

Disease and Economic Development

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based on joint work with Simon Johnson

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Questions

- What is the relationship between health and economic development?
- Are differences in health conditions and disease environments (e.g., tropics) a major cause of today's large gap in income per capita between rich and poor countries?
- How does the relationship between health and economics depend on population?
 - And what about the relationship between population and growth?

Recently Emerging Consensus

- Jeff Sachs and others: disease burden a big barrier to economic growth.
 - For example, Africa's growth deficit due to disease.
- Recent WHO commission (p.24 and p.i):
 - “in today's world, poor health has particularly pernicious effects on economic development in sub-Saharan Africa, South Asia, and pockets of high disease and intense poverty elsewhere”
 - “...extending the coverage of crucial health services... to the world's poor could save millions of lives each year, **reduce poverty, spur economic development** and promote global security”

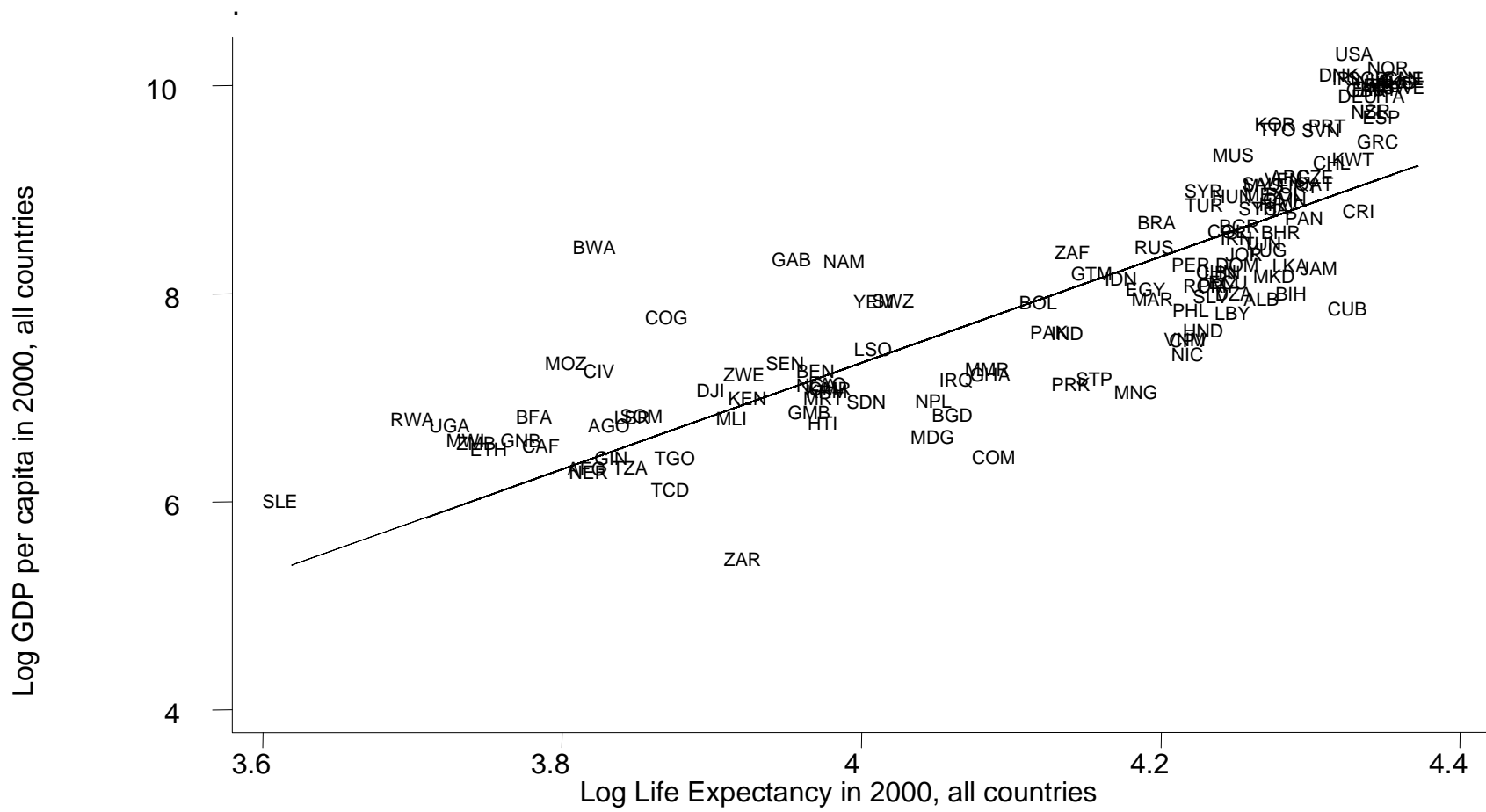
Possible Concerns

- Investing in health is an **excellent** social policy goal, for humanitarian reasons.
 - But the case that it will foster significant economic growth and close the income gap between rich and poor countries is much weaker.
 - And in thinking about the disease-growth link, we can not ignore population.
- If it is not in fact true that differences in health are a significant cause of the economic gap between poor and rich countries, then
 - we will be misled in our attempts to understand real sources of cross-country income differences
 - key complementary policy changes may be missed
 - potentially valuable health programs may be abandoned because they fail to meet their stated goal of stimulating economic growth.

Health and Economic Development

- Well-established positive cross-country correlation between measures of health (e.g., life expectancy) and income per capita.
- But what this cause and what is effect?
 - E.g., well-established in demography that rising income lengthened lives in 19th and early 20th centuries
 - Ample evidence for the effect of poor sanitary conditions and nutrition on health.
- Plausible micro reasons why unhealthy people are less productive or are less able to invest in human capital.
- But how to go from partial to [general equilibrium](#)?

Figure 0: Log GDP per capita against life expectancy in 2000
(all countries)



Health and Economic Development in General Equilibrium

- Why care about **general equilibrium**?
- That's the level where questions about economic growth are formulated and welfare can be evaluated.
- Micro effects may not always translate into macro effects because of general equilibrium.
 - Increase in health often comes with increase in population.
 - Possible “rat race” effects of health and the labor market.
- Also, difficult to infer macro effects from micro estimates, which range from very small to large, with substantial confidence intervals.
- Need for theory and estimates that exploit equilibrium differences.

The Crude Big Picture

- Life expectancy at birth as key measure of health.
- Relatively exogenous convergence in life expectancy between 1940 and 1980 around the world: Figure 1.
- No similar convergence in economic fortunes: Figure 2.
- Natural specification has fixed country and time effects: otherwise serious omitted variable bias and not interpretable
- Focus on “exogenous” convergence in life expectancy; otherwise bias in either direction:
 - Positive: because life expectancy may increase more in places with greater growth potential
 - Negative: because life expectancy may increase more in places with initial lower life expectancy (and this could have a negative long-run effect on growth)

Figure 1: Log life expectancy at birth for initially rich, middle-income and poor countries

