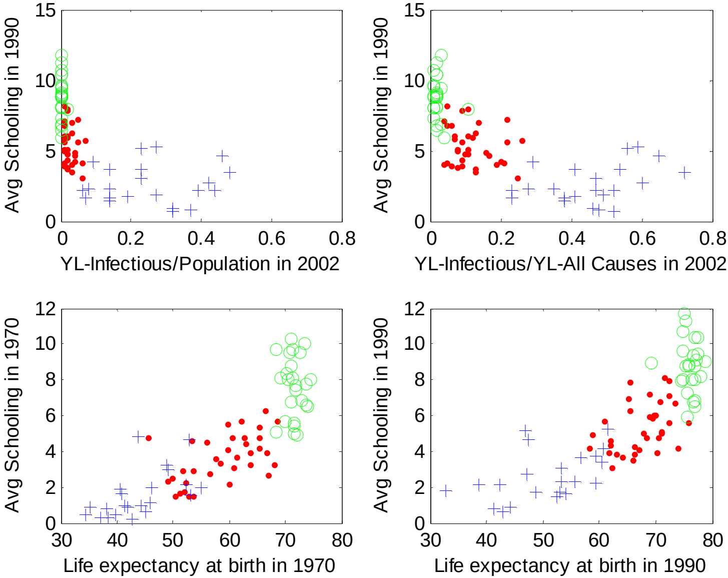
- The results of the economic literature on effect of diseases on economic outcomes, are at best mixed.
    1. There can be a Malthusian effect with a negative effect as the capital-labor ratio falls: Young (2005).
    2. There are insignificant effects of controlling diseases: Acemoglu and Johnson (2007), Ashraf, Lester and Weil (2009).
    3. There are significant effects of controlling diseases: Bleakley (2007), Bloom and Canning (2005), Bloom, Canning and Fink (2009), Gallup and Sachs (2001).

3 groups of countries

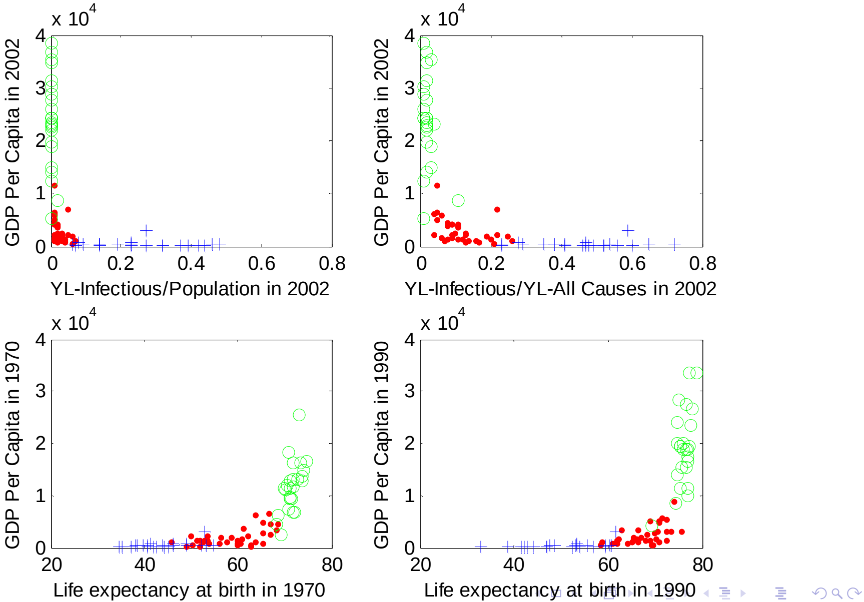
	Avg Schooling Years		GDP Per Capita (Constant 2000 US$)			Avg Growth Rate (1970-2002)	
	1970	1990	1970	1990	2002	For GDP Per Capita	For GDP
Group 1	1.58	2.61	476.17	450.14	454.40	-0.001	0.025
Group 2	3.57	5.31	1897.90	2334.60	2912.40	0.017	0.037
Group 3	7.58	8.73	11715.00	19021.00	23781.00	0.022	0.030

	Life Expectancy at Birth			DALY(Infectious)/Total Population in 2002	DALY(Infectious)/All Causes in 2002	Prevalence of Tuberculosis (Per 100,000 Population)	
	1970	**1990**	**2002**			**1990**	**2000**
Group 1	43.95	50.57	52.26	0.25	0.46	336.82	387.32
Group 2	58.77	67.57	71.25	0.02	0.12	168.77	122.90
Group 3	71.56	76.01	78.58	0.00	0.02	25.52	16.88

