Disease and Development: A Reply to Bloom, Canning, and Fink

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Abstract

In Acemoglu and Johnson (2006, 2007), we used the "*international epidemiological transition*"—a wave of global health innovations and improvements that began in the 1940s—to construct an instrument that can help estimate the effect of life expectancy on economic performance. This identification strategy exploited the differential effect of these global health interventions on countries with high levels of mortality from the affected diseases. Using this strategy, we found that the instrumented changes in life expectancy have a large effect on population: a 1% increase in life expectancy leads to an increase in population of about 1.7-2%. Life expectancy has a much smaller effect on total GDP. Consequently, there is no evidence that this large exogenous increase in life expectancy led to a significant increase in per capita income.

Bloom, Canning, and Fink (2009) argue that the Acemoglu and Johnson regressions are misspecified because they do not take account of potential convergence in income per capita. Their critique is incorrect for three reasons. First, both in our published paper (2007) and, at greater length, in the NBER working paper version (2006), we addressed this issue and showed that our results are robust to various different specifications that allow for convergence effects. Second, the specifications used by Bloom, Canning, and Fink do not follow from the standard model incorporating mean reversion (i.e., convergence) in income. Third, using additional checks for convergence effects, we find no evidence that incorporating such effects has any impact on our previous findings. In addition, there is a logical inconsistency between the Bloom, Canning, and Fink second stage and their instrument strategy.

Keywords: disease environment, economic development, economic growth, health, international epidemiological transition, life expectancy, mortality.

JEL Numbers: I10, O40, J11.

1 Introduction

Improvements in health increase individual productivity. Some leading experts, as well as the World Health Organization (e.g., WHO, 2001), argue that this implies big potential gains in income per capita from big health interventions. For example, in one of the most widely cited studies, Gallup and Sachs (2001, p. 91) argue that wiping out malaria in sub-Saharan Africa could increase that continent's per capita growth rate by as much as 2.6% a year.

In Acemoglu and Johnson (2007) we exploited the large improvements in life expectancy driven by international health interventions, more effective public health measures, and the introduction of new chemicals and drugs starting in the 1940s. This episode, which we refer to as the *international epidemiological transition*, led to an unprecedented improvement in life expectancy in a large number of countries. As a consequence, health conditions in many poor countries today, though still in dire need of improvement, are significantly better than the corresponding health conditions were in Western Europe at the same stage of development.

These historical events also enable an investigation of the effect of potentially exogenous improvements in life expectancy on income, population, and income per capita. Countries varied widely in terms of the mortality rates from diseases that were affected by the international epidemiological transition, so the impact of this transition on a high mortality country was very different from its impact on a low mortality country. Exploiting these differences, we constructed a plausible instrument for changes in life expectancy, "predicted mortality," based on initial mortality by disease and the timing of global disease interventions. Instrumented changes in life expectancy have a fairly large effect on population—a 1% increase in life expectancy implies an approximately 1.7-2% increase in population over a 40-60 year horizon. The magnitude of this estimate, and our related results directly on birth rates, indicates that while there was some decline in fertility rates after the health improvements, this was insufficient to compensate for increased life expectancy.

We also found positive but small (and sometimes statistically insignificant) effects of life expectancy on total GDP. Consequently, over this time period, countries experiencing large increases in life expectancy had lower increases in GDP per capita and GDP per working age population. In fact, our estimates of the effect of life expectancy on GDP per capita or per working age population exclude any positive effects over 40- or 60-year horizons. These results are robust to a range of specification checks and to the inclusion of various controls. We also

documented that our results are not driven by life expectancy at very early ages.

Bloom, Canning, and Fink (2009) take issue with our findings on the grounds that we did not appropriately account for potential income convergence effects (Bloom, Canning, and Fink refer to this as "disequilibrium," e.g., in deriving their main specification, equation (11) on page 13). They argue that to incorporate such convergence effects we should include initial per capita income and initial life expectancy in our specifications. They further claim specifications that deal with convergence effects substantially alter the results in Acemoglu and Johnson (2007).

However, the Bloom, Canning, and Fink critique has three serious problems.

1. In our published paper, and more extensively in the working paper version (Acemoglu and Johnson, 2006), we reported results using econometric specifications that explicitly allowed for convergence or other types of mean reversion dynamics in income per capita and our other dependent variables (including population and total GDP). As Bloom, Canning, and Fink appear to have overlooked these results, we review them in Section 2.

2. Bloom, Canning, and Fink's estimating equation does not follow from their emphasis on income convergence. Concerns regarding potential income convergence lead to specifications similar to those estimated in Acemoglu and Johnson (2006, 2007) or to specifications such as those shown in Section 2 below (which recap our previous results). Instead, in all of their specifications, in addition to any terms that might result from income convergence, Bloom, Canning, and Fink always add initial life expectancy—that is, the level of initial life expectancy 40 or 60 years ago in addition to change in life expectancy. However, as already mentioned above, our instrumental variable strategy exploits the differential impact of the international epidemiological transition on countries with high and low initial mortality (and thus low and high initial life expectancy). Thus, including initial life expectancy in the second stage equation explicitly contradicts our exclusion restriction. Therefore, Bloom, Canning, and Fink's second-stage specifications *cannot be* estimated using our predicted mortality variable as instrument—they are *logically inconsistent*. Not surprisingly in light of this, Bloom, Canning, and Fink's first-stage regressions suffer from an extreme degree of collinearity (though curiously they never show their first stages). This and the fact that they have two endogenous regressors and a single instrument make any kind of meaningful estimation impossible.

3. In Section 3, we report new regression results from specifications that further address the issue of income convergence. These results show no evidence of positive effects of life expectancy on income per capita at 40 or 60 year horizons, and no support for any of the

claims in Bloom, Canning, and Fink (2009).