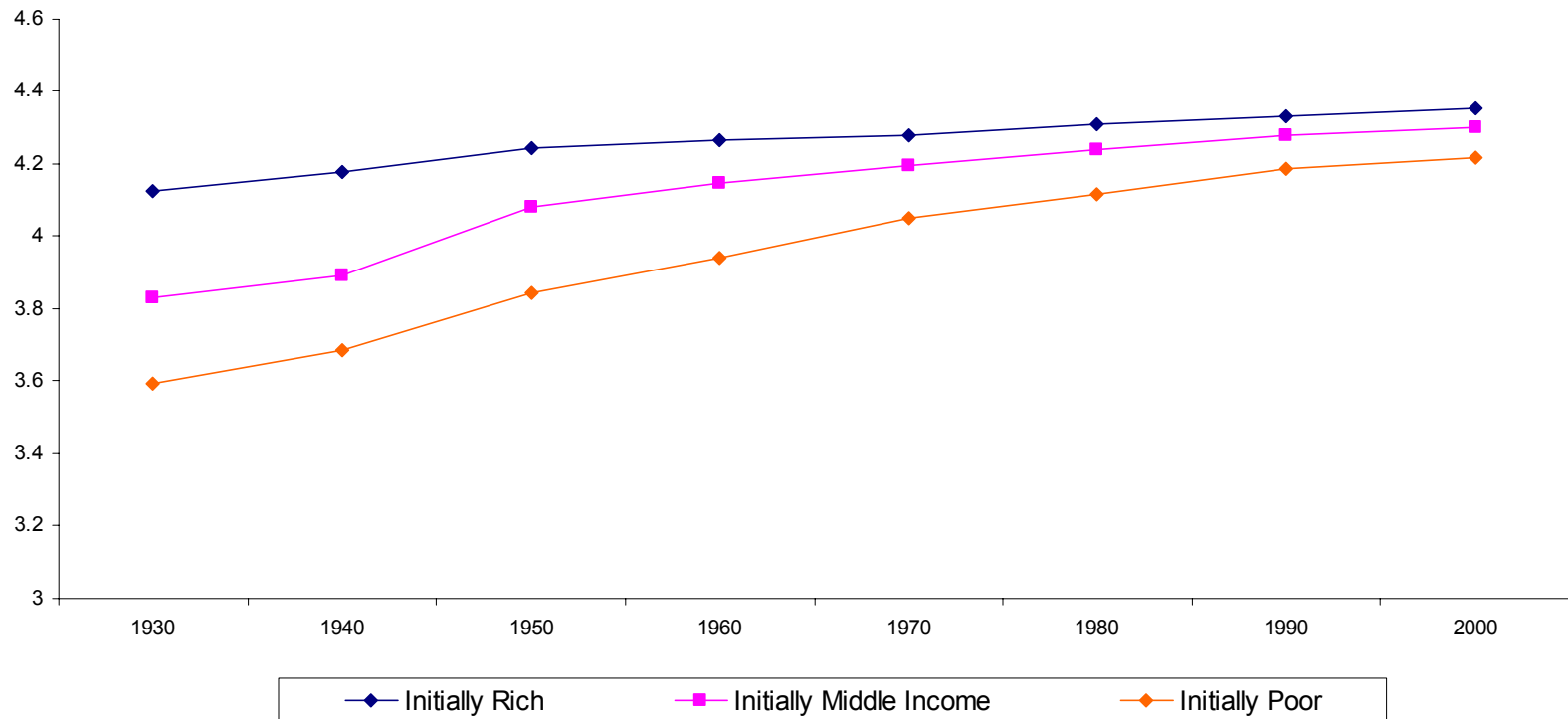
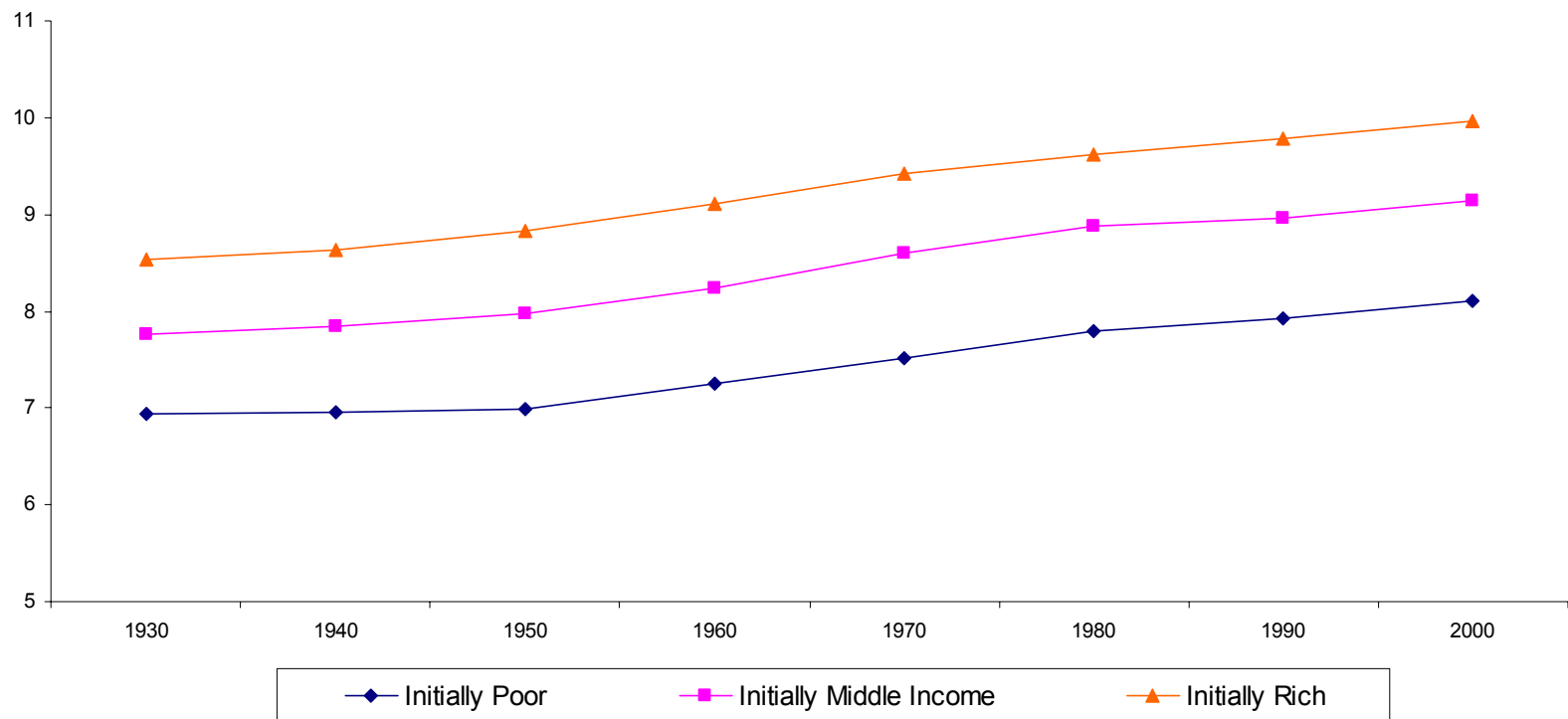


Figure 2: Log GDP per capita for initially rich, middle-income and poor countries



International Epidemiological Transition

- Need a source of large and exogenous variation in health.
- Candidate: the “international epidemiological transition” 1940s and 1950s
 - invention of new drugs (antibiotics), vaccines (yellow fever), and chemicals (DDT)
 - extension of public health programs to high-mortality areas of the world during and after World War II: WHO.
 - successful campaigns against malaria in Asia and Americas and spread of immunization and antibiotics in LDCs.
- Before this transition (e.g., 1920s and 1930s) life expectancy low in Latin America, South Asia, and Africa because of tuberculosis, malaria, pneumonia, influenza, typhoid, smallpox, yellow fever, cholera, and other infectious diseases.

Health Interventions

- Most major improvements after 1940, although some before.
- Samuel Preston:

“It seems to have been predominantly broad-gauged public health programmes of insect control, environmental sanitation, health education, and maternal and child health services that transformed the mortality picture...”

After the 1930s, “Universal values assured that health breakthroughs in any country would spread rapidly to all others...”
- Therefore, in the 1940s and 1950s, big relatively exogenous improvements in health in Latin America, South Asia and Eastern Europe.
- Consequently, LDCs in the 1960s and today **much** healthier than Western Europe at a comparable stage of development:
 - life expectancy in India in 1999 around **60**, and Britain in 1820, \approx **40**.
- **Important:** interventions improving overall health and morbidity, not just mortality.

Theoretical Considerations

- Better health (longer life expectancy) expected to increase income per capita by improving the productivity of workers (“TFP” of the economy) and encouraging more education.
- But at the same time, greater population may reduce the capital labor ratio (and also the per-person resources in the education sector), especially if the country in question does not have access to international capital markets and has inelastic savings.
- Potential negative effects in the “medium run”.

Aggregate Production Function

- Suppose economy i has aggregate production function; standard neoclassical properties

$$Y_{it} = (A_{it}H_{it})^\alpha K_{it}^\beta L_{it}^{1-\alpha-\beta},$$

where H_{it} is the effective units of labor given by

$$H_{it} = h_{it}N_{it}$$

N_{it} is total population and everybody works; h_{it} is human capital per person in country i at time t .

- Throughout, ignore technological progress
- Capital depreciates at the rate δ and the savings rate of this country is constant at s_i , then

$$K_{it+1} = s_i Y_{it} + (1 - \delta) K_{it}$$

Effects of Better Health

- Let X_{it} be life expectancy at birth or similar health variable.
- To model the effect of health on productivity, suppose that

$$A_{it} = \bar{A}_i X_{it}^\gamma \text{ and } h_{it} = \bar{h}_i X_{it}^\eta, \quad (1)$$

- Naturally, better health will also lead to greater population (both directly and also potentially indirectly through fertility), so let

$$N_{it} = N_i X_{it}^\lambda$$

Long Run Effects

- In the long run, once the capital stock has adjusted, we have

$$y_i = \text{constant} + \frac{1}{1-\beta} (\alpha(\gamma + \eta) - (1 - \alpha - \beta)\lambda) x_i$$

where $x_i \equiv \log X_i$ is log life expectancy and $y_i \equiv \log (Y_i/N_i)$.

- Increase in life expectancy will lead to significant increase in long-run income when
 - there are limited diminishing returns
 - there is a substantial externality on technology,
 - encourages increase in human capital
 - not increase population

Medium Run Effects

- However, in the “medium run,” for many of the countries in question, the capital stock might be fixed or adjust only slowly.
- In this case, we have

$$\frac{Y_i}{N_i} = \bar{K}_i^\beta (A_i h_i)^\alpha N_i^{-(1-\alpha)}$$

or

$$y_i \equiv \text{constant} + (\alpha (\gamma + \eta) - (1 - \alpha) \lambda) x_i.$$

- Therefore, negative or zero effects possible.
- We may expect medium run effects over 20-50 year horizons, since working age population increases with a 20-30 year delay following initial increases in life expectancy.

