General ecological models for human subsistence, health and poverty

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May 31, 2016

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International Clinics on Infectious Disease Dynamics and Data: The ICI3D Program

SACEMA
DST/NRF Centre of Excellence in Epidemiological Modelling and Analysis

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Background and emperical trends

- More than one billion people live in extreme poverty
- About 1.22 billion people lived below the poverty line in 2010 compared to about 1.94 billion people in 1981
- Sharp decline in extreme poverty with 720 million fewer people in 2010 than in 1981
- Reduction more significant in middle-income countries
- In 2010, 33% of the extreme poor lived in low-income countries, compared to 13% in 1981
- With the exception India and China, the poor in low-income countries in 2010 were almost just as bad as they were in 1981

Background and empirical trends

- 70% of the global poor live in rural areas, mostly subsistence
- 35% suffer from chronic malnutrition
- 75% of deaths among the poor are due to infectious diseases

The extremely poor are characterized by : Subsistence agriculture and high burdens of disease

Background and empirical trends

- 70% of the global poor live in rural areas, mostly subsistence
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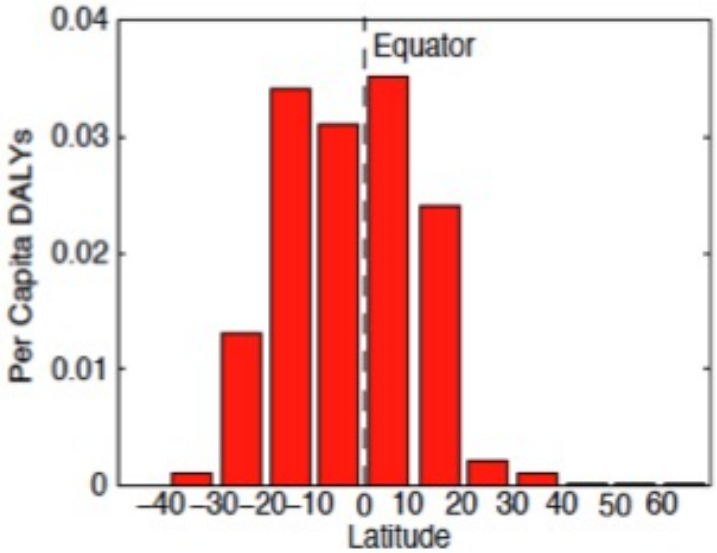
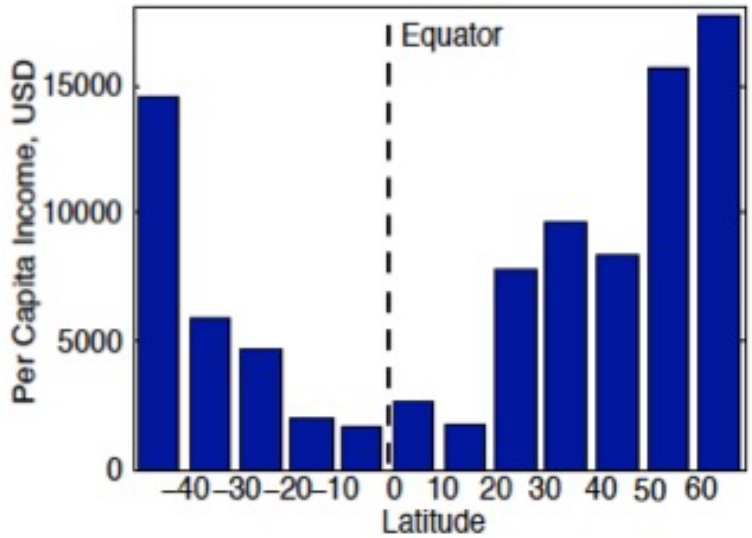
The extremely poor are characterized by : Subsistence agriculture and high burdens of disease

Evidence of feedback between disease and poverty

- Diseases cause morbidity and mortality
- Diseases are the leading killers of the poor
- Malaria caused 438,000 mortalities on 2015 (WHO Malaria Report 2015)
- HIV/AIDS is highly prevalent in Africa