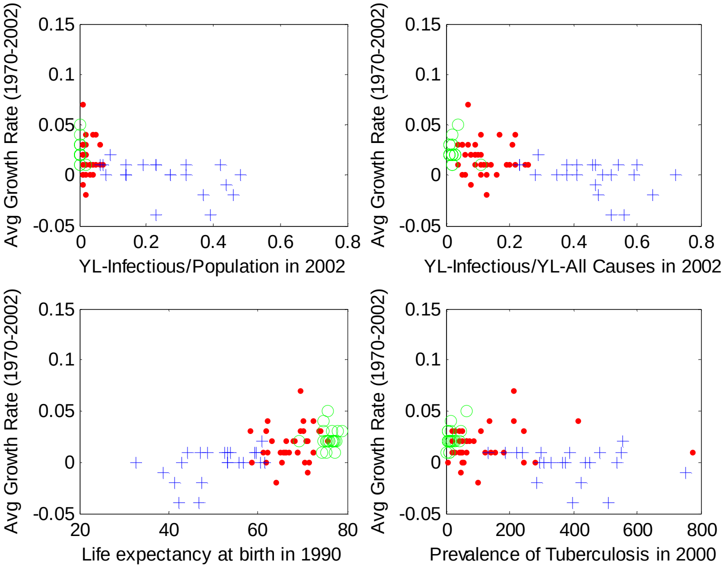
Infectious diseases and schooling, life expectancy and schooling



Infectious diseases and GDP p.c., life expectancy and GDP p.c.



Infectious diseases and p.c. GDP growth, life expectancy and p.c. GDP growth



Infectious Diseases

- Diseases have two effects:
  - Mortality: Death due to disease
  - Morbidity: Ill health due to disease
- This paper argues that morbidity can have significant economic impact.
- Chakraborty, Papageorgiu and Perez Sebastien (2010) look at the impact of mortality.

Non-Fatal Infectious Diseases

Table 31-3

The burden of disease in DALYs by cause in developing countries, in thousands, in 2002 (WHO, 2003b)

	Africa	Americas	Eastern Mediterranean	South-East Asia	World
Trypanosomiasis	1,494	0	39	0	1,535
Chagas disease	0	662	0	0	667
Schistosomiasis	1,334	74	227	7	1,702
Leishmaniasis	383	44	248	1,358	2,090
Lymphatic filariasis	2,011	10	122	3,219	5,777
Onchocerciasis	470	2	10	0	484
Leprosy	23	18	25	118	199
Dengue	5	69	30	381	616
Japanese encephalitis	0	0	83	306	709
Trachoma	1,212	164	283	168	2,329
Intestinal nematode infections	1,138	168	225	804	2,951
Ascariasis	858	62	158	409	1,817
Trichuriasis	233	71	60	368	1,006
Hookworm disease	46	0	2	9	59

Reproduced by kind permission of the World Health Organization. Although with relatively low rates of mortality, neglected diseases constitute a real threat and impediment to development by their extravagant burden

Non-Fatal Infectious Diseases

Table 31-4

Prevalence of selected neglected diseases[a]

Disease	Number endemic countries	Population infected (millions)	Population at risk (millions)
Lymphatic filariasis	80	40	1,300
Leishmaniasis	88	12	350
Schistosomiasis	76	200	600
African trypanosomiasis	36	18	100
Dengue	100	50	2,500
Chagas disease	21	20	100
Trachoma	100	150	600

[a]Author's estimation

Altogether, neglected diseases affect more than one sixth of the world population, exclusively living in developing countries

Non-Fatal Infectious Diseases

Table 31-5

Poverty and lymphatic filariasis (WHO, 2003a)

Countries	Number of countries	Number of LF endemic countries	Population living in endemic countries (millions)	Population at risk for LF (millions)
Least developed	38	32	86.0	289.5
Other Low-income	21	11	75.6	633.3
Lower-middle-income	19	10	4.3	39.7
Upper-middle-income	3	1	0.3	1.3

Reproduced by kind permission of the World Health Organization. Like most of neglected diseases, lymphatic filariasis can be seen both as a cause and a consequence of poverty

Schistosomiasis

- Borne by helminths and is endemic in 74 countries and infects over 200 million people.
- Rarely fatal it is a chronic disease which can damage internal organs and in children impair growth and cognitive development.
- Bleakley (2007) finds that eradication of hookworm led to significant gains in educational attainment in Southern USA.
- Recent experiments (ALJ Poverty Action Lab, MIT) find that most effective intervention to increase school attendance in India, is to treat hookworm.
- These papers do not control for who had hookworm, and who did not when looking at changes in education.