Simple Estimating Framework

- Our approach: fixed effect regressions to remove fixed factors affecting both health and economic outcomes:

$$y_{it+k} = \pi x_{it} + \zeta_i + \mu_t + Z'_{it}\beta + \varepsilon_{it+k}$$

where y could be log population, log GDP, log GDP per capita, log GDP per working age population, fertility or education.

- We can look at various leads to capture medium-run effects of improved life expectancy and health.

Identification Problem and Strategy

- But correlation is not causation.
- **Identification problem:** $Cov(x_{it}, \varepsilon_{it+k})$ not equal to 0, because even conditional on fixed effects, health endogenous to economics.
- Implication: ordinary least square regressions (just like correlations) potentially biased.
- Potential solution: exploit potentially exogenous source of variation in life expectancy because of interventions.
- Instrumental variables strategy.

Empirical Methodology

- Construct a data set of disease mortality and potentially-exogenous U.N. interventions and vaccine/drug discovery.
- Construct **predicted mortality** based on exogenous interventions.
- Examples:
 - Mass production of antibiotics after World War II.
 - USAID and WHO anti-malaria campaigns, with discovery and use of DDT against malaria.
 - WHO drive to eradicate smallpox, after Soviets joined (following Stalin's death).
- Use predicted mortality as **econometric instrument** for life expectancy.

Evidence of Large Health Effects? (OLS, fixed effects)

- Strong effect of life expectancy on population, with an elasticity between 1 and 2 (Table 2).
- Strong effect on total number of births (consistent with some increase in fertility) (Table 2).
- Positive and typically significant effect of life expectancy on total GDP (Table 3).
- No evidence of a positive effect of life expectancy on GDP per capita (Table 3).
- But these effects not necessarily causal (positive or negative biases possible).

Table 2

Life Expectancy, Population, and Births: OLS Estimates

	<i>All Countries</i>	<i>Base Sample</i>		<i>Low & Middle Income Countries</i>
	No leads (1)	No leads (2)	No leads (3)	No leads (4)
<i>Panel A: Dependent variable is log population</i>				
	Panel, 1960- 2000	Panel, 1960- 2000	Panel, 1940- 1980	Panel, 1940- 1980
Log Life Expectancy	1.46 (0.29)	1.69 (0.43)	1.21 (0.20)	1.24 (0.28)
Number of observations	600	294	282	249
Number of countries	120	59	59	48

Table 3 (part 1)

Life Expectancy, GDP and GDP per capita: OLS Estimates

	<i>All Countries</i>	<i>Base Sample</i>		<i>Low & Middle Income Countries</i>
	No leads	No leads	No leads	No leads
	(1)	(2)	(3)	(4)
<i>Panel A: Dependent variable is log GDP</i>				
	Panel, 1960- 2000	Panel, 1960- 2000	Panel, 1940- 1980	Panel, 1940- 1980
Log Life Expectancy	1.35 (0.49)	1.70 (0.45)	0.73 (0.35)	0.65 (0.42)
Number of observations	600	294	283	228
Number of countries	120	59	59	48

Table 3 (part 2)

Life Expectancy, GDP and GDP per capita: OLS Estimates

	<i>All Countries</i>	<i>Base Sample</i>		<i>Low & Middle Income Countries</i>
	No leads	No leads	No leads	No leads
	(1)	(2)	(3)	(4)
<i>Panel C: Dependent variable is log GDP per capita</i>				
	Panel, 1960- 2000	Panel, 1960- 2000	Panel, 1940- 1980	Panel, 1940- 1980
Log Life Expectancy	-0.10 (0.48)	0.003 (0.46)	-0.44 (0.30)	-0.44 (0.23)
Number of observations	600	294	283	228
Number of countries	120	59	59	48

Interpreting the Estimates

- To interpret the effect of (log) life expectancy on (log) population, suppose each individual faces a Poisson death rate of $1/a$; Life expectancy then equal to a .
- Assume flow of total births is only a function of life expectancy, $B(a)$
- The flow of deaths is N/a .
- Equating and taking logs gives steady state population

$$\ln N = \ln a + \ln B(a).$$

- In our fixed effect regression, elasticity of 1 possible only when total number of births remains constant in response to an increase in life expectancy (a decline of fertility)
- If no decline in fertility, expect an elasticity greater than 1 (perhaps substantially greater).

Interventions (Details)

- Tuberculosis: primarily caused by *Mycobacterium tuberculosis*, transmitted through the air.
 - Control methods: early treatment with streptomycin.
 - Discovery of streptomycin in 1944 (Nobel Prize in 1952).
 - Campaign against tuberculosis starting in the 1940s and intensifying in the 1950s.
 - Some return of TB as secondary infection to AIDS.

Interventions (Details, continued)

- Malaria: caused by any of four types of parasites, transmitted by the bite of an infected female *Anopheles* mosquito.
 - Control method: control of mosquito vectors, more effective with DDT, and also draining of swamps and use of mosquito nets. Also use of quinine, chloroquine and successors.
 - Campaigns against malaria: use of DDT starting in the 1940s (e.g., Greece), 1955 WHO campaign decision and 1957 start of global campaign.
 - Reappearance of malaria in the 1970s-80s due to relaxation of international efforts, ban on the use of DDT, and development of insecticide resistant mosquitoes and drug-resistant strains of malaria.

Interventions (Details, continued)

- Pneumonia: caused by a variety of infectious agents and toxins, including various bacterial and viral pathogens.
 - Frequently, secondary infection, and cause of death, in cases of tuberculosis, influenza, and more recently AIDS.
 - Antibiotics, esp. penicillin, highly effective against bacterial pneumonia in the 1940s (resistant strains developed).
 - Also starting in the 1940s, partially effective vaccines.
- Cholera: caused by the bacterium *Vibrio cholerae*, transmitted by drinking contaminated water or eating contaminated food.
 - Control methods: public health and environmental hygiene, rehydration, use of antibiotics to reduce the duration of symptoms.
 - No global campaign, but WHO efforts to deal with sanitary conditions and outbreaks.

Interventions (Details, continued)

- Yellow fever: caused by yellow fever virus, transmitted by the bite of infected *Aedes aegypti* mosquito.
 - Control method: vaccination and control of the mosquito vector.
 - Development of the first vaccine by Max Theiler in the 1930s (Nobel Prize in 1951), vaccination starting in the 1940s.
 - Yellow fever largely but not entirely eradicated (still present in animals, reappearing in Liberia).
- Dysentery (*Shigella*): caused by bacteria or a specific protozoan, transmitted by person to person contact or contaminated water and food.
 - Control method: public health and environmental hygiene, antibiotic and rehydration.
 - Campaign thanks to antibiotics of the 1940s.

Interventions (Details, continued)

- Influenza: caused by various strains of the influenza virus, transmitted by air; often leading to secondary bacterial infections.
 - Control method: vaccination, but also use of antibiotics reduces deaths from secondary infections.
 - No global campaign to eradicate influenza, but WHO efforts to control and track starting in the 1950s.
- Smallpox: caused by various strains of viruses, transmitted by air.
 - Control method: vaccination.
 - Campaign against smallpox: WHO resolution in 1958, intensified in 1967. In 1979, smallpox declared entirely eradicated.

Exploiting Changes from the International Epidemiological Transition

- Construct an instrument for changes in life expectancy from the international epidemiological transition.
- Mortality in country i from disease d at time t : M_{dit} .
- Then econometric instrument: predicted mortality:

$$M_{it}^I = \sum_d ((1 - \Delta_{dt})M_{di,40} + \Delta_{dt}M_{dFt})$$

where M_{di40} is pre-period mortality, and Δ_{dt} is a dummy for intervention for disease d at time t .

- M_{dFt} : frontier mortality rate.
- Note Δ_{dt} not subscripted by i ; no issues of endogeneity of “takeup” (similar to the effect of treatment on the treated).
- Loosely speaking:
Predicted Mortality \approx predicted number of deaths due to baseline diseases
- Changes in pretty good mortality only from interaction of initial disease distribution and world-level timing of interventions/campaigns.

Instrumental Variables Strategy

- Instrumental variables strategy to obtain causal effects.
- Use predicted mortality as a source of variation in life expectancy at birth.
- First stage of the instrumental variables strategy

$$x_{it} = \psi M_{it}^I + \tilde{\zeta}_i + \tilde{\mu}_t + Z'_{it}\tilde{\beta} + u_{it}$$

where M_{it}^I is predicted mortality driven by “exogenous” factors.

- Identifying assumption: $Cov(M_{it}^I, \varepsilon_{it+k}) = 0$

Construction

- Mortality rate from a disease goes to the “frontier”, which is zero in the base case, if there is a global intervention for that disease. Until then, it stays at its preperiod (1940) value.
- Data on mortality from tuberculosis, malaria, pneumonia, influenza, measles, yellow fever, smallpox, plague, dysentery, typhus, cholera, typhoid, whooping cough, and diphtheria
 - Caution: classification of deaths to various diseases not exact, especially during this period.
- Interventions: discovery and production of new drug, vaccine, or chemical acting against the disease; or WHO campaign.