Vector-borne and parasitic disease burden

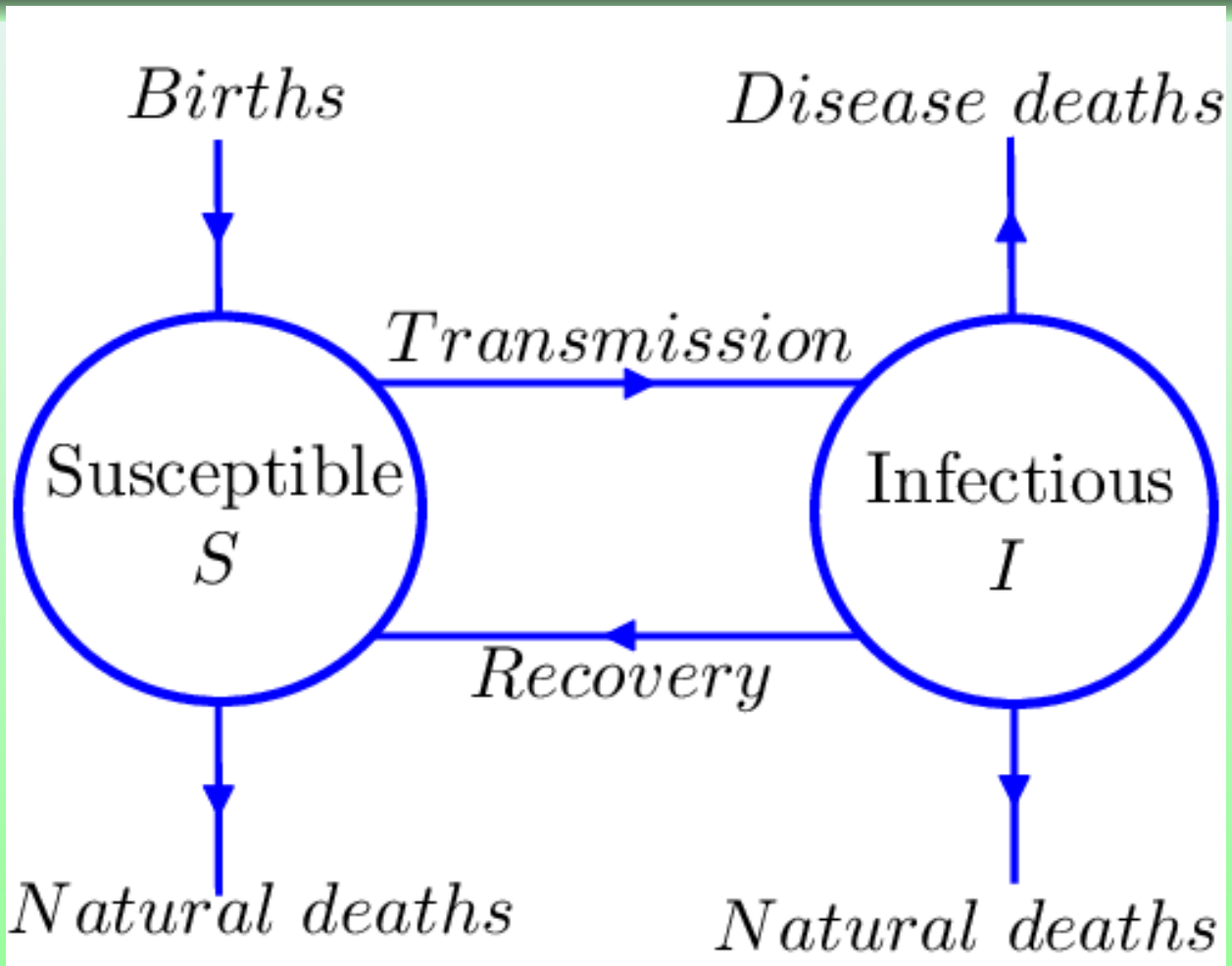


Income

Bonds et al. PLoS Biology, 2012

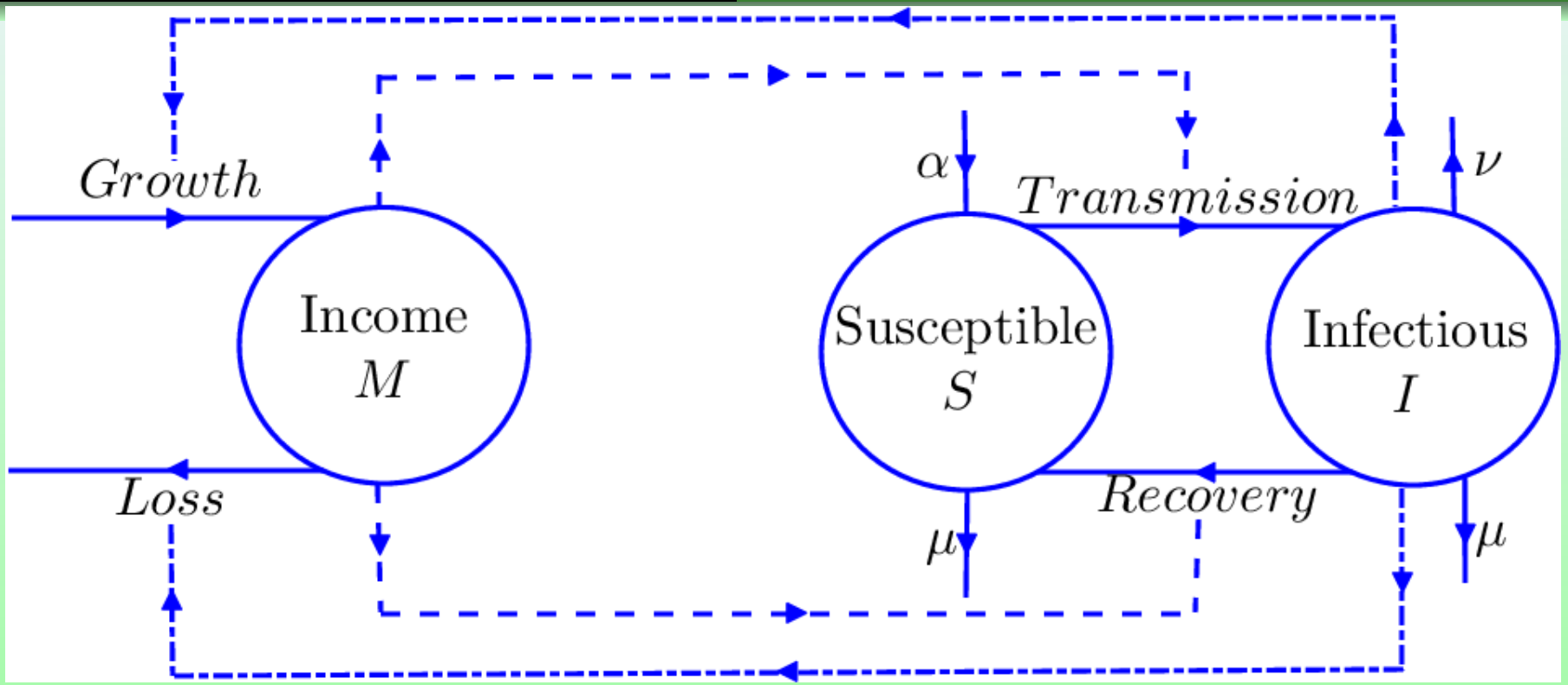
Evidence of feedback between disease and poverty

- Malaria reduced per capita income by 1.3% (Gallup and Sachs, 2001)
- Hookworm reduced income by 35% (Bleakly, 2008)
- Nutrition supplements increased wages by 47% (Hoddinot et al., 2008)
- Deworming reduced absenteeism by 25% and improved exam. scores (Miguel and Kremer, 2003)



Disease model

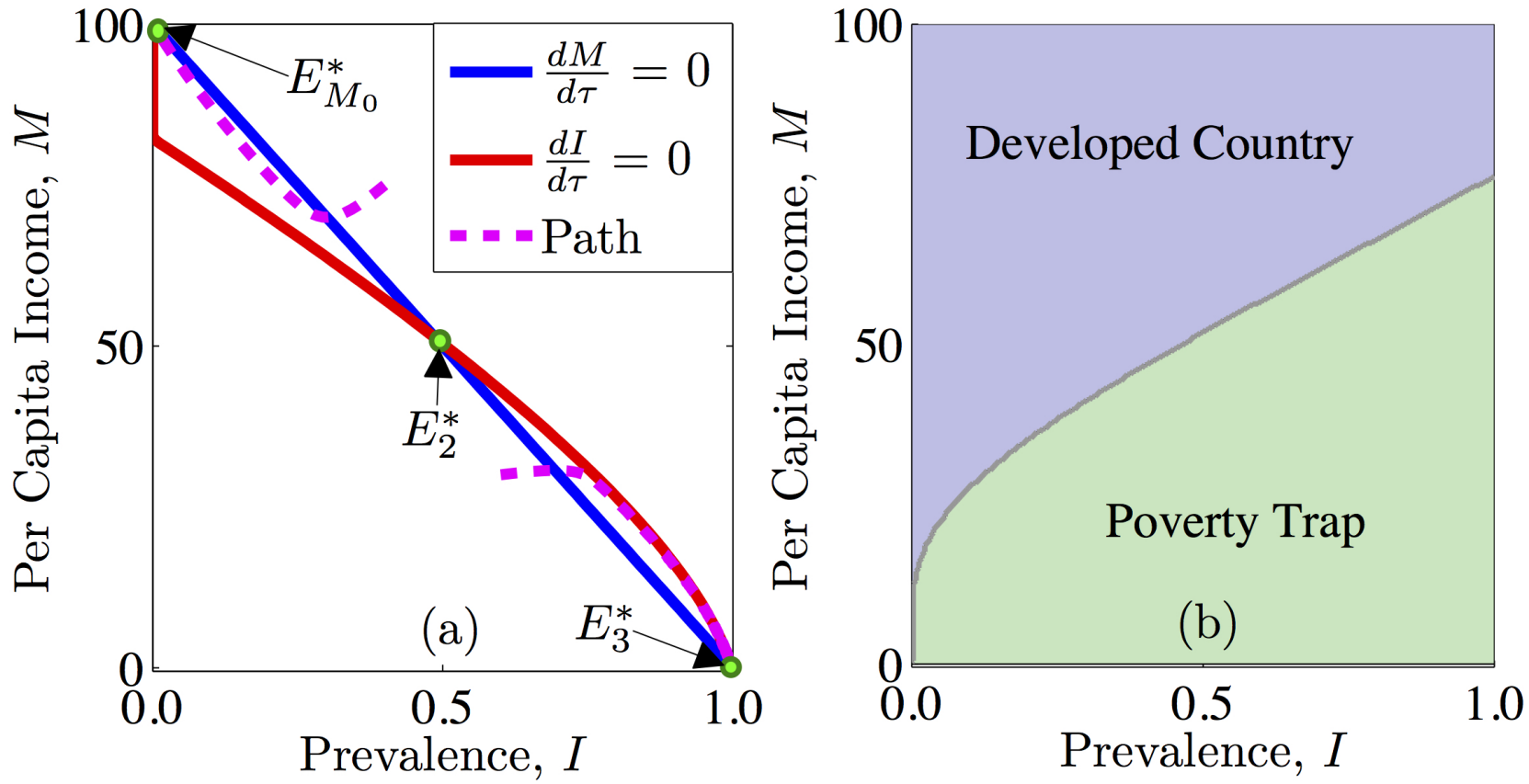
$$\dot{I} = \beta(1 - I)I - (\alpha + \gamma + \nu)I + \nu I^2.$$



Basis of feedback between disease and income

- Disease transmission and recovery depend on income
- Income, M, depends on disease prevalence, I.