This paper

- We want a theoretical model to address:
  1. What is effect of disease control on the economy? Is there a poverty trap due to high prevalence of infectious diseases?
  2. When is the Malthusian argument true? That is examine the effect of exogenous increase in life expectancy on the economy.
- This paper argues that there are two effects of diseases:
  1. The direct effect of productivity - who can work/study and who cannot.
  2. It changes *incentives* to accumulate human capital.

Modeling strategy

- Integrate epidemiology models into an endogenous growth framework where there is a choice of how much human capital to accumulate.
- This allows us to look at the two effects in a dynamic general equilibrium framework.
- It allows us to look inside the “black box” of the interaction of disease transmission.

Epidemiology

- Goenka and Liu (2010): One-way effect - disease affects productivity. Disease dynamics are "biological."
  - Discrete time model: cycles and chaos emerge as infectivity of disease increases.
  - Studies how to stabilize the economy through isolation and vaccination.
- Goenka, Liu and Nguyen (2011) Study the two-way interaction between disease transmission and economic outcomes when the disease parameters can be affected by health capital expenditures.
  - There can be multiple steady states and bifurcations.
  - Studies how steady states are affected by health expenditures. While there are level effects, growth effects are not modeled.
- The current paper extend the analysis to an endogenous growth framework with a two-way interaction so both level and growth effects can be studied.

Outline

SIS Epidemiology Model

- Population is divided into compartments based on their epidemiological status
  - Susceptible (S): Healthy but can catch the disease
  - Infectious (I): Infected and capable of transmitting it to others
- Movements between compartments by some laws of motion.

SIS Epidemiology Model

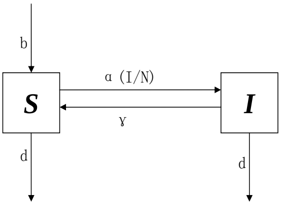


Figure 2: The transfer diagram for the SIS epidemiology model

- Individuals are born healthy, with birth rate b
- Homogeneous mixing
- Horizontal incidence(frequency dependant incidence) - depending on contact rate α and proportion of the infected I/N
- Recovery rate γ
- Mortality rate d with no disease-related mortality rate

SIS Epidemiology Model

- Laws of motion:

$$dS/dt = bN - dS - \alpha SI/N + \gamma I$$
$$dI/dt = \alpha SI/N - (\gamma + d)I$$
$$dN/dt = (b - d)N$$

- In terms of $s_t = S_t/N_t$,

$$\dot{s}_t = (1 - s_t)(b - \alpha s_t + \gamma)$$

- Under the assumption that only healthy individuals work with inelastic labor supply, the above equation gives the evolution of labor supply.

SIS Epidemiology Model

- Steady states:
  - Disease-free steady state:
    $s^* = 1$ exists for all parameter values.
  - Endemic steady state:
    $s^* = \frac{b+\gamma}{\alpha}$ exists only when $\frac{b+\gamma}{\alpha} < 1$.

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The Model

- Endogenous growth model with human capital accumulation (Lucas 1988)
- Labor supply:
  - Among N individuals, there are $L \leq N$ number of healthy individuals ($l = \frac{L}{N}$)
  - A healthy individual - 1 unit of labor divided into:
    - μ for production
    - $1 - \mu$ for human capital accumulation
  - An infected individual - the labor is unproductive in either use
  - $l(t)$ inherits the dynamics of $s(t)$:

$$\dot{l} = (1 - l)(b + \gamma - \alpha l)$$

The Model

- Human captial:
  - The average human capital given by e , and

$$\dot{e} = \delta l(1-\mu)e$$

  - The effective labor supply is μeL
- Production:
  - Cobb-Douglas technology for production:

$$Y = AK^{\beta}(\mu Le)^{1-\beta}$$

  - Resource constraint:

$$\dot{K} = AK^{\beta}(\mu Le)^{1-\beta} - C$$

- Consumption: Assuming full insurance, each individual has the same consumption irrespective of his health status.