2 The Estimating Framework

2.1 Basic Specification in Acemoglu and Johnson (2007)

In Acemoglu and Johnson (2007), we derived our estimating equation directly from standard neoclassical growth theory (i.e., Section II.A of that paper leads directly to equation (6) on p.933). With an error term and potential covariates added, this basic estimating equation is,

$$y_{it} = \pi x_{it} + \zeta_i + \mu_t + \mathbf{Z}'_{it}\boldsymbol{\beta} + \varepsilon_{it}, \tag{1}$$

where i denotes country and t is time period; y is log income per capita; x is log life expectancy (at birth or at other ages); the ζ_i's denote a full set of fixed effects to capture cross-country differences in time-invariant characteristics (in particular, permanent differences in total factor productivity, which are likely correlated with permanent differences in health across countries); the μ_t's incorporate time-varying factors common across all countries; and $\mathbf{Z}_{it}$ denotes a vector of other controls. The coefficient π is the parameter of interest.[1]

Since we do not expect the yearly or decadal changes in life expectancy to have their full effect on income per capita or on other economic variables immediately, we estimated (1) in *long differences*, that is, in a panel including only two dates, t_0 and t_1 (in practice 1940 and 1980, or 1940 and 2000).[2] These long difference regressions also make interpretation easier because they directly measure the effect of change in life expectancy between two dates on change in economic variables between the same two dates. Since in the long difference specification we only have two dates, (1) is (algebraically) equivalent to estimating the first-differenced specification,

$$\Delta y_i = \pi \Delta x_i + \Delta\mu + \Delta\mathbf{Z}'_i\boldsymbol{\beta} + \Delta\varepsilon_i, \tag{2}$$

where $\Delta y_i \equiv y_{it_1} - y_{it_0}$, and Δx_i, $\Delta\mu$, $\Delta\mathbf{Z}'_i$ and $\Delta\varepsilon_i$ are defined similarly, and time subscripts

[1] Bloom, Canning, and Fink complain in passing (footnote 5) that we only used life expectancy as a measure of health. This is true, but they neglect to mention that this is what the literature does—and what they have emphasized in their own work, e.g., see Table 1 in Bloom, Canning, and Sevilla (2004).

[2] The rhetoric in Bloom, Canning, and Fink (2009, e.g., p.2) suggests that we somehow assumed changes in health have immediate effects on income per capita. On the contrary, we looked at 40 or 60 year horizons precisely to allow for slow-acting effects of health differences to be reflected in income per capita. Our working paper, Acemoglu and Johnson (2006), put even more explicit emphasis on investigating a wide variety of potential lagged effects.

are dropped to simplify notation.[3]

2.2 Identification Strategy

Our instrument, *predicted mortality,* is constructed as

$$M_{it}^{I} = \sum_{d \in \mathcal{D}} \left((1 - I_{dt}) M_{di40} + I_{dt} M_{dFt} \right), \tag{3}$$

where M_{dit} denotes mortality in country i from disease d at time t, I_{dt} is a dummy for intervention for disease d at time t (it is equal to 1 for all dates after the intervention), and $\mathcal{D}$ denotes a set of 15 infectious diseases for which we have data - including the major killers around the world in 1940, as well as some more minor diseases. It is measured as the number of deaths per 100 individuals per annum. M_{di40} refers to the pre-intervention mortality from disease d in the same units, while M_{dFt} is the mortality rate from disease d at the *health frontier* of the world at time t. In our baseline instrument, we take M_{dFt} to be equal to zero.

Predicted mortality, M_{it}^{I}, thus uses a country's initial mortality rate from the 15 diseases until there is a global intervention, and after the global intervention, the mortality rate from the disease in question declines to the frontier mortality rate.

We then use our measure of predicted mortality, M_{it}^{I}, as an instrument for life expectancy in the estimation of (1). In particular, we posit the following first-stage relationship between log life expectancy and predicted mortality

$$x_{it} = \psi M_{it}^{I} + \tilde{\zeta}_i + \tilde{\mu}_t + \mathbf{Z}_{it}' \tilde{\boldsymbol{\beta}} + u_{it}. \tag{4}$$

The key exclusion restriction for our IV strategy is $\text{Cov}(M_{it}^{I}, \varepsilon_{it}) = 0$, where recall that ε_{it} is the error term in the second-stage equation, (1).

Equation (3) makes it clear that the only source of variation in predicted mortality comes from the interaction of the baseline distribution of diseases with global interventions (in particular, note that M_{di40} applies until the time of the relevant global intervention). Whether a country has successfully eradicated a disease or has been quick at adopting international technologies will have *no* effect on M_{it}^{I}; the dummy I_{dt} turns on for all countries at the same time.

[3] In our working paper version, Acemoglu and Johnson (2006), we also reported extensive results using a panel specification, with data every 10 years. This approach yielded essentially the same results as the long differences and we did not report these in the published version of the paper to save space. We also focus on long difference specifications here both to save space and to maintain maximum degree of transparency.

This makes our exclusion restriction $\text{Cov}(M_{it}^I, \varepsilon_{it}) = 0$ plausible. Since variations in M_{it}^I are unrelated to any actions or economic events in the country, there is no obvious reason for it to be correlated with economic or population shocks in the country in question. As emphasized at great length in our working and published papers, the major—and essentially only—potential threat to the exclusion restriction would be that the baseline mortality rates, the M_{di40}'s, are correlated with future changes in population or income. *If this were the case, our instrument and exclusion restriction would be invalid.* To demonstrate this is unlikely to be the case, we showed the robustness of our IV results to the inclusion of differential trends that are parameterized as functions of various baseline characteristics (see equations (5) and (9) below). In addition, we reported a range of falsification exercises illustrating that the variable M_{it}^I has *no* predictive power for life expectancy or other economic variables *before* the international epidemiological transition (see Table 7 in Acemoglu and Johnson 2006 and 2007).

As a first step, our papers investigated whether potential correlation between our instruments and baseline country characteristics could account for our first-stage relationship. This issue is investigated in columns 6 through 8 of Table 5 in our working paper and columns 4 through 6 of Table 5 in our published paper. These columns report regressions of the form:

$$x_{it} = \psi M_{it}^I + \tilde{\zeta}_i + \tilde{\mu}_t + \sum_{t=1940}^{1980} \mathbf{c}_i' \tilde{\boldsymbol{\omega}}_t + u_{it}, \tag{5}$$

where $\mathbf{c}_i$ denotes "time invariant" characteristics of country i, in particular, either a measure of average quality of institutions (computed as the average of the constraints on executive from the Polity IV dataset over 1950-1970) in column 5, the 1930 value of GDP per capita in column 6, or a vector of continent dummies in column 7 (all in Table 5 of our published paper). Since equation (5) includes a full set of time interactions with $\mathbf{c}_i$, differential trends related to these characteristics are taken out. In our long difference regressions, this specification is equivalent to including an interaction between the 1980 (or the 2000) dummy and the baseline characteristics.