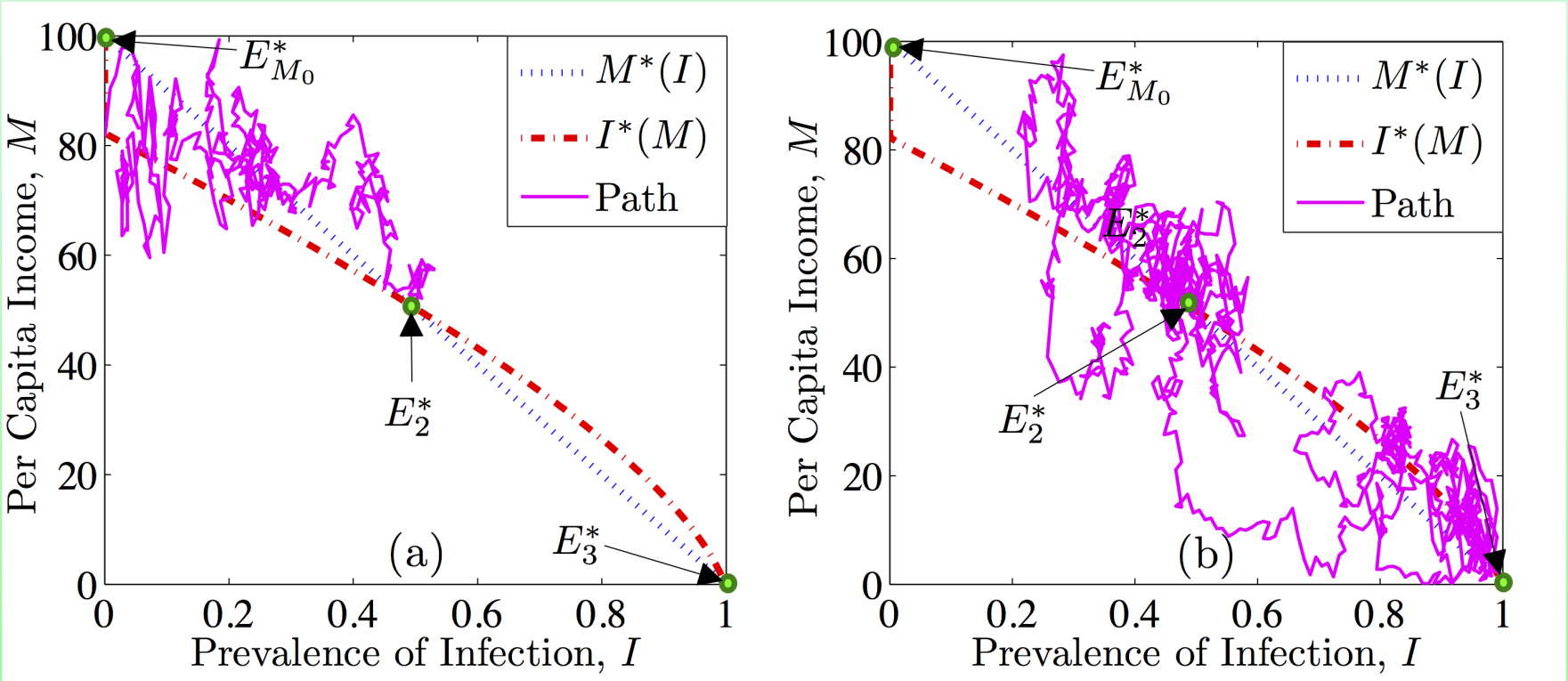
$$\begin{aligned} \dot{I} &= \beta(M)(1-I)I - (\alpha + \gamma(M) + \nu)I + \nu I^2, \\ \dot{M} &= -rM(M - M_0(1-I)). \end{aligned}$$



- The population is stuck in poverty trap or remains developed
- Breaking poverty traps requires substantial efforts

Plucinski MM, Ngonghala CN, Bonds MH (2011) *Journal of The Royal Society Interface*

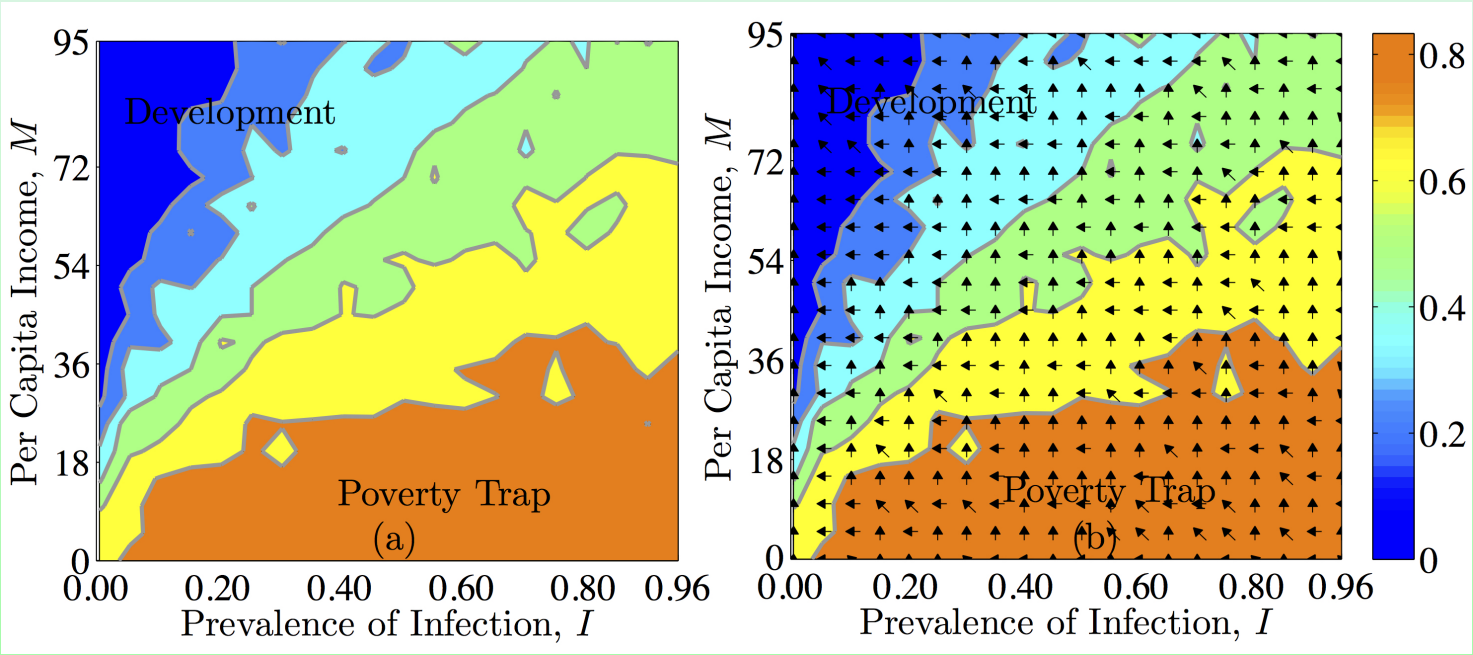
Path to development or poverty trap



Stochastic simulations. $(I, M) = (0.5, 50)$

Plucinski MM, Ngonghala CN, Bonds MH (2011) *Journal of The Royal Society Interface*