Zeroth-Stage Estimates

- Figure: Global mortality from TB, pneumonia and pneumonia declines with intervention at the right time.
 - Control group: cancers and tumors.

- Zeroth stage regression:

$$M_{idt} = \theta \Delta_{dt} + \mu_t + \pi_d + \delta_i + v_{it}$$

- Decline in mortality when there is an intervention for that particular disease, i.e., $\theta < 0$.
- See Table 4
 - Large and significant estimates of θ .
 - Current value of Δ_{dt} , not lead or lag, significant.
 - Similar results for each disease separately.

Figure 3: Average mortality rates from cancer, malaria, tuberculosis and pneumonia (deaths per 100,000 per annum)

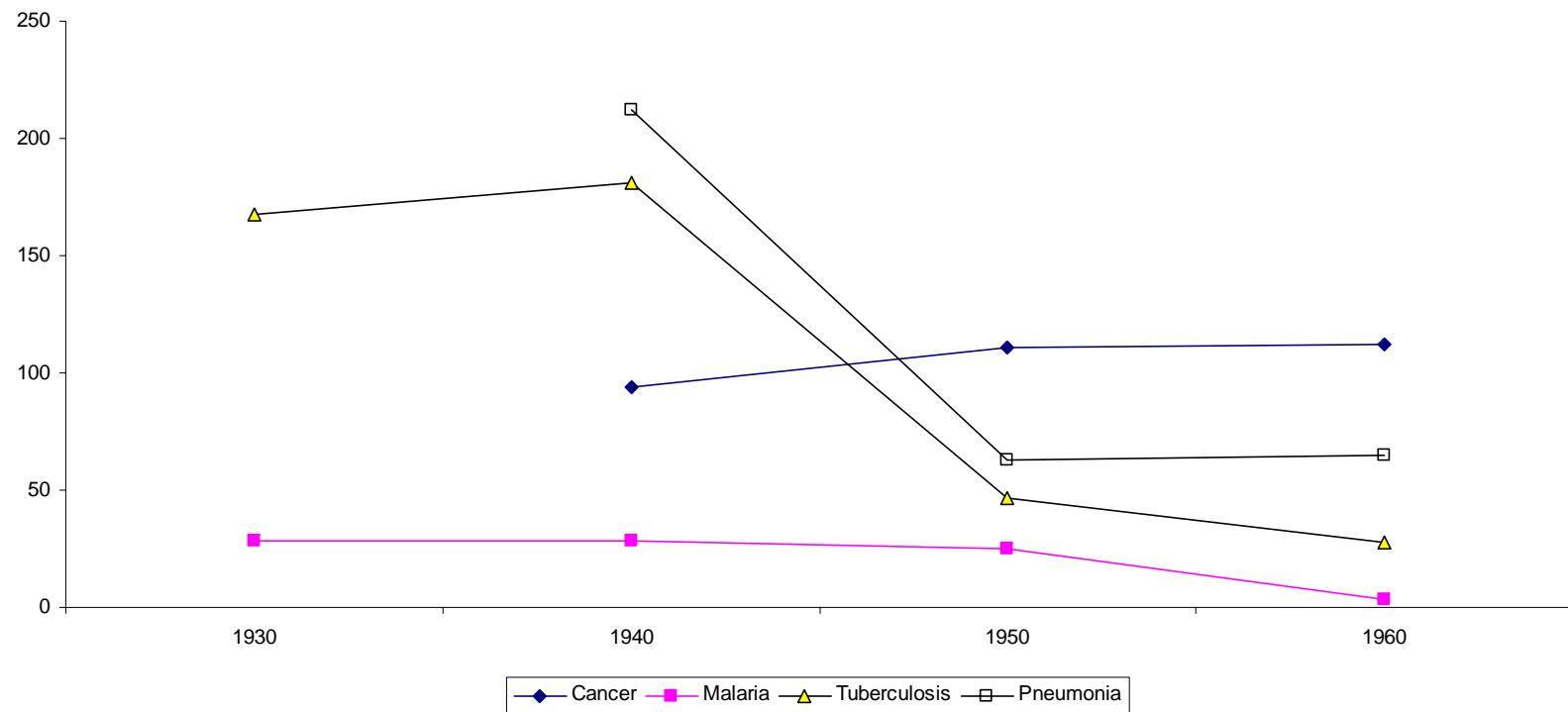


Figure 3: Average mortality rates from cancer, malaria, tuberculosis and pneumonia
(log deaths per 100,000 per annum)

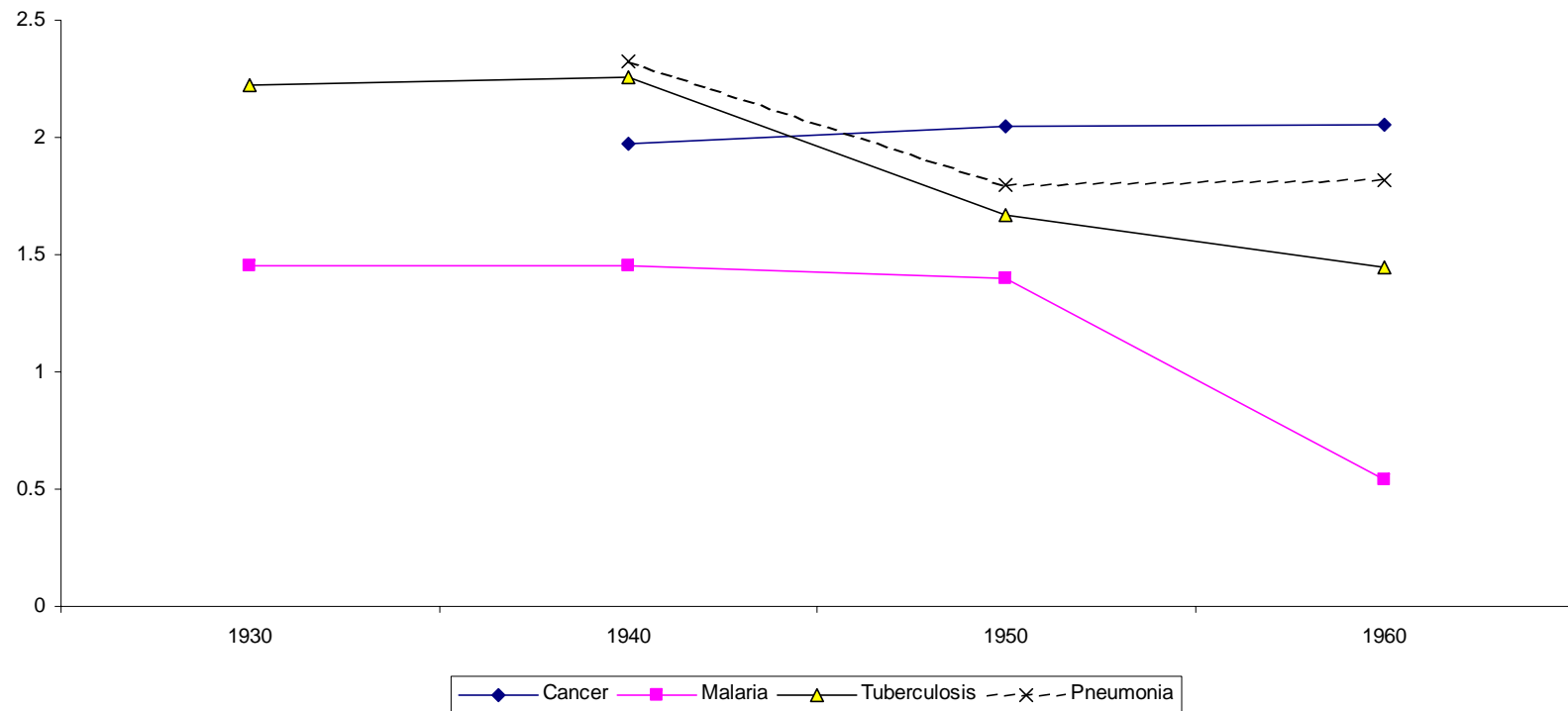


Table 4

The Effect of Interventions on Disease Mortality (zeroth stage)

<i>Dependent Variable is mortality per 100,000 from disease i in country j at period t</i>							
<i>Panel A: diseases are --</i>	<i>Base Sample</i>	<i>Base Sample</i>	<i>Base Sample</i>	<i>Without TB</i>	<i>Without pneumonia</i>	<i>Without malaria</i>	<i>Without influenza</i>
	Panel, 1930-1960						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Intervention	-46.04 (9.40)	-43.33 (10.36)	-46.04 (9.40)	-33.93 (8.66)	-36.31 (8.99)	-48.57 (9.23)	-48.62 (9.69)
Lagged Intervention		-4.59 (8.05)					
Lead Intervention			20.57 (9.47)				
R-squared	0.52	0.47	0.47	0.49	0.48	0.48	0.48
Number of observations	1479	1479	1479	1327	1364	1361	1328
<i>Panel B: diseases are --</i>	<i>Just scarlet fever</i>	<i>Just typhoid</i>	<i>Just diphtheria</i>	<i>Just TB</i>	<i>Just pneumonia</i>	<i>Just malaria</i>	<i>Just influenza</i>
Intervention	-0.25 (0.10)	-8.84 (3.01)	-2.47 (0.92)	-108.51 (22.91)	-137.92 (26.96)	-19.97 (9.67)	-14.95 (11.37)
R-squared	0.56	0.71	0.63	0.72	0.82	0.58	0.61
Number of observations	140	148	147	152	115	118	151
Number of countries	49	49	49	49	49	49	49

OLS regressions with a full set of disease, year, and country fixed effects. Robust standard errors, adjusted for clustering by country-disease pair, in parentheses. Unbalanced panels with data for 1930, 1940, 1950 and 1960. Data are stacked; dependent variable is deaths per 100,000 from disease i in country j at year t. Base sample is 15 infectious diseases plus cancer and malignant tumors. Independent variables: dummy for intervention (e.g., for malaria equals 1 for 1950 and 1960, zero otherwise), dummy for lead intervention (e.g., for malaria equals 1 for 1940, 1950 and 1960), dummy for lagged intervention (e.g., for malaria equals 1 for 1960).

