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DISEASE AND DEVELOPMENT:
A REPLY TO BLOOM, CANNING, AND FINK

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ABSTRACT

Bloom, Canning, and Fink (2014) argue that the results in Acemoglu and Johnson (2006, 2007) are not robust because initial level of life expectancy (in 1940) should be included in our regressions of changes in GDP per capita on changes in life expectancy. We assess their claims controlling for potential lagged effects of initial life expectancy using data from 1900, employing a nonlinear estimator suggested by their framework, and using information from microeconomic estimates on the effects of improving health. There is no evidence for a positive effect of life expectancy on GDP per capita in this important historical episode.

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1 Introduction

Beginning in the 1940s, a wave of health innovations and more effective international public health measures led to a rapid and large improvement in health — for example, in some relatively poor countries, life expectancy at birth quickly rose from around 40 years to over 60 years. In Acemoglu and Johnson (2006, 2007, hereafter AJ) we constructed an instrument for these changes in life expectancy: "predicted mortality," which is calculated from initial mortality by disease and the timing of global disease interventions. Across a wide range of specifications, our work suggests no positive effects — over 40 or 60 year horizons — of life expectancy on GDP per capita (or GDP per working age population).

Bloom, Canning, and Fink (2014, hereafter BCF) argue that the *level* of life expectancy in 1940 affected *subsequent growth rates* and should be included in our long-difference specifications, i.e., the level of life expectancy in 1940 should be included on the right-hand side when 1940-1980 or 1940-2000 changes in GDP per capita are the dependent variables. In a linear regression framework, their specification introduces a great deal of multicollinearity and the standard errors become very large.

The specifications in AJ (2006, 2007) allowed for potential long-run effects of health improvements, and supported our empirial strategy by showing that changes in the predicted mortality instrument were uncorrelated with its own past changes and past changes in population, GDP, and GDP per capita. There are three further ways to assess BCF's concerns. First, we include the initial level of life expectancy from 1900, interacted with time dummies in our decadal panel data set (which runs from 1940). Second, we use a nonlinear estimator suggested by BCF's framework to estimate directly their proposed equation with reasonable precision. Third, from microeconomic estimates in Ashraf, Lester, and Weil (2009, hereafter ALW) we calculate potential macroeconomic effects of current life expectancy on future growth and examine the implications for our baseline findings. Our results remain robust throughout.

2 The Estimating Framework

Our estimating equation in AJ (2006, 2007) was,

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

Here i denotes country and t is time period; y is log GDP 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; the μ_t's incorporate time-varying factors common across all countries; and $\mathbf{Z}_{it}$ denotes a vector of other controls. (We use the subscript $it+k$ as a shorthand for $i, t+k$). The case where $k > 0$ allows for lagged effects of life expectancy.

We instrumented life expectancy with *predicted mortality,* constructed as:

$$M_{it}^{I} = \sum_{d \in \mathcal{D}} \left((1 - I_{dt}) M_{di40} + I_{dt} M_{dFt} \right), \tag{2}$$

where M_{dit} denotes mortality in country i from disease d at time t, I_{dt} is a dummy for intervention on disease d at time t (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 most major communicable causes of death around the world in 1940, as well as some less common killers. 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. For our baseline instrument, M_{dFt} is set equal to zero.

Any change in life expectancy is unlikely to have its full effect on any demographic or economic variables instantaneously — or even in the same decade. For this reason, in AJ (2007), we estimated equation (1) in *long differences*, i.e., regressing change on change in a panel including only two years, t_0 and t_1 (in practice 1940 and 1980, or 1940 and 2000). In AJ (2006) we also presented a range of panel specifications using decadal observations; these results were very similar to those from the long-difference specifications that were emphasized in AJ (2007). We explicitly discussed the adjustment dynamics of population and GDP, and allowed for potential health effects to show up after a long lag — after 40 or 60 years in the long-difference specifications and with 10, 20, 30 or 40 year horizons in panel specifications.