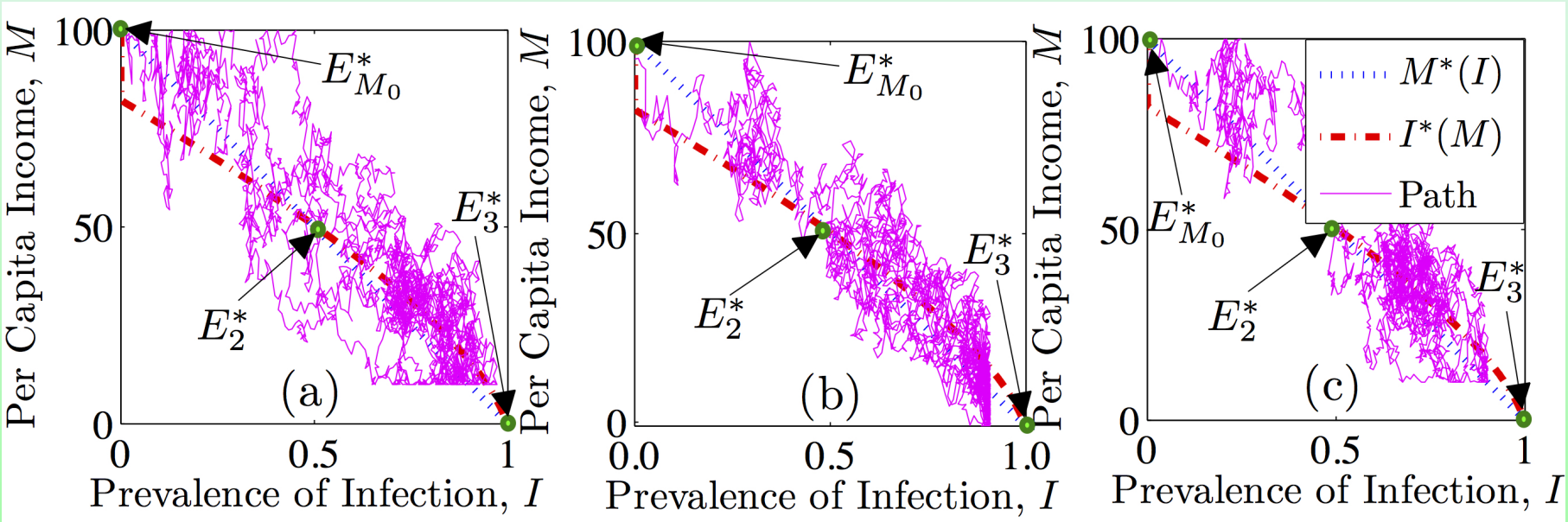
Escaping poverty traps



- Best strategy depends on status of income and disease
  - Increase income when arrow points vertically upward
  - More health when arrow points horizontally to the left
  - Both health and income when arrow points diagonally upwards

Plucinski MM, Ngonghala CN, Bonds MH (2011) *Journal of The Royal Society Interface*

Safety nets

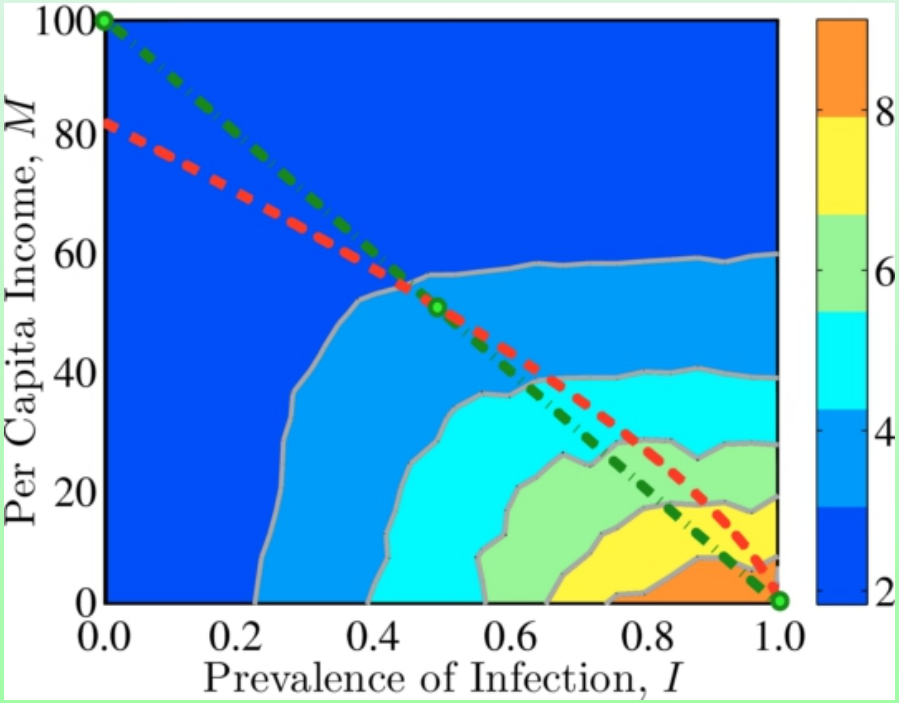


(a) Income safety net, $M = 10$, (b) Health safety net, $I = 0.9$ and (c) Income and health safety net, $I = 0.9, M = 10$.

- Single safety nets can lead to development
- Double safety net leads to shorter time to development

Plucinski MM, Ngonghala CN, Bonds MH (2011) *Journal of The Royal Society Interface*