2.3 How We Previously Addressed Potential Convergence Effects

In Section 4.1 of Acemoglu and Johnson (2006), we pointed out that equation (1) does not allow for mean-reverting dynamics in the outcome variables, e.g., potential convergence in income per capita (see the discussion of equations (8) and (9) in that working paper). A more

general model would be

$$y_{it} = \rho y_{it-1} + \pi x_{it} + \zeta_i + \mu_t + \mathbf{Z}'_{it}\boldsymbol{\beta} + \varepsilon^m_{it}. \tag{6}$$

In Acemoglu and Johnson (2006), we considered the same model with the dependent variable y_{it+k} on the left-hand side, which allows for even richer dynamics (e.g., Tables 2, 3, 8, 9, 10, 11, and 12 in that version). Clearly, since $\Delta y_{it} \simeq g_{it}$ (recall y refers to log income), this is equivalent to the standard growth regression, though augmented with country fixed effects (see, e.g., Barro, 1991, Acemoglu, 2009):

$$g_{it} = \tilde{\rho} y_{it-1} + \pi x_{it} + \zeta_i + \mu_t + \mathbf{Z}'_{it}\boldsymbol{\beta} + \varepsilon^m_{it}, \tag{7}$$

where $\tilde{\rho} \equiv \rho - 1$.

We focused on (1) rather than (6) for three reasons. First, convergence effects are small in practice and should not have major effects over the time span covered by our main specifications (40 or 60 years).[4] To substantiate this point, we reported in Acemoglu and Johnson (2006) panel data models with 10, 20, 30, and 40 year lags, showing practically indistinguishable effects from our baseline specifications. Second, although (6) is more general than (1), it is harder to estimate consistently because of the simultaneous presence of fixed effects and a lagged dependent variable, which makes consistent estimation of the parameter ρ or $\tilde{\rho}$ difficult (see, e.g., Wooldridge, 2002, Chapter 11).[5] Third, even if the data generating process were given by (6), instrumental-variables estimate of (1) would lead to consistent estimates of π as long as $\text{Cov}(M^I_{it}, \varepsilon_{it}) = 0$, where ε_{it} refers to the error term in (1). If the correct model is (6), then this condition is equivalent to $\text{Cov}(M^I_{it}, \rho y_{it-1} + \varepsilon^m_{it}) = 0$.

Our first check for the importance of convergence effects, adopted both in our working paper version (Acemoglu and Johnson, 2006) and in the published version, is to control directly for y_{it-1}, so that, dropping the covariate vector, $\mathbf{Z}_{it}$, to simplify notation, the long difference model (2) becomes:

$$\Delta y_{it} = \rho y_{it-1} + \pi \Delta x_{it} + \Delta \mu_t + \Delta \varepsilon_{it}. \tag{8}$$

Alternatively, in the panel data models estimated in Acemoglu and Johnson (2006), we include

[4] Bloom, Canning, and Fink are aware that convergence effects are small relative to the size of difference in income per capita across countries, but they do dwell on this fact (p.2).

[5] This is why we pursued an alternative estimation strategy to deal with mean reversion in Appendix Table C3 of Acemoglu and Johnson (2006). This strategy is discussed further below.

a full set of time interactions with initial GDP per capita, so that the estimated models take the form

$$y_{it} = \pi x_{it} + \zeta_i + \mu_t + \sum_{t=1940}^{1980} \lambda_t y_{i,1930} + \varepsilon_{it}^d, \tag{9}$$

where $y_{i,1930}$ denotes the 1930 ("initial") value of the dependent variable. To the extent that the restriction $\text{Cov}(M_{it}^I, \rho y_{it-1} + \varepsilon_{it}^m) = 0$ is violated, this specification should give very different results from our baseline model. These specifications are reported in column 6 in Tables 5, 8, and 9 in Acemoglu and Johnson (2007) and throughout Acemoglu and Johnson (2006). The results are very similar to our baseline estimates and show no evidence that life expectancy has a large positive effect on income per capita. In fact, there is no meaningful difference in the results from specifications that do not control for convergence. From the wording towards the bottom of their p.9, Bloom, Canning, and Fink appear to have overlooked our results that include initial income per capita.[6]

In Acemoglu and Johnson (2006), we also reported on another strategy (discussed in Section 7.2, pages 31-32, with results reported in Appendix Table C3).[7] Since the difficulty with (6) is consistent estimation of the parameter ρ, we checked the robustness of our results assuming that the correct model is (6) with alternative plausible values of ρ imposed. More specifically, suppose that we know the mean-reversion parameter ρ in equation (6). We can then subtract ρy_{it-1} from y_{it}, which, using (6) without covariates, gives

$$\tilde{y}_{it}^{\rho} = \pi \tilde{x}_{it}^{\rho} + \zeta_i^{\rho} + \mu_t^{\rho} + \tilde{\varepsilon}_{it}^{\rho}, \tag{10}$$

where the transformed dependent variable is $\tilde{y}_{it}^{\rho} \equiv y_{it} - \rho y_{it-1}$, and on the right hand side we have $\tilde{x}_{it}^{\rho} \equiv x_{it} - \rho x_{it-1}$ (and $\tilde{\varepsilon}_{it}^{\rho} \equiv \varepsilon_{it} - \rho \varepsilon_{it-1}$). M_{it}^I can then be used as an instrument for $\tilde{x}_{it}^{\rho}$ in this equation (since $\text{Cov}(M_{it}^I, \varepsilon_{it+k}) = 0$ for all k, we also have $\text{Cov}(M_{it}^I, \varepsilon_{it}^{\rho}) = 0$). Therefore, a 2SLS regression of $\tilde{y}_{it}^{\rho}$ on $\tilde{x}_{it}^{\rho}$ will identify the coefficient of interest, π. Since, in reality, we do not know ρ, we implemented a two-stage version of this procedure by first estimating ρ.[8]

[6] Bloom, Canning, and Fink's last two sentences on p.9 read, "[Acemoglu and Johnson] do show that their results are robust to including average institutional quality, and initial population, interacted with a post-intervention dummy, but other variables could be added. In the empirical section below we investigate adding initial life expectancy and initial income interacted with a post-intervention dummy, as additional explanatory variables".