First-Stage Estimates

- Figure 3: change in log life expectancy versus change in predicted mortality: 1940-1980.
- Figure 4: change in log life expectancy versus change in predicted mortality: 1940-1980 for initially low and middle income countries only.
 - still a strong first stage relationship
- Table 5: regression results both with baseline predicted mortality and alternative instrument.
- Bottom panel: long differences; more appropriate since many interventions acted slowly.
- Similar results for initially low and middle-income, including Eastern Europe, and balanced panel

Figure 3: Change in log life expectancy and change in predicted mortality, 1940-80, base sample

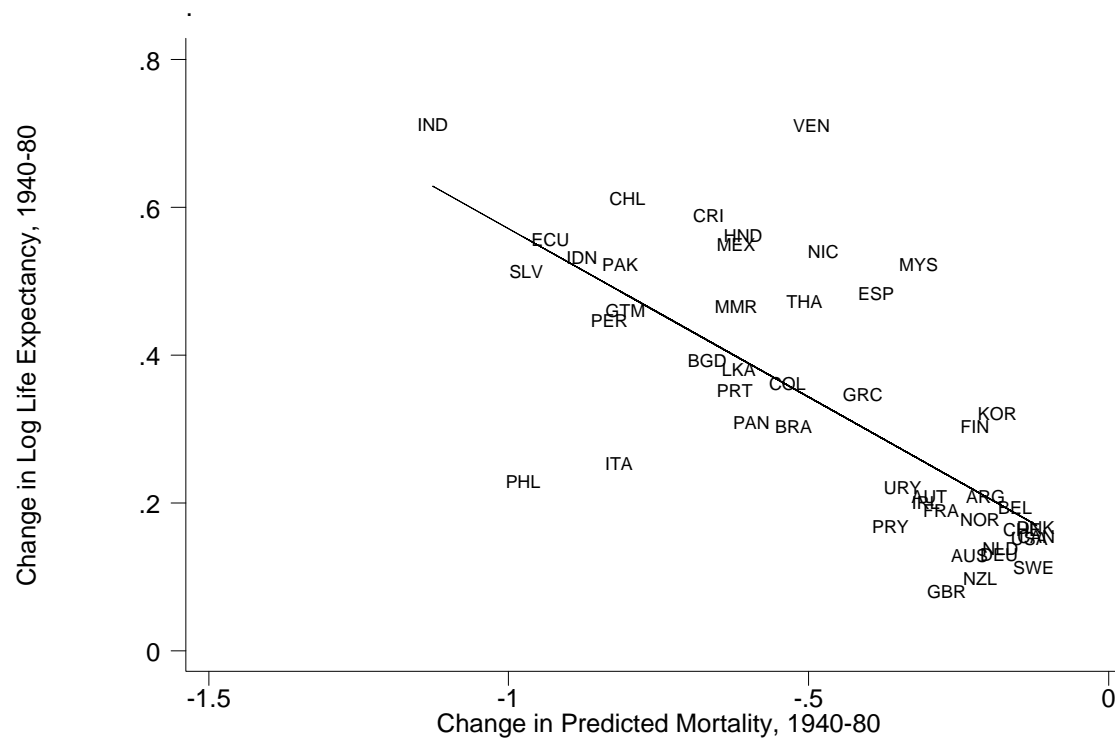


Figure 4: Change in log life expectancy and change in predicted mortality, 1940-80, low and middle-income countries

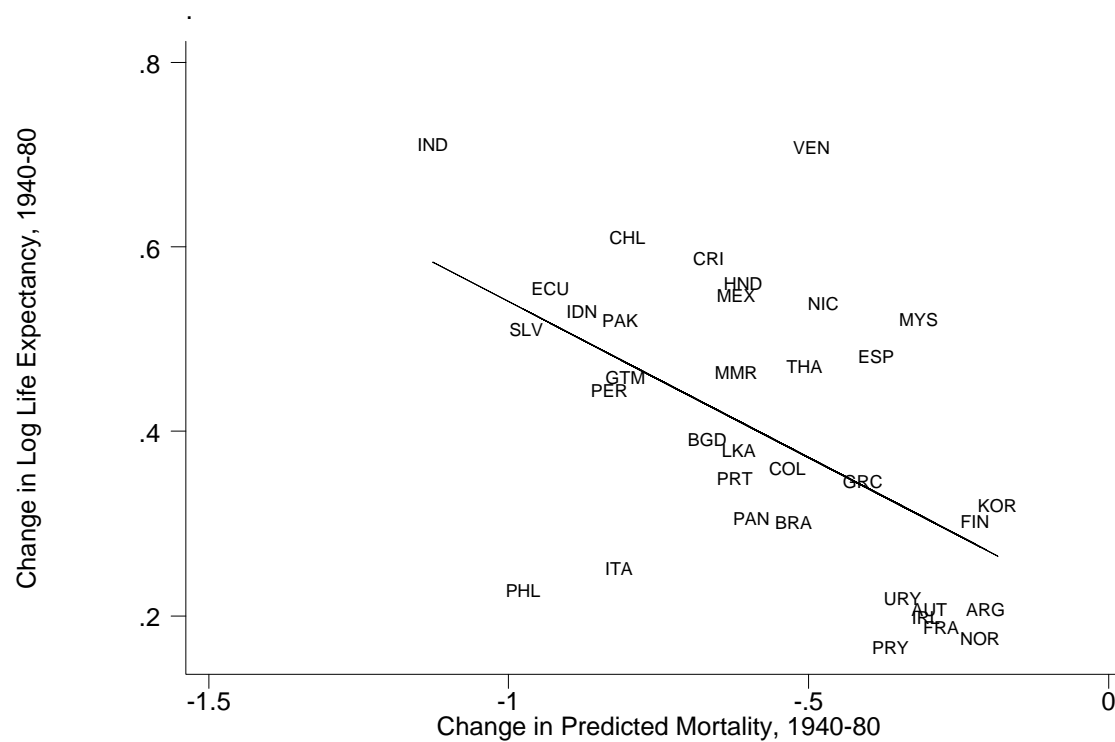


Table 5 (selected columns)
First Stage Estimates: Predicted Mortality and Life Expectancy

	<i>Dependent Variable is log life expectancy</i>				
	Baseline predicted mortality				
	<i>Base Sample</i>	<i>Low and Middle Income Countries Only</i>	<i>Base Sample, Interaction with Institutions</i>	<i>Sample, Interaction with Initial (1930) log GDP p.c.</i>	<i>Sample, Interaction with Continent Dummies</i>
	(1)	(4)	(6)	(7)	(8)
<i>Panel A</i>	Panel, 1940-1980	Panel, 1940-1980	Panel, 1940-1980	Panel, 1940-1980	Panel, 1940-1980
Predicted Mortality	-0.33 (0.06)	-0.23 (0.08)	-0.27 (0.07)	-0.24 (0.10)	-0.25 (0.07)
R-squared	0.93	0.93	0.94	0.95	0.95
Number of observations	283	228	271	243	283
Number of countries	59	48	56	49	59

First-Stage Estimates (robustness)

- Results robust to controlling for flexible time interactions with initial institutions, initial GDP per capita and continent dummies.
 - Not the effect of differential trends, differential disease environments, etc.
- Very similar results with global mortality instrument
- Robust to changing the timing of key interventions (malaria is the most important issue).
- Robust to alternative instruments.
- Robust to dropping each of the diseases one at a time.

First-Stage Estimates (falsification)

- **Falsification exercise 1:** change in life expectancy during the pre-period, 1900-1930 as a function of future changes in mortality.
- No evidence that significant declines in mortality in countries that would later experience big interventions.
- Figures 5 and 6: change in log life expectancy 1900-1930 versus change in predicted mortality 1940-1980
- Table 7, Panel A: regression evidence is similar.
 - In fact a positive (i.e., the reverse) relationship.
- Caution: 1900 data less reliable.