Planning problem

$$
\begin{aligned}
\max_{\{c,\mu\}} \quad & \int_0^\infty e^{-(\rho-b+d)} \frac{c^{1-\sigma}-1}{1-\sigma} N_0 dt \\
\text{s.t.} \quad & \dot{k} = Ak^\beta (\mu l e)^{1-\beta} - c - k(b-d) \\
& \dot{e} = \delta e l (1-\mu) \\
& \dot{l} = (1-l)(b+\gamma-\alpha l) \\
& c > 0,\ 0 \leq \mu \leq 1,\ 0 \leq l \leq 1,\ k_0, e_0, l_0 \text{ given.}
\end{aligned}
$$

We focus on BGP, in which l^* and μ^* are constant, and all other variables grow at a constant rate. In fact, we show they all grow at the same rate

$$g = \delta l^* (1-\mu^*) \geq 0$$

BGP

The Hamiltonian is:

$$H = \frac{c^{1-\sigma}-1}{1-\sigma} + \lambda_1 [Ak^{\beta}(\mu le)^{1-\beta} - c - k(b-d)] +$$
$$\lambda_2 \delta el(1-\mu) + \lambda_3 (1-l)(b+\gamma-\alpha l) + \lambda_4 (1-\mu) + \lambda_5 (1-l).$$

- $0 \leq l^* \leq 1$:

$$\text{Case I:} \quad l^* = 1$$
$$\text{Case II:} \quad l^* = \frac{b+\gamma}{\alpha} < 1$$

- $0 \leq \mu^* \leq 1$:

$$\text{Case I:} \quad \mu^* = 1 \quad \text{and} \quad \lambda_4 = \lambda_1 (1-\beta) \frac{y}{\mu} - \lambda_2 \delta el > 0$$
$$\text{Case II:} \quad \mu^* < 1 \quad \text{and} \quad \lambda_4 = \lambda_1 (1-\beta) \frac{y}{\mu} - \lambda_2 \delta el = 0$$

BGP

- We assume

$$\frac{b+\gamma}{\alpha} < \frac{\rho - b + d}{\delta} < 1.$$

Disease-free Case

- Disease is eradicated :

$$l^* = 1$$

- Human capital accumulation:

$$1 - \mu^* > 0$$

- Economy grows at rate

$$g = \frac{1}{\sigma}[\delta - (\rho - b + d)] > 0$$

.

Disease-endemic Case

- Disease is endemic :

$$l^* = \frac{b+\gamma}{\alpha} < 1$$

- No human capital accumulation:

$$1 - \mu^* = 0$$

- No economic growth

$$g = 0$$

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The Model

- Endogenize disease dynamics - contact rate:

$$\alpha \quad \to \quad \alpha\left(\frac{h}{k}\right)$$

- Properties of the function $\alpha(\frac{h}{k})$:
  - $\alpha' \leq 0$, $\alpha'' \geq 0$,
  - $\lim_{\frac{h}{k} \to 0} \alpha \to \overline{\alpha}$.
  - $\lim_{\frac{h}{k} \to \infty} \alpha \to \underline{\alpha}$.

Planning problem

$$
\begin{aligned}
\max_{\{c,m,\mu\}} \quad & \int_0^\infty e^{-(\rho-b+d)} \frac{c^{1-\sigma}-1}{1-\sigma} N_0 dt \\
\text{s.t.} \quad & \dot{k} = Ak^{\beta}(\mu l e)^{1-\beta} - c - m - k(b-d) \\
& \dot{e} = \delta e l(1-\mu) \\
& \dot{l} = (1-l)(b+\gamma-\alpha(\frac{h}{k})) \\
& \dot{h} = m - h(b-d) \\
& c > 0,\ 0 \leq \mu \leq 1,\ 0 \leq l \leq 1,\ m \geq 0,\ h \geq 0,\ k > 0,\ e > 0 \\
& \text{and } e_0, k_0, l_0, h_0 \text{ given.}
\end{aligned}
$$

BGP

The Hamiltonian is given as:

$$H = \frac{c^{1-\sigma}-1}{1-\sigma} + \lambda_1[Ak^{\beta}(\mu le)^{1-\beta} - c - m - k(b-d)] + \lambda_2 \delta el(1-\mu) +$$
$$+\lambda_3(1-l)(b+\gamma-\alpha(\frac{h}{k})) + \lambda_4(m - h(b-d)) + \lambda_5(1-\mu) + \lambda_6(1-l)$$

- Assume

$$\frac{b+\gamma}{\overline{\alpha}} < \frac{\rho-b+d}{\delta} < \frac{b+\gamma}{\underline{\alpha}} < 1$$

Disease-free Case

- Disease is eradicated :

$$l^* = 1$$

- Human capital accumulation:

$$1 - \mu^* > 0$$

- Economy grows at rate

$$g = \frac{1}{\sigma}[\delta - (\rho - b + d)] > 0$$

.