[7] This further investigation was briefly noted on p. 971 (Section VII.A) of Acemoglu and Johnson (2007), and the reader was referred to our working paper for more details.

[8] In regressions of log income per capita on its lag and country and time fixed effects, the estimates of ρ vary between 0.4 and 0.75 depending on estimation strategy and on whether or not log life expectancy is included.

Appendix Table C3 in Acemoglu and Johnson (2006) reported results from applying this procedure using a range of values for ρ that encompasses (and exceeds) the range of estimates of ρ, both in our own estimation and in the literature. There is a robust first stage between transformed log life expectancy and predicted mortality, and the second-stage estimates are similar to (but somewhat more negative than) those in Table 11 of Acemoglu and Johnson (2006). These estimates show that irrespective of the value of ρ, the relationship between life expectancy and GDP per capita is never positive (the point estimate is always negative).[9]

3 Additional Evidence

3.1 Specification Including Initial Income Per Capita

Bloom, Canning, and Fink's main concern is that initial income per capita should be included in our core specifications, to deal with what they call "disequilibrium" effects. They argue that income convergence effects are potentially important, and omitting these variables leads to bias in our instrumental variables estimates. To deal with such convergence effects, they propose to estimate a model of the form:

$$\Delta y_i = \pi \Delta x_i + \Delta \mu + \Delta \mathbf{Z}_i' \boldsymbol{\beta} + \pi' x_{i0} + \rho' y_{i0} + \mathbf{Z}_{i0}' \boldsymbol{\beta}' + \Delta \varepsilon_i, \tag{11}$$

where the subscripts 0 refer to initial values; this is their equation (7), though there appears to be a typo in their version.

As noted above, equation (11) is highly problematic. We emphasized in Acemoglu and Johnson (2007) that identification in our model comes from variation in changes in predicted mortality. Changes in predicted mortality are, mechanically, obtained from the interaction of baseline mortality and global trends due to the international epidemiological transition. Therefore, including initial life expectancy is *inconsistent* with our exclusion restriction (discussed above). One may have some good theoretical reasons for focusing on (11)—even though we do not think there are. But if this is the case, predicted mortality *cannot be used as an instrument.* Bloom, Canning, and Fink's strategy of using predicted mortality as an instrument for (11) cannot be justified under any circumstances. This is also related to the fact that it is a very high degree of collinearity in their first stage.

[9] From the discussion Bloom, Canning, and Fink, it appears they did not consult our working paper version and were not aware of these additional checks for convergence effects.

Our identification strategy and exclusion restriction are plausible theoretically and receive support from available evidence. First, there is no reason to expect that initial life expectancy should have a direct effect over 40 or 60 year horizons.[10] Second, our exclusion restriction that initial life expectancy does not belong in this equation was subjected to battery of robustness checks and falsification exercises (see Table 7 in our working paper and published version). In particular, before the international epidemiological transition, there are no differential trends in GDP per capita or population across countries with different levels of mortality or life expectancy (again, see our previous Table 7), bolstering our assumption that mortality rates have no direct effects on future income or population at 40-year or similar horizons.

Even though (11) contradicts the logic of our instrumental-variables strategy and cannot be used with predicted mortality (contrary to what Bloom, Canning, and Fink do), one might still wonder whether this equation could indeed result from the presence of convergence effects as Bloom, Canning, and Fink claim. The answer is no. Bloom, Canning, and Fink do not derive (11) from an equation with potential convergence effects. In fact, concerns about income convergence do not naturally lead to a specification like (11).[11] Using the same notation as above and again dropping covariates to simplify notation, we write:[12]

$$y_{it} = \rho y_{it-1} + \pi x_{it} + \zeta_i + \mu_t + \varepsilon_{it}, \tag{12}$$

[10] Bloom, Canning, and Fink have a good discussion, in the middle of p.2, of the micro evidence regarding how improvements in health affect productivity. But none of these effects should take longer than 40, let alone 60 years, to manifest themselves.

[11] Bloom, Canning and Fink arrive at this equation through a circuitous route. First, they argue that our equation (2) cannot be estimated consistently using predicted mortality as an instrument. Instead they rewrite this model, substituting from (1) (which is the equation initially used to derive (2)!), as

$$\Delta y_{i1} = \pi \Delta x_{i1} + \Delta \mu_1 + \Delta \mathbf{Z}'_{i1}\boldsymbol{\beta} + \varepsilon_1 - (\pi x_{i0} + \mu_0 + \mathbf{Z}'_{i0}\boldsymbol{\beta} - y_{i0}),$$

where we include time subscripts 0 and 1 for the post- and pre-periods. They argue that while (2) cannot be estimated, this equation can; we do not follow this argument, since, algebraically, this equation implies exactly the same moment conditions as (2). They then suggest that adding convergence effects, this equation becomes (11). As we show below, convergence effects do *not* give rise to (11). One could derive a model similar to (11) by introducing different types of dynamics, in particular, mean reversion in the error term *instead of fixed effects*, in particular, assuming that: $y_{it} = \pi x_{it} + \mu_t + \varepsilon_{it}$ and $\varepsilon_{it} = \lambda \varepsilon_{it-1} + \upsilon_{it}$, with υ_{it} being iid. However, if this is the underlying specification, there is no reason to estimate (11). Instead, one could achieve consistent estimation either by using standard 2SLS allowing or correcting for serial correlation in residuals, or by using GMM estimation of this model.