BCF propose a "partial adjustment model" that takes the following form:[1]

$$\Delta y_{it} = \pi \Delta x_{it} + \lambda \pi x_{it-1} - \lambda y_{it-1} + \alpha_t + \xi_{it}, \tag{3}$$

where $\Delta y_{it} \equiv y_{it} - y_{it-1}$, and Δx_{it} is defined similarly. They derive this from our equation (1), assuming an AR(1) specification for the error term ($\varepsilon_{it} = \lambda \varepsilon_{it-1} + \xi_{it}$). This equation allows for convergence dynamics (through the λ term) and a potential impact of the lagged *level* of

[1] This is their equation (3), using their notation, except that we denote the error term by ξ_{it} to distinguish it from our error term, ε_{it}, in (1), and we use π instead of their β for consistency.

log life expectancy, x_{it-1}, on *subsequent changes* in GDP per capita.

3 The Impact of Initial Life Expectancy

BCF's IV regressions generate very imprecise estimates for the effect of life expectancy on GDP per capita. This simply reflects the fact that it is impossible to distinguish the impact of the level of life expectancy in 1940 (x_{it-1}) and of the subsequent change in life expectancy (Δx_{it}) in long difference using only the variation in predicted mortality (M_{it}^{I}).

If the true effect of life expectancy on GDP per capita were positive — for example, because the level of life expectancy affects subsequent changes in GDP per capita — then estimates of the relationship between changes in life expectancy and changes in GDP per capita over a 60-year horizon should capture much of these positive effects even if there are reasonable lags.[2] Our long-difference specifications should thus reveal any long-run, positive relationship between life expectancy and GDP per capita. Our estimates in AJ (2006 and 2007) using 60-year changes show no such positive effect.

There are three further ways to check if potential long-term effects from lagged life expectancy modify any of our conclusions: (a) run panel regressions including initial life expectancy in 1900, interacted with time dummies, (b) employ a nonlinear estimator implied by BCF's equation (3), and (c) use reasonable estimates for direct effects of health improvements based on microeconomic evidence.

3.1 Controlling for Initial Life Expectancy

To facilitate comparison with models that control for the effect of initial life expectancy, column 1 of Table 1 reports baseline estimates of (1) using decadal observations as in the panel data models of AJ (2006). Panel A is for 1940-1980 and Panel B is for 1940-2000.[3] The standard errors in this and subsequent models are robust and allow for arbitrary serial correlation at the country level. In column 1 of Panel A, $\hat{\pi} = -1.307$, with a standard error of 0.455, indicating a negative impact of life expectancy on GDP per capita. Column 1 of Panel B shows a similar estimate that is larger in absolute value (i.e., more negative) for the period

[2] For example, even if only a third of the impact of lagged life expectancy on GDP per capita materializes over a generation (i.e., over 20 years), the bulk of these effects should be evident in our specification using 60-year changes (1940 to 2000).

[3] We have data on GDP, life expectancy, and other variables of interest every 10 years from 1940 to 2000. We also look at the period 1940-1980 to avoid the potential effects of the onset of HIV-AIDS as a global disease.

1940-2000, $\hat{\pi} = -1.394$.[4]

The remaining columns in Table 1 include a full set of time interactions with log life expectancy in 1900 — allowing initial life expectancy to flexibly impact future GDP per capita. Using the 1900 value for life expectancy, rather than the 1940 level, alleviates the mechanical correlation between 1940 life expectancy and predicted mortality. It is equally valid if there is an impact from the *level* of initial life expectancy on *future growth* as proposed by BCF.[5]

Column 2 shows results from including these interactions without controlling for lagged GDP per capita. In Panel A, the estimate is $\hat{\pi} = -0.100$ with a standard error of 0.421. Thus there is a negative (and far from significant) impact of life expectancy on GDP per capita, which is much smaller than the estimate in column 1. The estimate in Panel B ($\hat{\pi} = -0.928$, s.e. $= 0.486$) is larger in absolute value (i.e., more negative), much closer to the estimate in column 1, and marginally statistically significant.