Disease-endemic Case

- Disease is endemic :

$$l^* = \frac{b+\gamma}{\alpha(\frac{h^*}{k^*})} < 1$$

- Human capital accumulation and economic growth:
  - Case 1: If $l^* > \frac{\rho - b + d}{\delta}$,

$$1 - \mu^* > 0 \quad \text{and} \quad g = \frac{1}{\sigma}[\delta l^* - (\rho - b + d)]$$

  - Case 2: If $l^* < \frac{\rho - b + d}{\delta}$,

$$1 - \mu^* = 0 \quad \text{and} \quad g = 0$$

Disease-endemic Case

- Let $x = \frac{h}{k}$, and there exists $\hat{x}$ such that

$$\frac{b+\gamma}{\alpha(\hat{x})} = \frac{\rho - b + d}{\delta}$$

- The optimal solution is x^* ($\frac{b+\gamma}{\alpha(x)} = l^*$), and we have
  - Case 1: If $x^* > \hat{x}$,

$$1 - \mu^* > 0 \quad \text{and} \quad g = \frac{1}{\sigma}[\delta l^* - (\rho - b + d)]$$

  - Case 2: If $x^* < \hat{x}$,

$$1 - \mu^* = 0 \quad \text{and} \quad g = 0$$

where x^* is determined by

$$(\rho - b + d) + (\sigma - 1)g =$$
$$= -\frac{1-\beta}{\beta}(1 - l(x))\alpha'(x)(1+x)\frac{\rho - b + d + \sigma g}{\rho - b + d + (\sigma - 1)g} + (b + \gamma - \alpha)$$

Comparative Statics

- If d decreases: Individuals become more patient, and invest more in health and human capital
- If γ increases: Diseases become less prevalent, fraction of labor force increases and more investment in human capital
- If ρ decreases: Individuals become more patient, and invest more in health and human capital
- If b increases: Diseases become less prevalent, fraction of labor force increases and more investment in human capital
- If β decreases: Physical capital becomes less important in production relative to human capital, and more investment in health and human capital.
- If δ increase: Human capital accumulation becomes more productive

Exogenous Increase in Life Expectancy

- Poor countries: disease-endemic case without any health expenditure
$$l^* = \frac{b+\gamma}{\overline{\alpha}} < \frac{\rho - b + d}{\delta}$$
There is no economic growth, and as life expectancy increases, income per capita declines ("Malthusian" equilibirum)

Exogenous Increase in Life Expectancy

- Developing countries: disease-endemic case with positive health expenditure. There are two scenarios:
  - If $l^* < \frac{\rho - b + d}{\delta}$, there is no economic growth. As life expectancy increases, income per capita declines ("Malthusian" equilibirum). However, if life expectancy increases a lot and the economy switches to an equilibrium with human capital accumulation and positive economic growth.
  - If $l^* > \frac{\rho - b + d}{\delta}$, there is positive economic growth with $g = \frac{1}{\sigma}[\delta l^* - (\rho - b + d)]$ and as life expectancy increases the growth rate increases.

Exogenous Increase in Life Expectancy

- Developed countries: disease-free case

$$l^* = 1 > \frac{\rho - b + d}{\delta} \quad \text{and} \quad g = \frac{1}{\sigma}[\delta - (\rho - b + d)]$$

As life expectancy increases the growth rate increases.

Decentralized Equilibrium

- Individuals do not internalize the externality of health expenditure, that is, they take as given the proportion of the population that is infected (π)
- SIS epidemiology model is now given as follows:

$$dS/dt = bN - dS - \alpha S\pi + \gamma I$$
$$dI/dt = \alpha S\pi - (\gamma + d)I.$$

  So the law of motion for labor force is:

$$\dot{l} = b + \gamma - (b + \gamma + \alpha(\frac{h}{k})\pi)l$$

- In equilibrium,

$$\pi = 1 - l$$

- x^* is smaller and it is more likely that the economy has no positive growth

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Conclusion

- We show that
  1. Incidence of infectious diseases can be the difference between whether there is sustained economic growth or not.
  2. Infectious diseases can cause a poverty trap by affecting incentives to accumulate human capital.
  3. There may be a Malthusian for countries with high incidence of infectious diseases, but not for others.
- Thus,
  1. There can be clustering effects as found in the data which are not picked in OLS regressions.
  2. Evaluating economic impact of diseases without taking into account these dynamic general equilibrium effects can be very misleading.