[12] Bloom, Canning, and Fink prefer regressions using annual average growth rates as the dependent variable, whereas our results are in terms of the total effect over the period under consideration. This difference in style does not affect anything of substance.

which is our equation (6) again. One lag of this equation is

$$y_{it-1} = \rho y_{it-2} + \pi x_{it-1} + \zeta_i + \mu_{t-1} + \varepsilon_{it-1}. \tag{13}$$

Subtracting this from the previous equation, our first-differenced specification becomes (now including time subscripts for clarity):

$$\Delta y_{it} = \rho \Delta y_{it-1} + \pi \Delta x_{it} + \Delta \mu_t + \Delta \varepsilon_{it}. \tag{14}$$

Note that this equation is very similar to (6) above, which was the basis of various different specifications in Acemoglu and Johnson (2006, 2007). The notable feature is that this equation, unlike (11), does not include initial life expectancy on the right-hand side, and thus can be estimated with two-stage least squares without creating collinearity and inconsistency. We now report direct estimates of this equation, as well as of equation (8) in which initial income per capita enters in a more ad hoc fashion.

3.2 Bloom, Canning, and Fink's Results

Table 1 replicates Table 2 from Bloom, Canning, and Fink (2009), in which change in log income per capita is regressed on change in log life expectancy. Columns 1 and 2 estimate equation (2), without covariates other than the change in log life expectancy. Column 1 is OLS, and in column 2 log life expectancy is instrumented with the change in predicted mortality. Our Table 1 also shows the first stages of the regressions (in Panel A)—first stages are not reported for any specifications in their tables.[13] The instrumental variables result in column 2 is exactly the same as in column 2, Panel B, of Acemoglu and Johnson (2007), which confirms we are using identical specifications.

However, in columns 4 through 6, Bloom, Canning, and Fink (2009) estimate

$$\Delta y_i = \alpha y_{i0} + \beta x_{i0} + \pi \Delta x_i + \Delta \mu + \Delta \varepsilon_i, \tag{15}$$

where y_{i0} is the initial (1940) level of log life expectancy and x_{i0} is the initial (1940) level of income per capita, and they do not include any other covariates. As we explained above, contrary to their claims, this specification does not follow from concerns about potential convergence in

[13] There is a very small difference in the standard errors between what we run and what is in Bloom et al. This is probably due to a difference in econometric programs. It does not affect anything substantive here.

income per capita—that equation would be (14) above. Moreover, is also emphasized above, equation (15) cannot be consistently estimated. It can certainly not be combined with predicted mortality, since the exclusion restriction of this instrument directly contradicts with (15). This is reflected in the extremely weak first stages in Bloom, Canning, and Fink's regressions (which they do not show in their tables). Mechanically, the term x_{i0}, when included in addition to Δx_i (which is instrumented using change in predicted mortality), will be highly correlated with the instrument (change in predicted mortality, constructed from the interaction of initial mortality, which is very highly collated with x_{i0}, with global health interventions).

Column 4 of our Table 1, which replicates their first IV estimate of (15), illustrates the weak first stage. This model excludes initial income per capita but includes initial life expectancy (which is treated as exogenous). The standard errors explode. Bloom, Canning, and Fink only report the second stage of this regression, but this clearly does not make sense in view of the first stage (upper panel of column 4, Table 1 here).

The same applies to their specification in column 6, which includes initial income per capita as well as initial life expectancy. It is curious that Bloom, Canning, and Fink, who repeatedly stress the effect of including initial per capita on our results, actually never report regressions that exclude initial life expectancy but include initial income per capita. They start with models that include initial life expectancy, and then add initial income per capita. As we show in the next subsection, and as was evident from the presentation of flexible interaction results using initial per capita income throughout Acemoglu and Johnson (2006, 2007), including initial income per capita has no effect on our results.[14]

3.3 Meaningful Estimates in the Presence of Convergence Effects

We turn now to results from specifications that build on, but were not reported in, our previous papers to illustrate the impact of income convergence and mean reversion dynamics on our estimates. In the estimation of (14), the time periods should ideally be balanced, i.e., the number of years covered in Δy_{it} should be the same as in Δy_{it-1}. To achieve this, our preferred specification focuses on the 1940-80 period and includes lagged values from 1900-1940. Doing this reduces our sample size. When we focus on initially low- and middle-income countries,

[14] In addition to the specifications shown here, Bloom, Canning, and Fink also report nonlinear estimates, where initial life expectancy as well as change in life expectancy are treated as endogenous, but these models both suffer from the same logical inconsistency between their second stage and the instrument, and also have a single instrument for two endogenous regressors.

the sample is further down to only 20 countries.

As an alternative, we also looked at specifications in which the lagged change is measured as the 1930-40 change, thus forgoing the balanced time periods. We also have to do this when we look at specifications focusing on 1940-2000 changes, which are Bloom, Canning, and Fink's preferred time period. Finally, we also looked at a slight variant of (14), where the lagged change is replaced by initial level, i.e., equation (8) above:

$$\Delta y_{it} = \tilde{\rho} y_{it-1} + \pi \Delta x_{it} + \Delta \mu_t + \Delta \varepsilon_{it}. \tag{16}$$

The specification enables us to maximize sample size.

Panel A of Table 2 uses change in income per capita over 1900-1940 as a regressor; this reduces our sample size to 31 countries. Panel B shows what happens if we use instead 1930-40 for the change in income per capita—in which case we keep our original sample.[15]

Bloom, Canning, and Fink prefer to look at outcomes over the period 1940-2000, despite the confounding circumstances of the HIV-AIDS epidemic. They drop some countries heavily affected by the epidemic, as noted in their footnote 6, but this relies on reported HIV infection rates and the data on this are notoriously inaccurate; their cut-off rate for exclusion from the sample is ad hoc. We prefer 1940-1980 (i.e., ending before widespread HIV infection takes hold) but, as in our earlier papers, we also report results for 1940-2000.

The first four columns of Table 2 show OLS results (for comparison) and columns 5 through 8 report results in which the change in log life expectancy is instrumented using change in predicted mortality. Columns 9 through 12 report OLS and 2SLS results just for initially low- and middle-income countries.