Figure 5: Change in log life expectancy, 1900-40, and change in predicted mortality, 1940-80, base sample

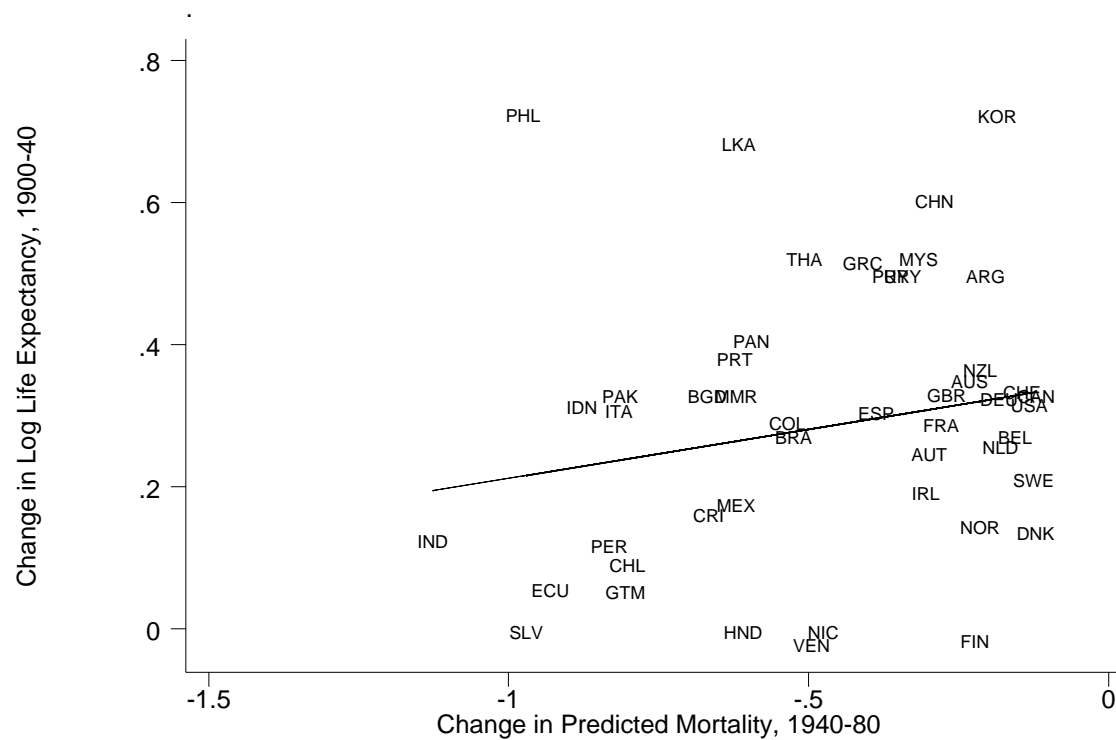


Figure 6: Change in log life expectancy, 1900-40, against change in predicted mortality, 1940-80, low and middle-income countries

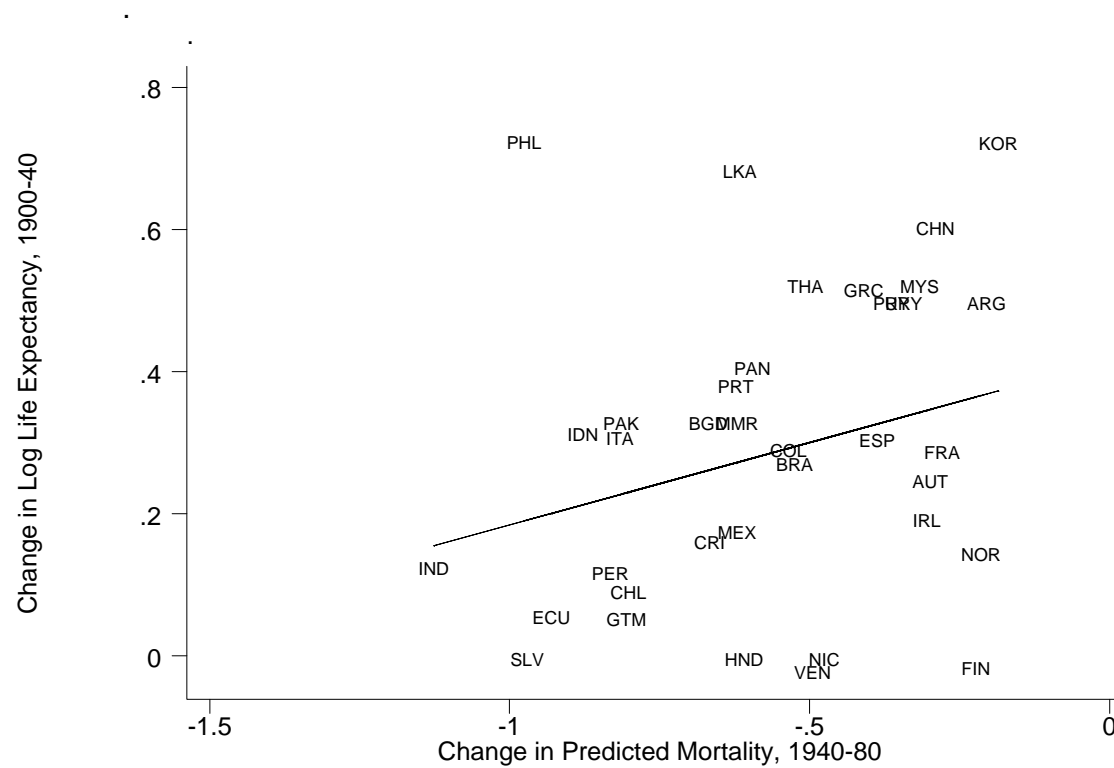


Table 7 (just Panel A: falsification exercise)

Falsification Exercise and Reduced Forms

	<i>Low & Mid. Income Countries Only</i>		<i>Low & Mid. Income Countries Only</i>		<i>Low & Mid. Income Countries Only</i>		<i>Low & Mid. Income Countries Only</i>	
	<i>Base Sample</i>		<i>Base Sample</i>		<i>Base Sample</i>		<i>Base Sample</i>	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<i>Dependent variable is: --</i>								
	<i>change in life expectancy from 1900 to 1940</i>		<i>change in log population from 1900 to 1940</i>		<i>change in log GDP from 1900 to 1940</i>		<i>change in log GDP per capita from 1900 to 1940</i>	
Change in Predicted Mortality from 1940 to 1980	0.14 (0.11)	0.21 (0.16)	-0.06 (0.14)	-0.08 (0.29)	-0.18 (0.22)	-0.27 (0.36)	-0.12 (0.17)	-0.18 (0.22)
R-squared	0.04	0.06	0.003	0.005	0.01	0.02	0.01	0.01
Number of countries	47	36	29	19	29	19	29	19

First-Stage Estimates (falsification, continued)

- **Falsification exercise 2:** the period 1930-1940 as a pre-period; some interventions, but not the most important global interventions yet.
- Figures 7 and 8: change in log life expectancy 1930-1940 versus change in predicted mortality 1940-1980 (baseline sample and initially middle and low income).
 - No relationship.
- Conclusion: our approach passes the falsification exercises.

Figure 7: Change in log life expectancy, 1930-40, and change in predicted mortality, 1940-80, base sample