Rate of development

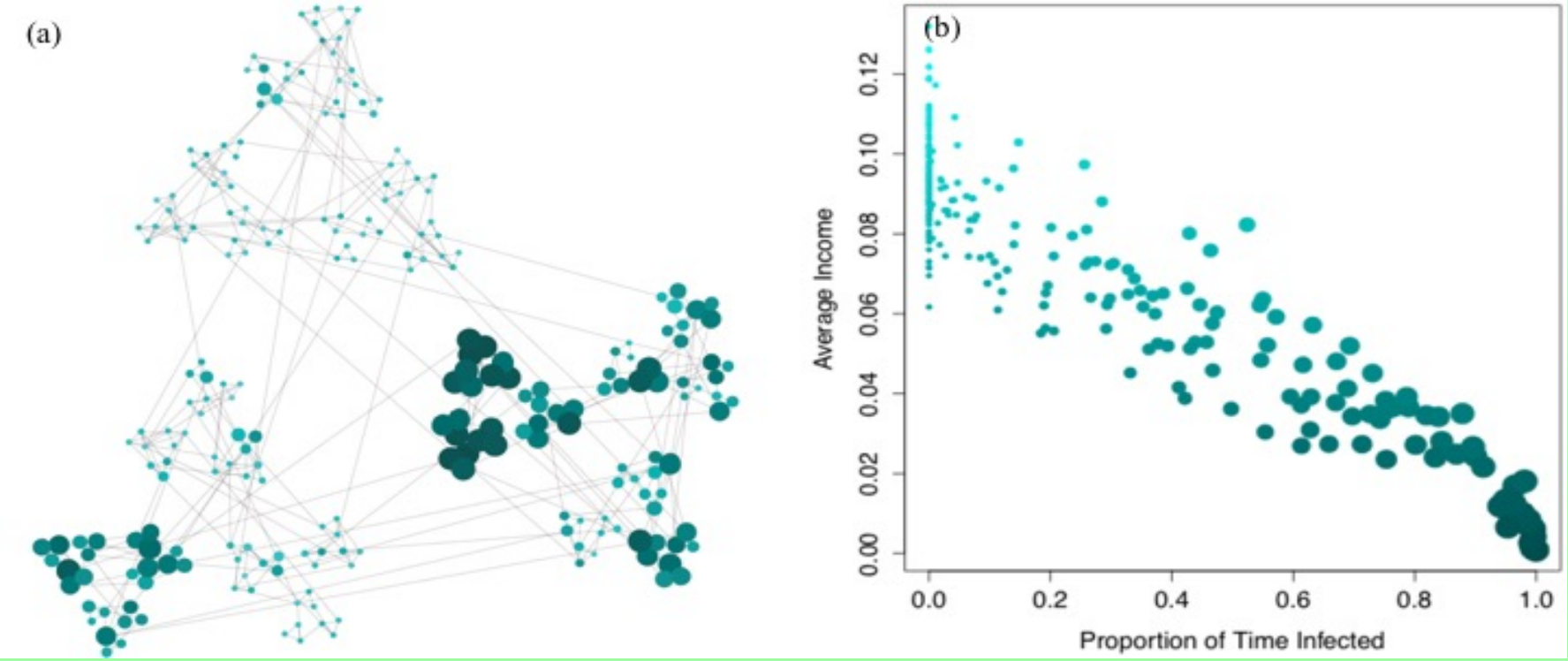


Average time to attain the development equilibrium from initial conditions reinforced by safety nets.

- Location of safety net determines rate of development

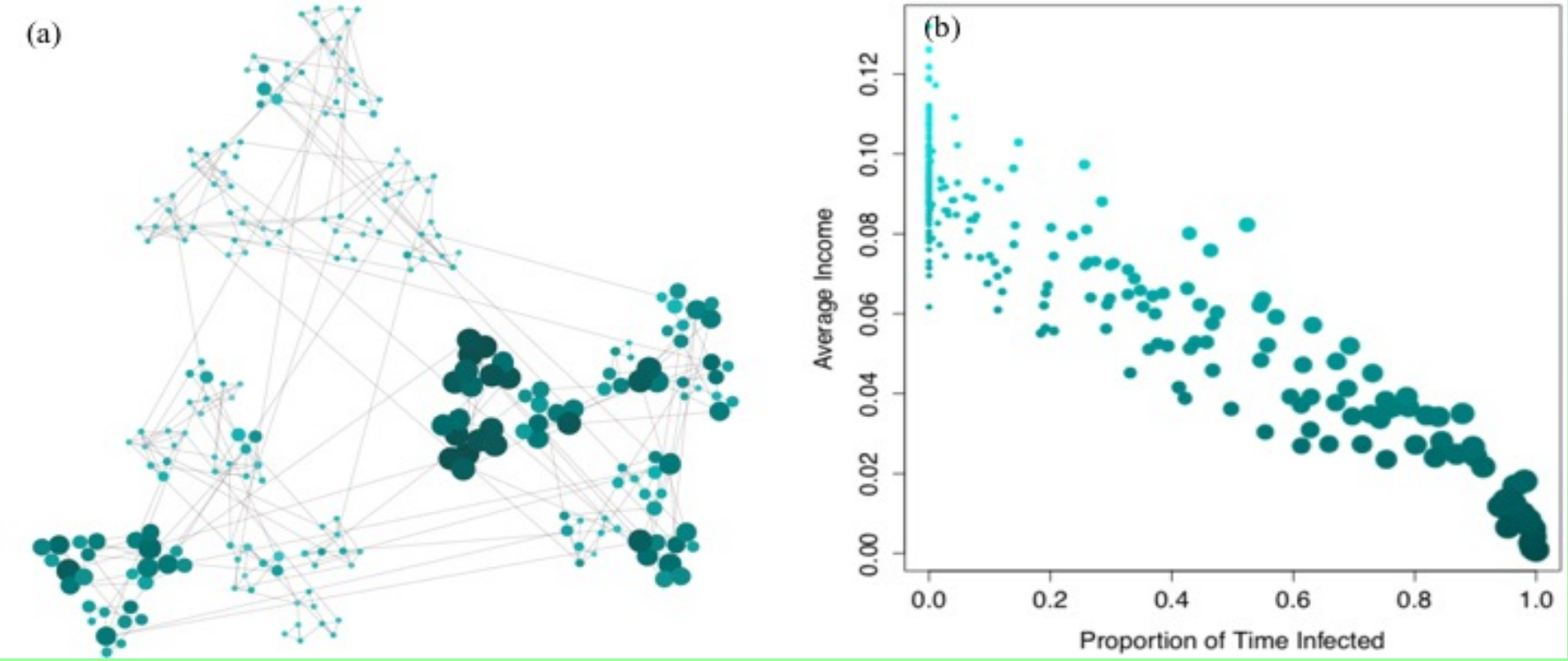
Plucinski MM, Ngonghala CN, Bonds MH (2011) *Journal of The Royal Society Interface*

Within population poverty traps



a)-b) Each point is an individual. Darker points: lower income, larger points: greater time spent infected. a) Equilibrium distribution of health and income in the network.

Within population poverty traps



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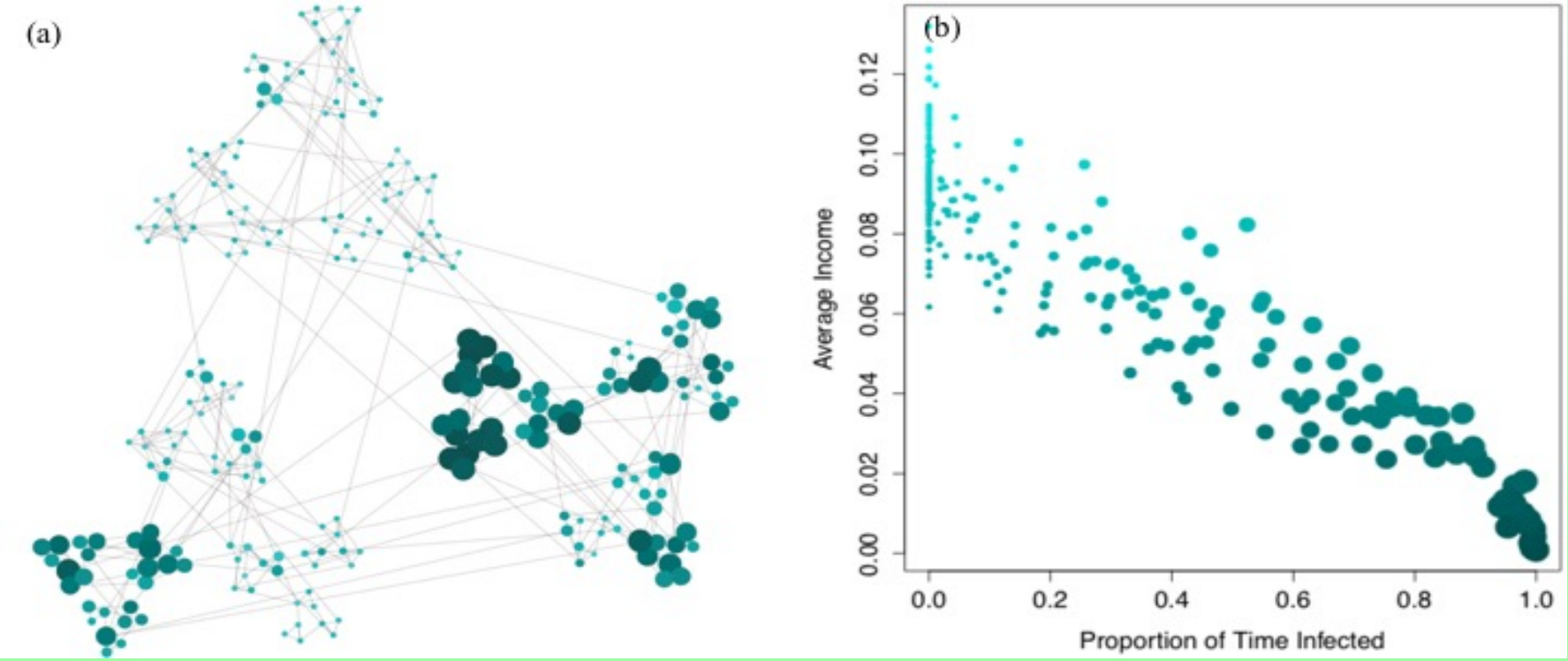
Plucinski et al. (2013) *Journal of The Royal Society Interface*