In both panels A and B, our main results remain intact. Compare, for example, columns 5 and 7 or columns 6 and 8; the parameter estimates and standard errors in our base sample are barely affected. The instrumental variable results for low- and middle-income countries (columns 11 and 12) lie well within the range of estimates reported in Acemoglu and Johnson (2007). There is no indication in any specification that a greater increase in life expectancy was associated with a bigger rise in income per capita over this period.

[15] Columns 5 and 6 in Panel B here are exactly equivalent to the regressions in columns 1 and 2 of Panel B, Table 9, in Acemoglu and Johnson (2007). However, because of how Stata 9 calculates clustered robust standard errors, there are small differences in standard errors between the regressions run in differences (here) and in levels (in our published paper). These differences do not affect any point of substance.

3.4 The Mechanism

Bloom, Canning, and Fink do not explicitly discuss the economic rationale for long lags in the effect of changes in life expectancy on income, i.e., the mechanism linking these variables. This topic was explicitly discussed in Acemoglu and Johnson (2006 and 2007), where we focused on the slow adjustment of population and fertility. We repeat the same exercise here using model (14), with the results shown in Table 3. The results are very similar to those reported in Acemoglu and Johnson (2006 and 2007), but allow lagged income per capita to enter in various ways.

Increases in life expectancy are robustly related to a greater increase in population (Panel A of Table 3). The point estimate of the effect on total GDP is positive (Panel B of Table 3), but smaller than the population effect, and sometimes insignificant. Overall, as in Acemoglu and Johnson (2006 and 2007), the somewhat negative effect on GDP per capita (or GDP per working age population, as we reported in those papers) is the outcome of a large effect on population and a smaller effect on GDP.

Dynamics resulting from population and fertility behavior in response to health changes are modelled directly in recent work by Ashraf, Lester, and Weil (2009). Their findings confirm the overall conclusions in Acemoglu and Johnson (2007) and also show how our results are consistent with Weil (2007).[16]

3.5 Alternative Specifications

We now turn to regressions of the form (16), which use initial level of income per capita, rather than the change in this variable over some previous period. As noted above, this is useful because it enables us to use a larger sample. In addition, it avoids the use of potentially lower quality data from 1900.

In Table 4, columns 1 and 2 report OLS regressions with change in log GDP per capita on the left hand side and change in log life expectancy on the right hand side. Column 1 covers 1940-1980, a time period which is long enough for any beneficial health improvement effects to manifest themselves on productivity, but which ends before the AIDS epidemic severely affects lower income countries. Column 2 covers 1940-2000, which is preferred by Bloom, Canning, and Fink (and also reported in Acemoglu and Johnson, 2006 and 2007)

[16] In contrast, Bloom, Canning, and Fink imply in their first paragraph that our results are inconsistent with those of Weil (2007).

Columns 3 through 8 show the results of two stage least squares (IV) regressions in which change in log life expectancy is instrumented by change in predicted mortality, i.e., using our identification strategy.

This specification is equivalent to what is reported in Acemoglu and Johnson (2007; specifically, Table 9, Panel B, columns 1 and 2). That version uses a "long difference" specification with fixed effects and two dates; here we are looking at the change on change between those two dates, but these are equivalent.

Columns 5 through 8 introduce initial income per capita. In Acemoglu and Johnson (2006, 2007), initial income per capita is from 1930 (to make this more likely exogenous vis-à-vis the big international heath improvements, which start in 1940). Bloom, Canning, and Fink prefer initial income per capita in 1940 (e.g., in their Table 2), so we report results here with that variable also.

In Table 4, column 5 of Panel A, the coefficient on change in log life expectancy, 1940-80, is -1.59, with a standard error of 0.91; this is significant at the 10% and is the same result as in Acemoglu and Johnson (2007), Table 9, Panel B, column 6. Initial income per capita in 1930 is far from significant in this specification. The same results hold in column 6 of Table 4, where we instead use initial income per capita in 1940.

In any case, while initial income per capita (from 1930 or 1940) is significant in columns 7 and 8, the effect of change in life expectancy (instrumented) on change in income per capita is more negative and more significant than in the Acemoglu and Johnson (2007) core specification.[17]

If we limit our sample to just countries that were initially low and middle-income, a robustness check used throughout Acemoglu and Johnson (2006 and 2007), the same pattern of results holds, even though the sample now falls to 36 countries and significance levels decline accordingly. Panel B of Table 1 shows these results: over 1940-80, initial income per capita does not matter and the original Acemoglu and Johnson results hold; over 1940-2000, there is a stronger case for including initial income per capita, but then the change in log life expectancy has a more negative and more significant effect on change in GDP per capita.

Table 5 again returns to the potential mechanism—the effects of health improvements on

[17] This is because the effect of increased life expectancy on population is greater in the 1940-2000 period than it is in the 1940-1980 period. Countries that had greater increases in life expectancy after 1940 experienced even greater increases in population 1940-2000 than 1940-1980. It is the population increase that swamps the small positive increase in GDP in both sample periods.

population and GDP—based on the specification approach in Table 3. The effects of change in log life expectancy, instrumented, on change in log population is very stable across the 2SLS results—and well within the range of estimates in Table 8, Panel A of Acemoglu and Johnson (2007): a 1 percent increase in life expectancy leads to a 1.7-2 percent increase in population. Initial income per capita is not significant in any specification.

The estimated effects of change in log life expectancy on change in total GDP, shown in Panel B, also fits with the results in Acemoglu and Johnson (2007), Table 9, Panel A. The parameter estimate is less stable and it is never significant. In Bloom, Canning, and Fink's preferred time period, 1940-2000, the sign on change in log life expectancy is actually negative.

4 Summary

In Acemoglu and Johnson (2006 and 2007), we adopted a variety of approaches to dealing with convergence and potential mean reversion in income per capita, all of them confirming our baseline results. Here we recap these results and supplement them with additional estimates, again showing no evidence that allowing for income convergence changes the relationship between life expectancy in income per capita that emerged following the international epidemiological transition. We find no specification that supports Bloom, Canning, and Fink's contention that controlling for income convergence has major effects on the results in Acemoglu and Johnson (2006, 2007).