In addition to year dummies interacted with initial life expectancy, column 3 adds a full set of time interactions with log GDP per capita in 1940. These interactions are useful, since any correlation with initial GDP per capita might otherwise load on to initial life expectancy. In Panel A, we now estimate $\hat{\pi} = -0.270$ (s.e. $= 0.522$) The coefficient on life expectancy in Panel B is larger, -1.317, very similar to our baseline estimate in column 1, and statistically significant at 5% (s.e. $= 0.627$).

Columns 4 and 5 add lagged log GDP per capita to the right-hand side, allowing for convergence effects. These two columns, respectively, use the standard 2SLS estimator and Arellano and Bond's (1991) optimally weighted two-step Generalized Method of Moments (GMM) estimator, with predicted mortality as external instrument. The results are again broadly consistent with our baseline results. The GMM estimate in column 5 is $\hat{\pi} = -0.171$ (s.e. $= 0.393$) in the 1940-1980 panel, and a larger (in absolute value), more precise, and statistically significant $\hat{\pi} = -0.598$ (s.e. $= 0.234$) in the 1940-2000 panel.

[4] These balanced panel estimates are very close to those reported in columns 1 and 2 of the unbalanced panel of Table 11 in AJ (2006) and to the long differences in columns 1 and 2 of Table 7, Panel B in AJ (2007).

[5] Econometrically, we are controlling for the effects of initial life expectancy by including a full set of time dummies interacted with initial life expectancy, i.e., terms of the form $\omega_t \times x_{i1900}$ (one for each t). This strategy potentially controls for two types of effects. The first is that life expectancy in 1900, x_{i1900}, directly impacts outcomes in subsequent years. The second is that the year t equation contains the term $\omega_t \times x_{it-1}$ (thus allowing for a general impact of lagged life expectancy). In this latter case, we can substitute for x_{it-1} in terms of log life expectancy in 1900, x_{i1900}. For example, following the model for the dynamics of life expectancy estimated in Table 6 of AJ (2007, equation (12), p.957), suppose that $x_{it} = \nu x_{it-1} + \eta_{it}$, with decadal observations and η_{it} being serially uncorrelated and orthogonal to other variables. Then substitute for x_{it-1} and its lags successively to obtain $x_{it-1} = \nu^{t-1} x_{i1900} + \eta_{it-1} + \nu\eta_{it-2} + \nu^2\eta_{it-3} + ...$, with $x_{i0} = x_{i1900}$. Then the coefficient on x_{it-1} in the year t equation would be $\omega_t \times \nu^{t-1}$, and all other coefficients can be estimated consistently.

Overall, controlling for the effects of initial life expectancy changes our point estimates, especially for the 1940-1980 period. However, in no case is there any evidence for a positive effect of life expectancy on GDP per capita, and the estimates in Table 1 for 1940-2000 show statistically significant negative effects of life expectancy on GDP per capita that are close in magnitude to the baseline results of AJ (2006, 2007).

3.2 Nonlinear Generalized Method of Moments

We can directly estimate BCF's proposed equation (3) using a nonlinear GMM approach (with nonlinear equivalents of the moment conditions used in column 5 of Table 1). Estimates for π and λ obtained in this fashion are shown in Table A1 of the Online Appendix. These imply long-run negative effects of life expectancy on GDP per capita that are very similar to our baseline results for both 1940-1980 and 1940-2000. For example, $\hat{\pi}$ is estimated as -1.261 for 1940-80 and -1.548 for 1940-2000, while our original estimates ranged from -1.21 to -2.70.[6]

3.3 Directly Incorporating Lagged Effects of Life Expectancy

An alternative strategy is to directly incorporate the potential effect of initial life expectancy in the long-difference specification from AJ (2007). Rewriting BCF's estimating equation gives:

$$\Delta\tilde{y}_{it} \equiv \Delta y_{it} - \kappa x_{it-1} = \pi\Delta x_{it} - \lambda y_{it-1} + \alpha_t + \xi_{it}. \tag{4}$$

Although we do not know the precise value of κ ($= \lambda\pi$), the microeconomic literature — surveyed by ALW (2009) — provides guidance on how large this could be. Specifically, we use their estimates to obtain an upper bound for plausible values of κ by supposing that *all* of the potential effects of initial life expectancy are captured by κ.