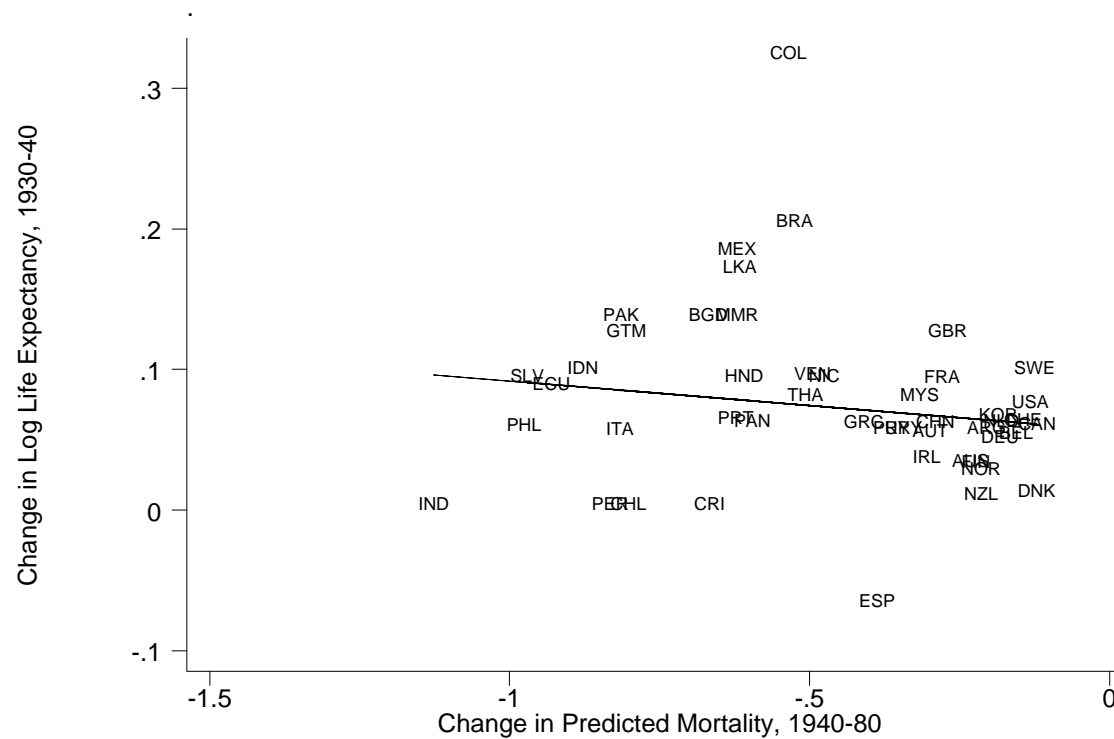
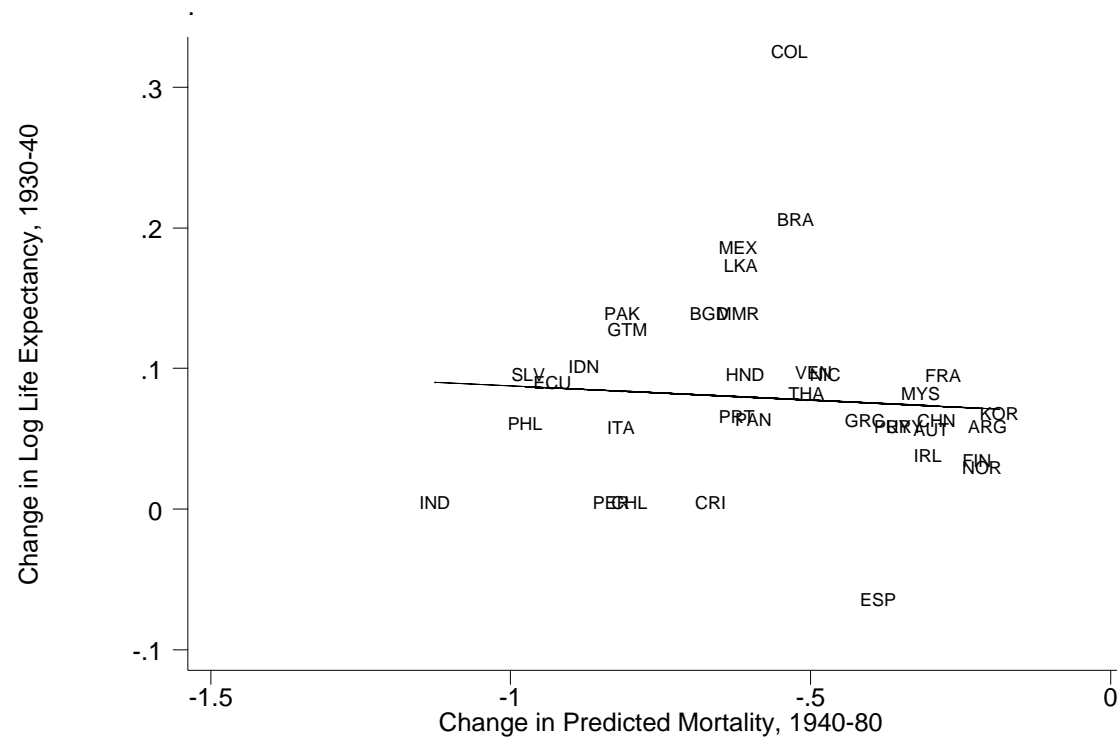


Figure 8: Change in log life expectancy, 1930-40, and change in predicted mortality, 1940-80, low and middle-income countries



The Reduced Form

- Again Table 7:
 - No pre-existing trends related to predicted mortality in population or GDP
 - Large effect of predicted mortality on population between 1940-1980.
 - Small effect of predicted mortality on total GDP between 1940-1980.
- Preliminary conclusion:
 - Valid experiment for population and GDP.
 - Large positive effects on population, no positive effects and likely negative effects on GDP per capita.

Table 7 (just Panel B: reduced forms)

Falsification Exercise and Reduced Forms

	<i>Low & Mid. Income Countries Only</i>		<i>Low & Mid. Income Countries Only</i>		<i>Low & Mid. Income Countries Only</i>		<i>Low & Mid. Income Countries Only</i>	
	<i>Base Sample</i>	<i>Countries Only</i>	<i>Base Sample</i>	<i>Countries Only</i>	<i>Base Sample</i>	<i>Countries Only</i>	<i>Base Sample</i>	<i>Countries Only</i>
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<i>Dependent variable is: --</i>								
		<i>change in life expectancy from 1940 to 1980</i>		<i>change in log population from 1940 to 1980</i>		<i>change in log GDP from 1940 to 1980</i>		<i>change in log GDP per capita from 1940 to 1980</i>
Change in Predicted Mortality from 1940 to 1980	-0.43 (0.07)	-0.30 (0.08)	-0.76 (0.15)	-0.65 (0.21)	-0.27 (0.25)	-0.03 (0.32)	0.48 (0.17)	0.59 (0.23)
R-squared	0.46	0.26	0.31	0.19	0.003	0.0003	0.12	0.12
Number of countries	57	46	49	38	49	38	49	38

The Second Stage

- Five outcome variables:
 1. log population;
 2. log births (fertility);
 3. log GDP;
 4. log GDP per capita (and GDP per working age population)
 5. years of schooling
- Two approaches:
 1. Full panel, 1940-80.
 2. Long difference.
- In all cases look at contemporaneous effects, and 10, 20, 30 and 40 year leads.
- Figures 9 and 10 : changes in log population and changes in log GDP versus change in predicted mortality: 1940-1980.

Figure 9: Change in log population and change in predicted mortality, 1940-80, base sample

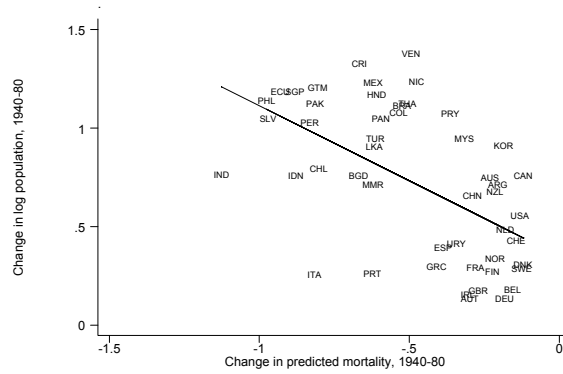
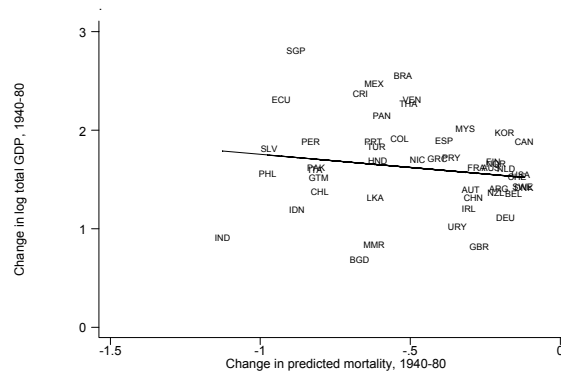


Figure 10: Change in log total GDP and change in predicted mortality, 1940-80, base sample



2SLS Estimates (Population)

- Estimates both in panel and long differences.
 - Long differences more satisfactory, since the experiment taking place over the entire forty-year period.
- Estimates using contemporaneous, ten-year, twenty-year, thirty-year, forty-year leads.
 - Results with leads useful to capture more long-term effects.
- Large, relatively precise, and robust effect of life expectancy on population; in both panel and long differences (Table 8).
- Elasticity between 1 and 2, slightly larger than OLS.
- Same results with global mortality instrument
- Same results including time interaction with initial institutions

Table 8 (selected columns)
The Effect of Life Expectancy on Log Population: 2SLS Estimates

	<i>Dependent variable is log population</i>				
	Baseline instrument				
	<i>Base Sample</i>	<i>Low and Middle Income Countries Only</i>	<i>Base Sample, Interaction with Institutions</i>	<i>Base Sample, Interaction with Initial (1930) Log Population</i>	<i>Base Sample</i>
	No leads Panel, 1940-1980 (1)	No leads Panel, 1940-1980 (4)	No leads Panel, 1940-1980 (5)	No leads Panel, 1940-1980 (6)	30 year lead Panel, 1940-1970 (10)
<i>Panel A</i>					
Log Life Expectancy	1.31 (0.37)	1.58 (0.76)	1.22 (0.50)	1.33 (0.35)	1.49 (0.37)
p-value for Year Dummies x Institutions or initial log population			[0.02]	[0.003]	
Number of observations	283	228	272	244	226
Number of countries	59	46	56	49	59

2SLS Estimates (Births)

- Regression results in Table 9.
- Large, relatively precise, and robust effect of life expectancy on births.
- Elasticity around 2.5.