Instead of controlling for income convergence effects, as we had already done in our working and published papers, Bloom, Canning, and Fink include initial life expectancy in their specification, which does not have any justification as a control for income convergence effects or mean reversion dynamics. More importantly, even if their specification had theoretical justification, it would be logically inconsistent to combine it would our predicted mortality instrument. Our exclusion restriction imposes that mortality rates do not directly affect income or population 40 or 60 years later. Bloom, Canning, and Fink use our instrument, based on this exclusion restriction, with a model that imposes that life expectancy affects income 40 or 60 years later. Therefore, their specifications cannot be estimated, and this is reflected in the fact that standard errors in their first stages explode – a fact not reported in their paper.

It is also worth emphasizing that Bloom, Canning, and Fink's specifications do not follow from the possible presence of mean reversion in income per capita, as shown above. More

importantly, for the narrow purpose of this note, these specifications explicitly contradict the identification assumptions in Acemoglu and Johnson (2006, 2007), which were supported with falsification exercises that demonstrated the lack of pre-existing trends.

Of course, there is nothing wrong with Bloom, Canning, and Fink disagreeing with our identification assumption or taking on directly the evidence we provide to make that identification assumption plausible in our working paper and published article. However, if this is their view, they should be writing a direct critique of our identification assumption or suggesting an alternative. Instead, they take our instrument, with which they evidently disagree, and combine it with a logically inconsistent second-stage equation. Not surprisingly, this leads to meaningless results.

Finally, if one wishes to take lags and dynamics seriously, these should be related to fertility, a topic carefully investigated in Ashraf, Lester, and Weil (2009). Although there is much to be investigated in this area, we think that doing this using growth regressions with arbitrary lags (without attention to what this is doing to first stage relationships) is not the way to go. Instead, there is much that can be learned about health, fertility, population, and income from combining general equilibrium models with microdata, as in Bleakley (2007), and also from more carefully modeling population dynamics as in Ashraf, Lester, and Weil (2009) and Bleakley and Lange (2006).

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Table 1
Change in Income Per Capita on Change in Life Expectancy
(Table 1 from Bloom, Canning, and Fink)

	Base Sample					
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	OLS	2SLS	OLS	2SLS	OLS	2SLS
	Panel A: First Stage, dependent variable is change in log life expectancy, 1940-2000					
Change in predicted mortality		-0.56		-0.01		-0.02
		(0.07)		(0.03)		(0.03)
Log life expectancy, 1940				-0.74		-0.80
				(0.03)		(0.04)
Log GDP per capita, 1940						0.026
						(0.014)
	Panel B: Second Stage, dependent variable is change in log GDP per capita, 1940-2000					
Change in log life expectancy, 1940-1980	-1.14	-1.51	3.68	-21.56	5.77	-21.45
	(0.26)	(0.40)	(1.31)	(82.76)	(1.18)	(68.77)
Log life expectancy, 1940			3.77	-15.23	6.85	-15.18
			(0.97)	(62.50)	(1.00)	(55.93)
Log GDP per capita, 1940					-0.69	0.01
					(0.11)	(1.87)
Number of observations	47	47	47	47	47	47

Robust standard errors. Columns 1, 3, and 5 are OLS, in which change in log GDP per capita is regressed on change in log life expectancy and log life expectancy in 1940, log GDP per capita in 1940, or both. Columns 2, 4, and 6 are 2SLS, in which change in log life expectancy is instrumented using change in predicted mortality. These regressions replicate results reported in Bloom, Canning, and Fink (although they do not report the first stages). Change in log life expectancy and change in predicted mortality are over the period 1940 to 2000.

Table 2
Effect of Including Lagged Change In Income Per Capita on Log GDP Per Capita Results

	Dependent variable: change in log GDP per capita, over period indicated in column heading											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	OLS				2SLS				OLS		2SLS	
	1940-1980	1940-2000	1940-1980	1940-2000	1940-1980	1940-2000	1940-1980	1940-2000	1940-1980	1940-2000	1940-1980	1940-2000
	Panel A: Using change in income per capita, 1900-1940											
	Base Sample								Low- and Middle-Income Countries Only			
Change in log life expectancy, 1940-1980	-0.49		-0.54		-0.86		-0.85		-1.19		-1.93	
	(0.36)		(0.36)		(0.47)		(0.44)		(0.48)		(0.82)	
Change in log life expectancy, 1940-2000		-0.56		-0.48		-0.59		-0.61		-1.10		-1.36
		(0.28)		(0.28)		(0.34)		(0.35)		(0.47)		(0.73)
Change in income per capita, 1900-1940			0.20	-0.39			0.23	-0.38	0.26	-0.37	0.32	-0.35
			(0.19)	(0.20)			(0.18)	(0.19)	(0.19)	(0.20)	(0.20)	(0.19)
Number of observations	31	31	31	31	31	31	31	31	20	20	20	20
	Panel B: Using change in income per capita, 1930-40											
	Base Sample								Low- and Middle-Income Countries Only			
Change in log life expectancy, 1940-1980	-0.81		-0.80		-1.32		-1.32		-1.19		-2.52	
	(0.26)		(0.26)		(0.36)		(0.36)		(0.37)		(0.83)	
Change in log life expectancy, 1940-2000		-1.14		-1.16		-1.51		-1.50		-1.79		-2.72
		(0.27)		(0.26)		(0.41)		(0.41)		(0.42)		(0.98)
Change in income per capita, 1930-1940			0.19	-0.23			0.14	-0.27	0.50	0.07	0.55	0.09
			(0.37)	(0.53)			(0.36)	(0.51)	(0.45)	(0.61)	(0.48)	(0.58)
Number of observations	47	47	47	47	47	47	47	47	36	36	36	36

Robust standard errors. Columns 1 through 4, 9 and 10 are OLS regressions of change in log GDP per capita on change in log life expectancy (1940-1980 or 1940-2000), plus (Panel A) change in income per capita, 1900-1940, and (Panel B) change in income per capita, 1930-1940. Columns 5 through 8, 11 and 12 are 2SLS, in which change in log life expectancy is instrumented using change in predicted mortality 1940-1980 (first stages not reported to save space). Odd columns use change in log GDP per capita from 1940 to 1980, while even columns use change from 1940 to 2000. Columns 1 through 8 use our base sample, while columns 9 through 12 use only countries that were initially low and middle income.