Within population poverty traps



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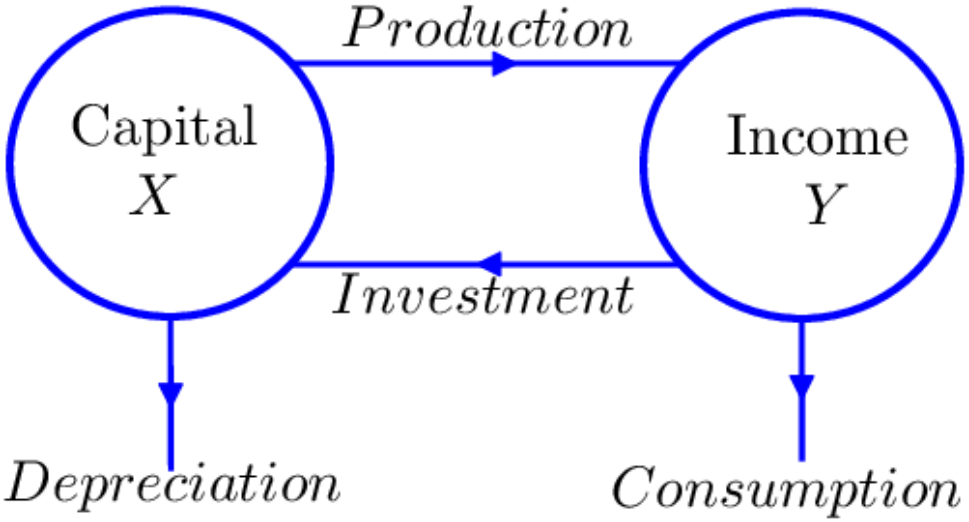
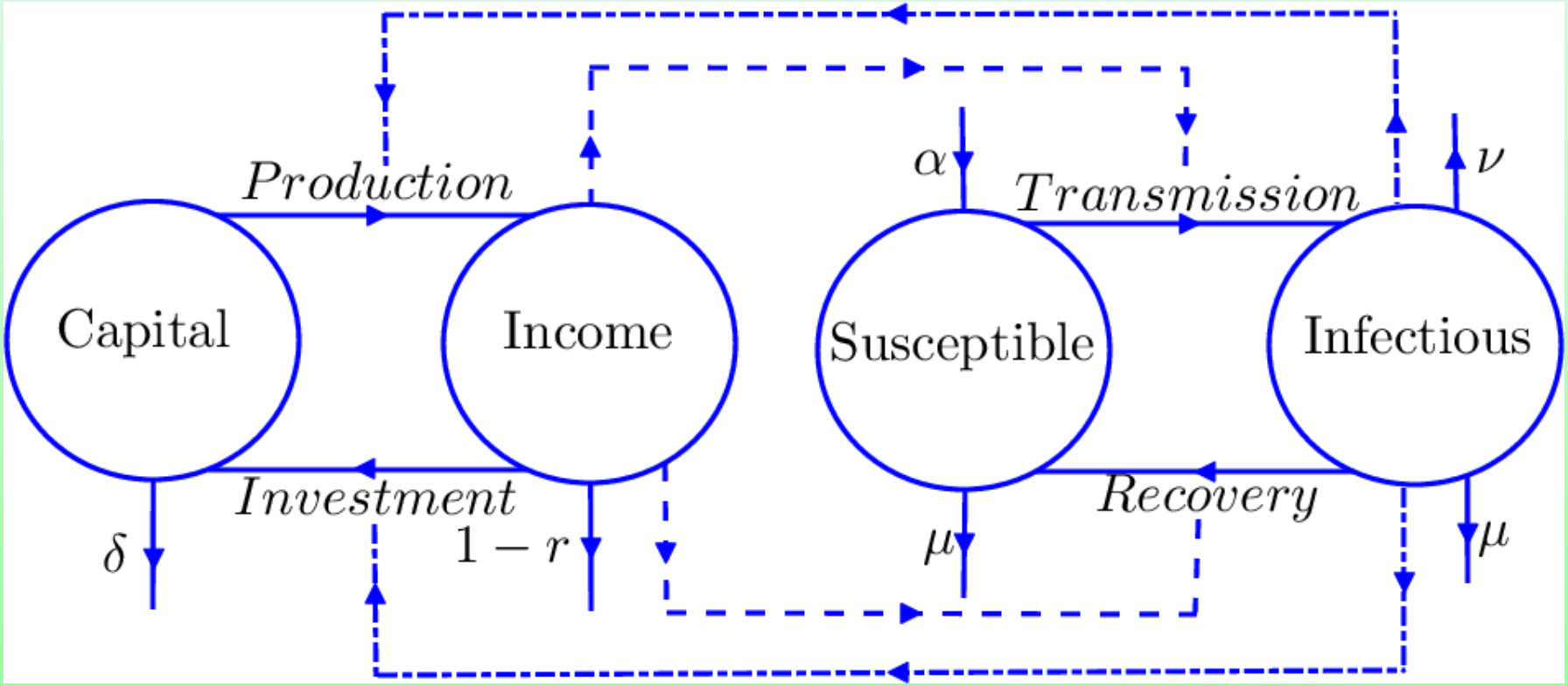
Production function: $Y = f(K, L)$