Table 9 (selected columns)
The Effect of Life Expectancy on Log Births: 2SLS Estimates

	<i>Dependent variable is log births</i>				
	Baseline instrument				
	<i>Base Sample</i>	<i>Low and Middle Income Countries Only</i>	<i>Base Sample, Interaction with Institutions</i>	<i>Base Sample, Interaction with Initial (1930) Log Population</i>	<i>Base Sample</i>
	No leads Panel, 1940-1980 (1)	No leads Panel, 1940-1980 (4)	No leads Panel, 1940-1980 (5)	No leads Panel, 1940-1980 (6)	30 year lead Panel, 1940-1970 (10)
<i>Panel A</i>					
Log Life Expectancy	2.39 (0.69)	3.10 (1.49)	2.32 (1.01)	2.27 (0.60)	1.03 (0.52)
p-value for Year Dummies x Institutions or initial log births			[0.33]	[0.03]	
Number of observations	233	178	233	221	140
Number of countries	47	36	47	45	47

2SLS Estimates (GDP)

- Table 10: no evidence of a large positive effect.
- Contemporaneous estimates generally negative and insignificant.
- Ten-year, twenty-year, thirty-year and forty-year leads positive (but no evidence of effects getting larger after 20 years).
- Same results with global mortality instrument, or if we included time dummies interacted with initial institutions
- In all cases, the increase in GDP is much smaller than the effect on population.

Table 10 (selected columns)
The Effect of Life Expectancy on Log GDP: 2SLS Estimates

	<i>Dependent variable is log GDP</i>				
	Baseline instrument				
	<i>Base Sample</i>	<i>Low and Middle Income Countries Only</i>	<i>Base Sample, Interaction with Institutions</i>	<i>Base Sample, Interaction with Initial (1930) Log Population</i>	<i>Base Sample</i>
	No leads Panel, 1940-1980 (1)	No leads Panel, 1940-1980 (4)	No leads Panel, 1940-1980 (5)	No leads Panel, 1940-1980 (6)	30 year lead Panel, 1940-1970 (10)
<i>Panel A</i>					
Log Life Expectancy	-0.03 (0.67)	-0.28 (1.19)	-0.35 (0.82)	-0.49 (0.58)	0.61 (0.60)
p-value for Year Dummies x Institutions or initial log GDP			[0.005]	[0.01]	
Number of observations	283	228	271	243	224
Number of countries	59	48	56	49	59

2SLS Estimates (GDP per capita and per working age population)

- Figure 11: change in log GDP per capita versus change in predicted mortality; 1940-1980.
- Table 11: negative effect on GDP per capita.
- Similar pattern in the panel and long differences.
- Longer-term effects typically not significant.
- Interpretation: weak positive effect or no effect on GDP, more than offset by the large increase in population.
- Appendix Table C2: results for GDP per working age population (similar to GDP per capita findings)

Figure 11: Change in log GDP per capita and change in predicted mortality, 1940-80, base sample

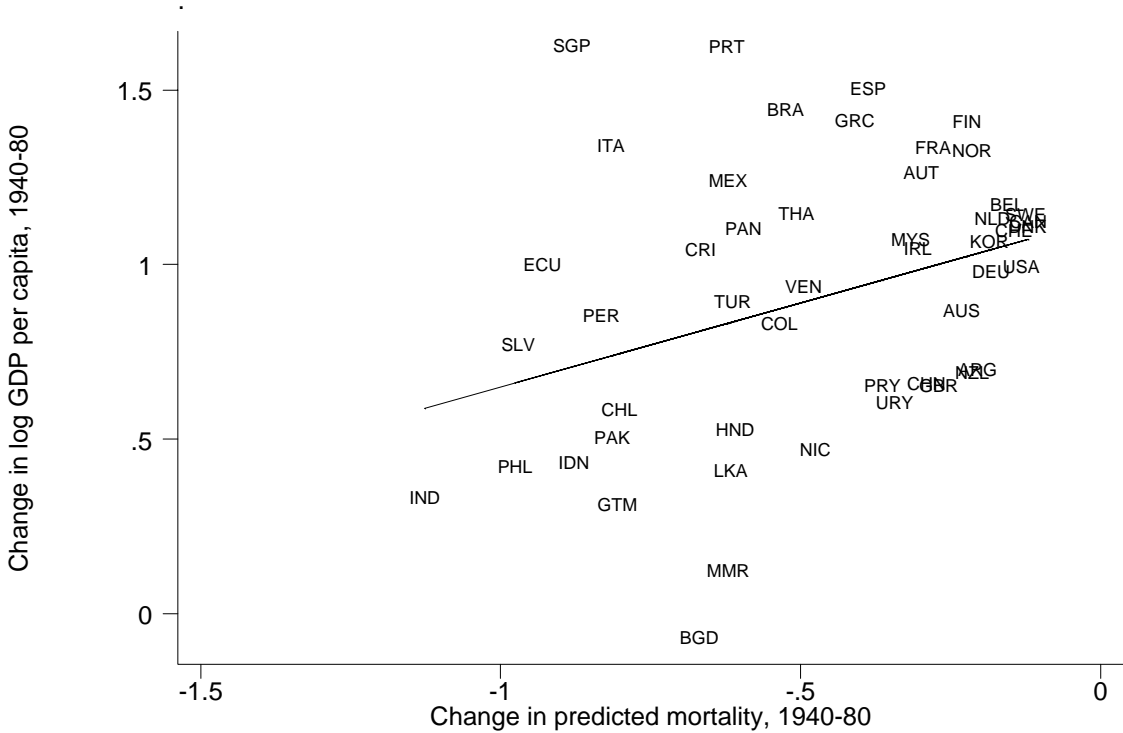


Table 11 (selected columns)
The Effect of Life Expectancy on Log GDP per capita: 2SLS Estimates

Dependent variable is log GDP per capita

Baseline instrument

	<i>Base Sample</i>	<i>Low and Middle Income Countries Only</i>	<i>Base Sample, Interaction with Institutions</i>	<i>Base Sample, Interaction with Initial (1930) Log Population</i>	<i>Base Sample</i>
	No leads Panel, 1940- 1980 (1)	No leads Panel, 1940- 1980 (4)	No leads Panel, 1940- 1980 (5)	No leads Panel, 1940- 1980 (6)	30 year lead Panel, 1940- 1970 (10)
<i>Panel A</i>					
Log Life Expectancy	-1.30 (0.53)	-1.76 (1.13)	-1.45 (0.74)	-0.46 (0.85)	-0.87 (0.55)
p-value for Year Dummies x Institutions or initial log GDP per capita			[0.02]	[0.03]	
Number of observations	283	228	271	243	224
Number of countries	59	48	56	49	59

Interpretation

- Back to the model.
- Low income economies, land important; choose $\alpha \approx \beta \approx 1/3$.
- The estimates imply that medium-run response of GDP per capita to life expectancy:

$$(\alpha (\gamma + \eta) - (1 - \alpha) \lambda) \approx -1.3$$

and response of population to life expectancy

$$\lambda \approx 1.5$$

implies $\gamma + \eta \approx 0$ or slightly negative.

- Instead $\lambda \approx 1.7$ would imply $\gamma + \eta$ slightly positive.
- Similar implications from longer-run calculations.

Robustness

- General pattern of effects on population, GDP, fertility, GDP per working age population, and education appear to be robust.
- Similar results in different subperiods, with different forms of the instrument.
- Global mortality instrument does not change results.
- Inclusion of interaction of time dummies with initial institutions, or initial income per capita, or continent dummies does not change results
- Adding (lower quality) data from Africa: same results
- Dropping countries affected by World War II: same results.

Mortality for Whom?

- Similar results using just mortality from tuberculosis (previously a major killer of young adults, more than infants or children)
- Declines in infant and childhood mortality were important
 - Similar first stage for infant mortality (comparable data only available from 1950)
- While the precise age distribution of effects is unclear, these large declines in mortality should have affected human capital decisions

Morbidity

- Improvements in mortality also reduced morbidity (ill health), e.g., decline in cases of malaria, as well as deaths from malaria
 - Venezuela, 817,000 cases in 1943 and 800 cases in 1958
 - Taiwan, 1 million cases in 1954 and 9 in 1969
 - Spain, 19,000 cases in 1950 and 28 in 1969
- Reducing the impact of non-fatal diseases could be different (without fertility effects?); these were not the primary focus of the large post-war interventions

Assessment

- Global interventions from 1940 had **beneficial** effects on health and life expectancy.
- On humanitarian grounds, big success.
- No evidence that the large convergence in life expectancy driven by exogenous factors led to convergence in income per capita.
- Improvements in life expectancy led to increases in population, and some increase in overall output.
- Net effect far from an increase in income per capita.
- Evidence in favor of the possibility of outside interventions improving health outcomes in life expectancy in less-developed countries, and big welfare gains (without any obvious economic losses, but also no major economic gains).
- Lessons particularly relevant to sub-Saharan Africa where fertility is still high.