Table 3
Effect of Including Lagged Change in Income Per Capita on Population and Total GDP Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS		2SLS					
	1940-1980	1940-2000	1940-1980	1940-2000	1940-1980	1940-1980	1940-2000	1940-2000
	Base Sample							
	Panel A: Dependent variable is change in log population, over period indicated in column heading							
Change in log life expectancy, 1940-1980	1.40		1.18		1.19	1.66		
	(0.25)		(0.31)		(0.29)	(0.33)		
Change in log life expectancy, 1940-2000		1.78		1.47			1.48	1.94
		(0.29)		(0.35)			(0.34)	(0.35)
Change in income per capita, 1900-1940					0.25		0.36	
					(0.11)		(0.15)	
Change in income per capita, 1930-1940						0.39		0.50
						(0.19)		(0.27)
Number of observations	31	31	31	31	31	47	31	47
	Panel B: Dependent variable is change in log total GDP, over period indicated in column heading							
Change in log life expectancy, 1940-1980	0.85		0.20		0.22	0.30		
	(0.51)		(0.65)		(0.56)	(0.48)		
Change in log life expectancy, 1940-2000		1.16		0.77			0.77	0.41
		(0.34)		(0.37)			(0.38)	(0.37)
Change in income per capita, 1900-1940					0.52		0.02	
					(0.18)		(0.18)	
Change in income per capita, 1930-1940						0.57		0.27
						(0.40)		(0.55)
Number of observations	31	31	31	31	31	47	31	47

Robust standard errors. The dependent variables are: in Panel A, change in log population; and in Panel B, change in log total GDP. Columns 1 and 2 are OLS regressions on change in log life expectancy and change in income per capita (over either 1900-1940 or 1930-1940). Columns 3 through 8 are 2SLS, in which change in log life expectancy is instrumented using change in predicted mortality, 1940-1980 (first stages not reported to save space). Columns 1, 3, 5, and 6 use change in the dependent variable from 1940 to 1980, while columns 2, 4, 7, and 8 use change from 1940 to 2000.

Table 4
Effect of Including Initial Income Per Capita on Log GDP Per Capita Results

	Dependent variable: change in log GDP per capita, over period indicated in column heading							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS		2SLS					
	1940-1980	1940-2000	1940-1980	1940-2000	1940-1980	1940-1980	1940-2000	1940-2000
	Panel A: Base Sample							
Change in log life expectancy, 1940-1980	-0.81		-1.32		-1.59	-1.47		
	(0.26)		(0.36)		(0.91)	(0.82)		
Change in log life expectancy, 1940-2000		-1.14		-1.51			-3.55	-3.25
		(0.27)		(0.41)			(1.25)	(1.11)
Initial income per capita in 1930					-0.07		-0.69	
					(0.21)		(0.32)	
Initial income per capita in 1940						-0.04		-0.59
						(0.18)		(0.28)
Number of observations	47	47	47	47	47	47	47	47
	Panel B: Low- And Middle-Income Countries Only							
Change in log life expectancy, 1940-1980	-1.17		-2.35		-2.23	-2.08		
	(0.38)		(0.79)		(1.15)	(1.04)		
Change in log life expectancy, 1940-2000		-1.79		-2.70			-4.12	-3.75
		(0.41)		(0.97)			(1.50)	(1.33)
Initial income per capita in 1930					0.04		-0.60	
					(0.21)		(0.32)	
Initial income per capita in 1940						0.09		-0.49
						(0.17)		(0.28)
Number of observations	36	36	36	36	36	36	36	36

Robust standard errors. Panel A reports results using our full sample, while Panel B reports results for countries that were initially low and middle income. Columns 1 and 2 are OLS regressions of change in log GDP per capita on change in log life expectancy and initial income per capita in 1930 or 1940. Columns 3 through 8 are 2SLS, in which change in log life expectancy is instrumented using change in predicted mortality, 1940-1980 (first stages not reported to save space). Columns 1, 3, 5, and 6 use change in dependent variable from 1940 to 1980, while columns 2, 4, 7, and 8 use change from 1940 to 2000.

Table 5
Effect of Including Initial Income Per Capita on Population and Total GDP Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS		2SLS					
	1940-1980	1940-2000	1940-1980	1940-2000	1940-1980	1940-1980	1940-2000	1940-2000
	Panel A: Dependent variable is change in log population, over period indicated in column heading							
Change in log life expectancy, 1940-1980	1.62		1.67		1.58	1.79		
	(0.18)		(0.34)		(0.77)	(0.72)		
Change in log life expectancy, 1940-2000		2.01		1.96			1.89	2.10
		(0.21)		(0.36)			(0.81)	(0.75)
Initial income per capita in 1930					-0.03		-0.02	
					(0.14)		(0.18)	
Initial income per capita in 1940						0.03		0.05
						(0.12)		(0.16)
Number of observations	47	47	47	47	47	47	47	47
	Panel B: Dependent variable is change in log total GDP, over period indicated in column heading							
Change in log life expectancy, 1940-1980	0.78		0.32		-0.07	0.29		
	(0.33)		(0.50)		(1.18)	(1.04)		
Change in log life expectancy, 1940-2000		0.85		0.42			-1.71	-1.18
		(0.28)		(0.36)			(1.13)	(0.99)
Initial income per capita in 1930					-0.10		-0.72	
					(0.26)		(0.33)	
Initial income per capita in 1940						-0.01		-0.54
						(0.22)		(0.28)
Number of observations	47	47	47	47	47	47	47	47

Robust standard errors. The dependent variables are: in Panel A, change in log population; and in Panel B, change in log total GDP. Columns 1 and 2 are OLS regressions on change in log life expectancy and initial income per capita in 1930 or 1940. Columns 3 through 8 are 2SLS, in which change in log life expectancy is instrumented using change in predicted mortality (first stages not reported to save space). Columns 1, 3, 5, and 6 use change in dependent variable from 1940 to 1980, while columns 2, 4, 7, and 8 use change from 1940 to 2000.