Solow growth model: *Change in capital = Investment - Depreciation*

R. Solow, 1956, *The Quarterly Journal of Economics*

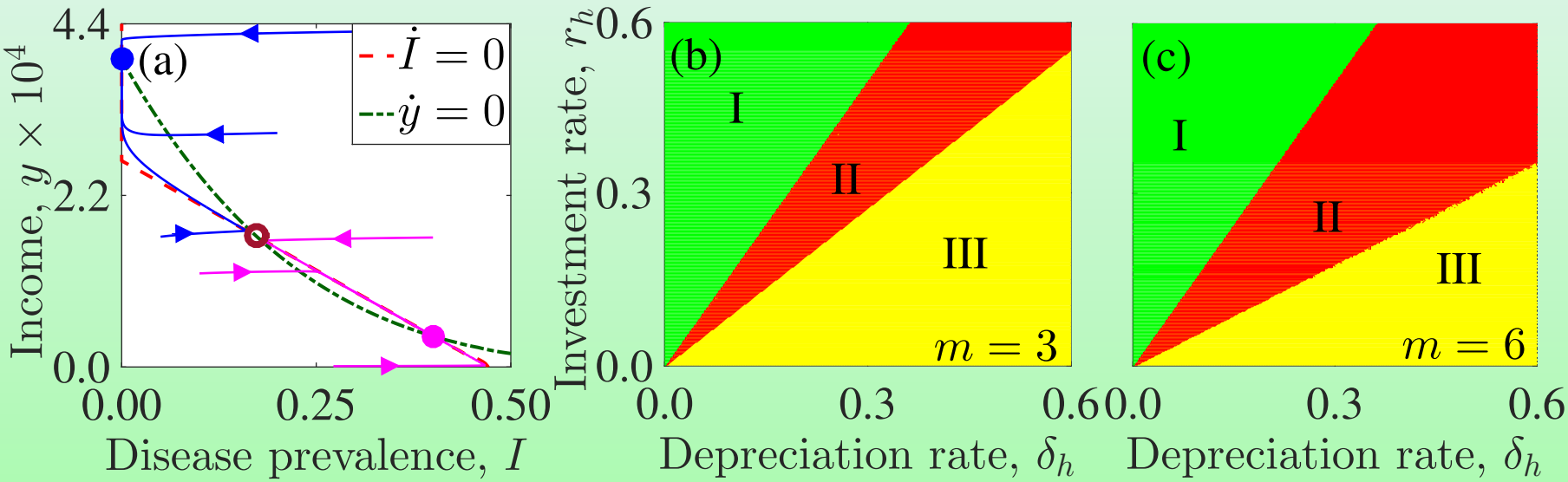
Coupled disease-economic system



$$\dot{I} = \beta(M)(1-I)I - (\alpha + \gamma(M) + \nu)I + \nu I^2,$$
$$\dot{h} = r_h(I)y - \delta h, \quad y(I) = \phi(I)h^\sigma.$$

Ngonghala et al. (2014) *PLoS Biology*

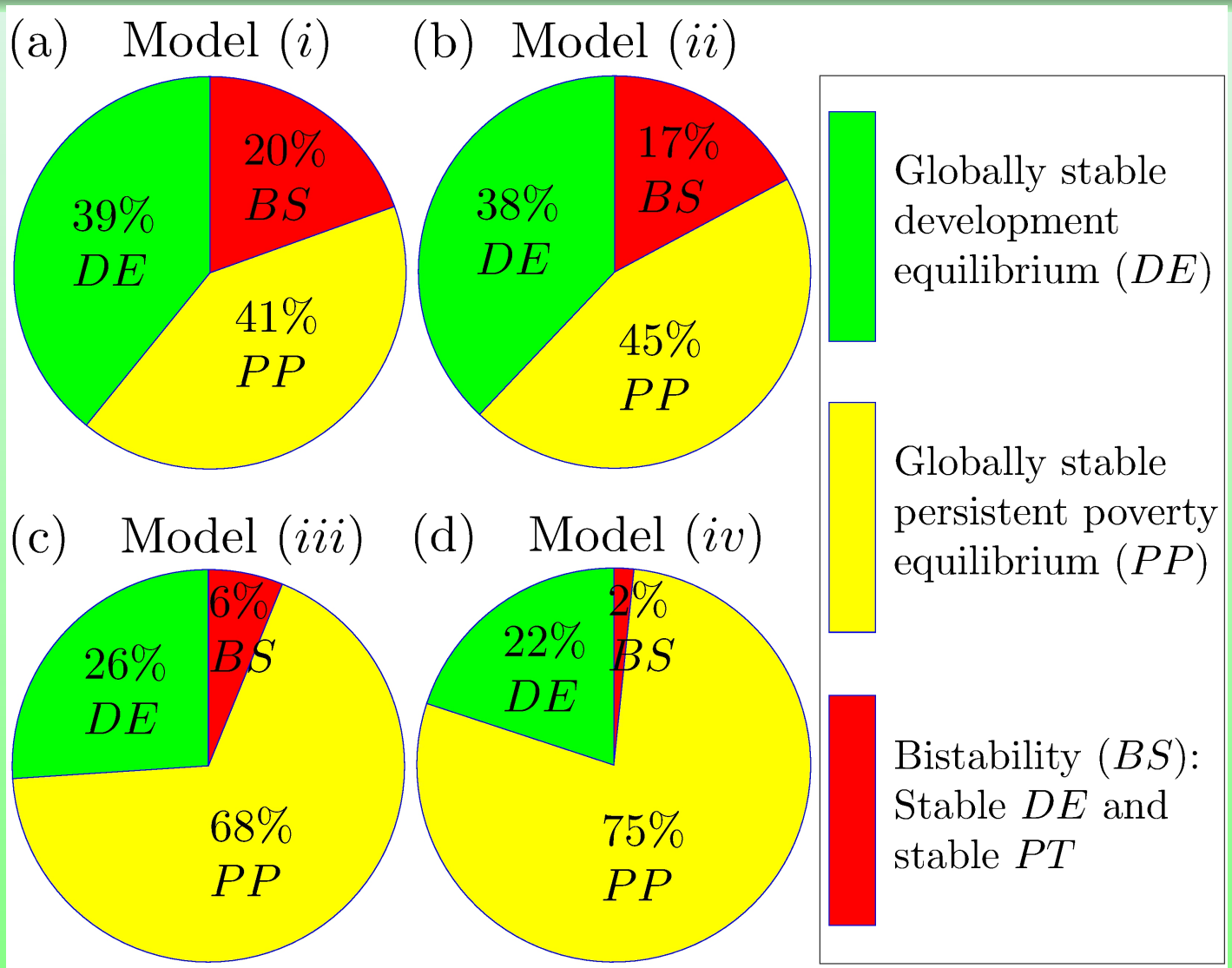
Effect of multiple pathogens on dynamics



- 3 regimes depending on the parameters:
  - global healthy/wealthy development,
  - global poverty, or
  - bistability
- Region of bistability grows with number of pathogens

Ngonghala et al. (2014) *PLoS Biology*

Region of bistability



Summary of results

- All systems exhibit: global healthy/wealthy development, global poverty, or bistability, depending on the parameters
- Bistability is a general property of disease-economic systems
- More complexity results in a larger parameter regime of globally stable poverty
- The overall proportion of parameter space leading to poverty is larger than that for healthy/wealthy development
- Each system is most sensitive to human disease parameters

Buruli ulcer in Cameroon

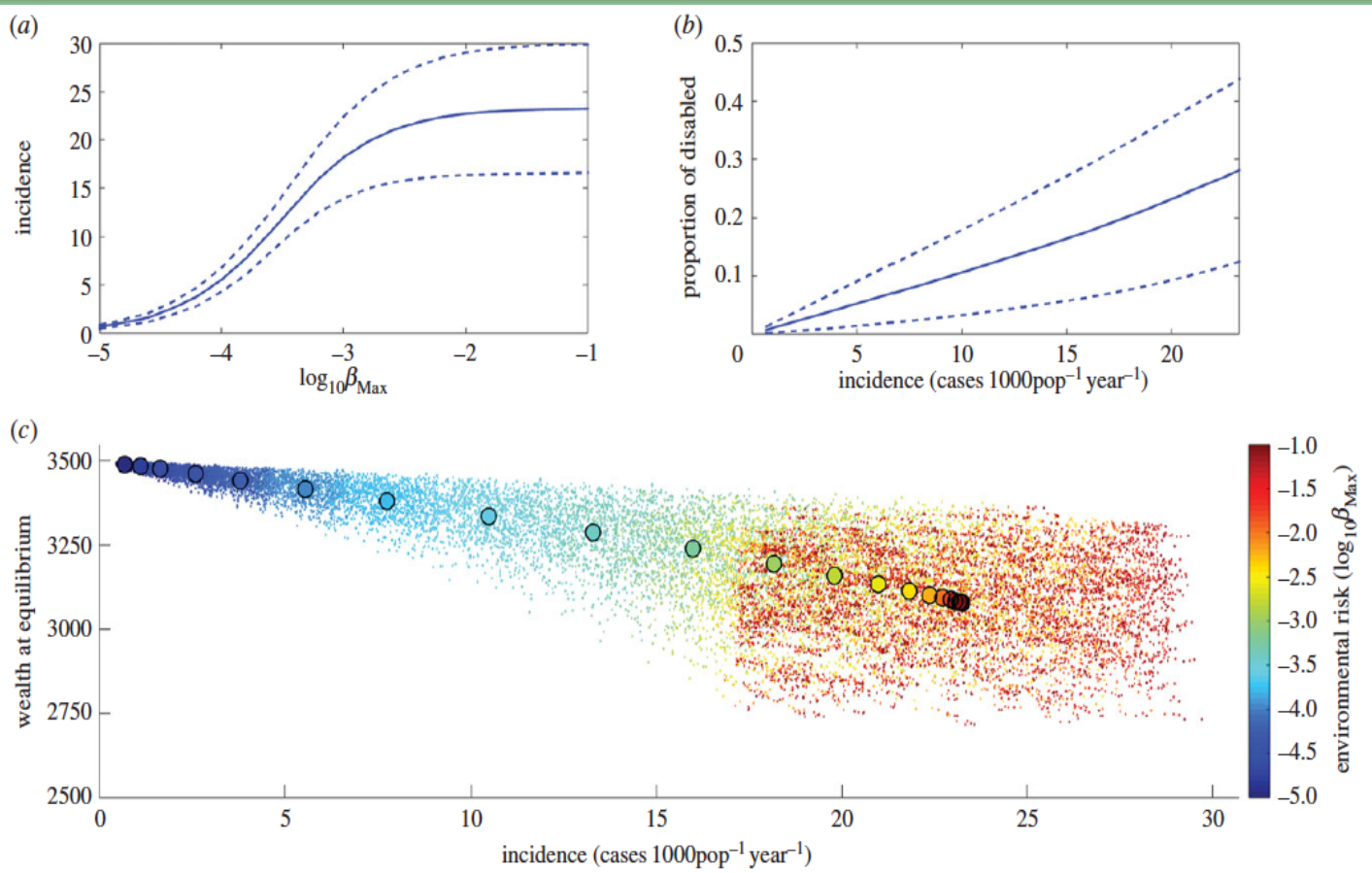
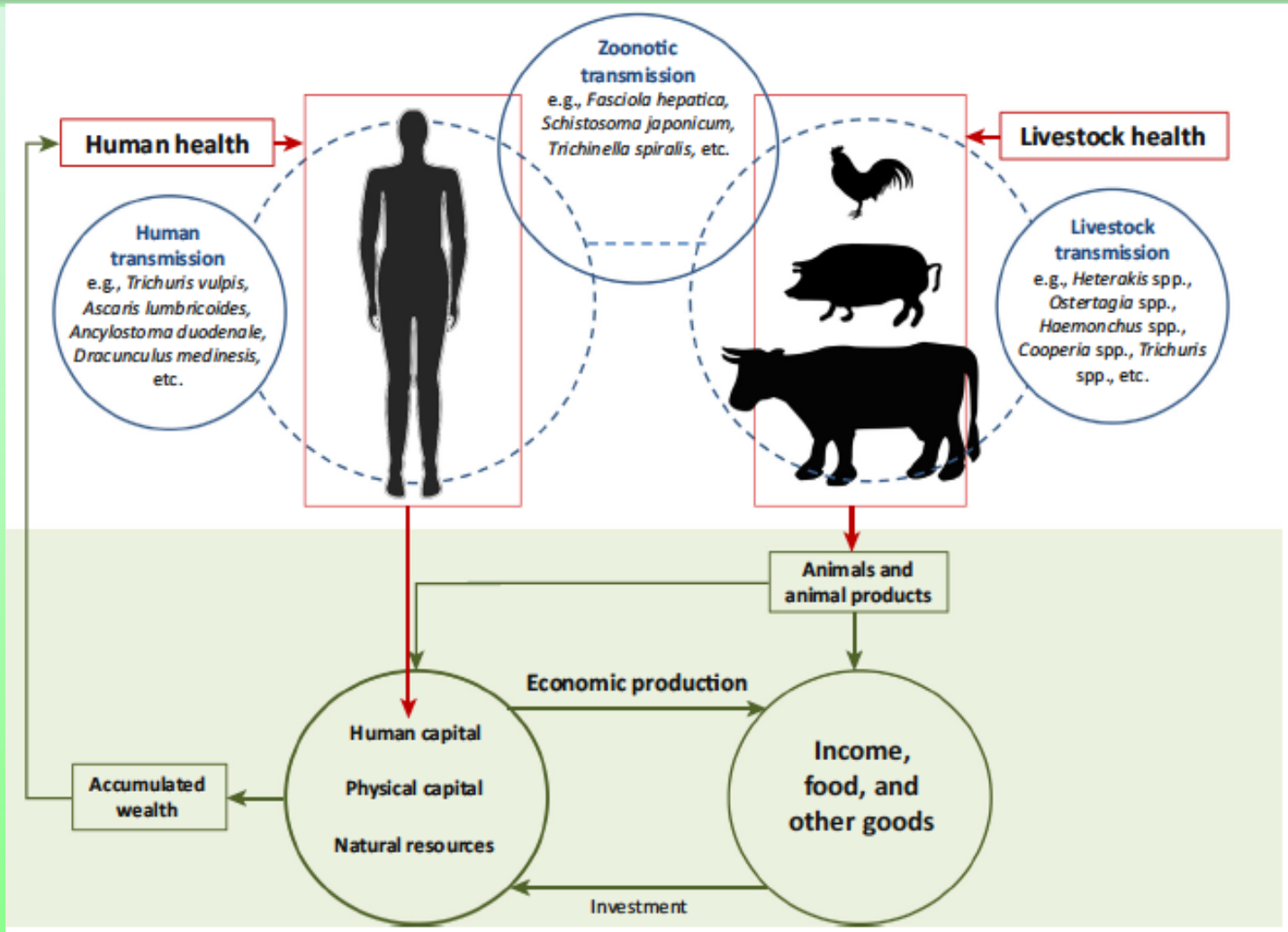


Figure: (a) Incidence vs. transmission, (b) Proportion disabled vs. incidence and (c) Wealth vs incidence.

Garchitorena et al. 2015, *Proceedings of the Royal Society B*

Economic burden of livestock diseases in Madagascar



Rist et al. 2015, *Trends in Parasitology and One Health*

Acknowledgements

Collaborators

- Matthew Bonds (Harvard Medical School)
- Giulio de Leo (Stanford University)
- Mercedes Pascual (University of Chicago)
- Andrew Dobson (Princeton University)
- Donald Keenan (Université Cergy-Pontoise, France)
- Andrés Garchitorena (Harvard Medical School)
- Cassidy Rist (Emory University)
- Mateusz Pluciński (Centers for disease control)
- Megan Murray (Harvard Medical School)
- Paul Farmer (Harvard Medical school)
- Wayne Getz (University of California, Berkeley)

Institutes

- National Socio-Environmental Synthesis Center
- National Center for Ecological Analysis and Synthesis
- National Institute for Mathematical and Biological Synthesis