In our sample, life expectancy among the countries with high initial mortality increased from about 40 to over 60 between 1940 and 1980. Increasing median life expectancy from 40 to 60 years would, according to ALW's base estimate, raise GDP per capita by 15 percent in the long-run (over 60 years). Using their high estimate — which assumes that all impacts of health are as positive as any microeconomic study could suggest — the increase in GDP per capita is 25 percent and the full long-run effect is achieved within 40 years.

In terms of equation (4), supposing that the 15 percent long-run effect is all captured by

[6] By setting $\Delta y_{it} = \Delta x_{it} = 0$ in equation (3), it can be verified that their π measures the long-run (e.g., 40 or 60 years) impact of life expectancy on GDP per capita, exactly as does the parameter π in our equation (1).

κ, this would imply a value of κ equal to 0.343, while a 25 percent long-run effect implies that κ equals 0.54.[7] We use $\kappa = 0.3$, 0.4, 0.5, and 0.6 to span a range for the upper bound for the effects of increased life expectancy on future growth. The estimate of 0.6, in particular, represents the strongest possible case for the BCF hypothesis.

We estimate equation (4) using 2SLS in two sets of specifications. First, we estimate (4) assuming no mean reversion, i.e., setting $\lambda = 0$ (odd-numbered columns in Table 2). Second, we estimate (4) including log GDP per capita in 1940 on the right-hand side to control for potential convergence effects in GDP per capita (even-numbered columns in Table 2). In either case, there is no evidence of a positive coefficient for π.

For example, for 1940-1980, with $\kappa = 0.6$ and log GDP per capita in 1940 included, the coefficient on change in life expectancy is -0.551 (Panel A, column 8). For 1940-2000, in Panel B of column 8, there is a significant negative coefficient on change in life expectancy: -2.534 with a standard error of 1.042.

As shown in Table 2, every 0.1 increase in κ reduces the negative effect of life expectancy by about 0.15 in absolute terms. This implies that to reach even a zero coefficient on change in life expectancy for the odd-numbered columns of Panel A (for 1940-1980 and without controlling for GDP per capita in 1940) would require a κ of around 0.9. This is far larger than anything that can reasonably be supported using the available microeconomic evidence. To imagine a positive effect for life expectancy on GDP per capita in the other specifications in Panel A or in Panel B (for 1940-2000) is even more far-fetched.

4 Conclusion

Estimates using 40-year or 60-year differences in AJ (2006 and 2007), which should capture any slow-acting effects of health improvements, did not show any evidence for a positive impact of life expectancy on GDP per capita. In this note, we report three additional approaches for assessing the potential effects of initial life expectancy on subsequent changes in GDP per capita. All these approaches confirm our main results are robust — there is no evidence that increases in life expectancy after 1940 had a positive effect on GDP per capita growth.

[7] We translate between ALW's simulation parameters and our regression coefficients as follows. A 15 percent increase in GDP per capita means the level of GDP per capita ends up at 1.15 (i.e., if it starts at 1), so the impact measured in natural logarithms is $\ln(1.15) = 0.139$. Initial life expectancy is 40 years and $\ln(40) = 3.69$. Final life expectancy is 60 years and $\ln(60) = 4.09$. The change in log life expectancy is 0.405. Assuming that *all* of this is accounted for by κ gives an upper bound for κ equal to $(0.139/0.405) = 0.343$ in the base case.

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Online Appendix

In the text, we explained how BCF's equation (3) is used to motivate their argument that there is a potential impact from the initial level of life expectancy on future growth. In this Appendix, we report estimates from equation (3) using nonlinear GMM, with moment restrictions corresponding to using past values of predicted mortality and life expectancy in 1900 as instruments — as in Arellano and Bond's GMM, reported in Table 1. The results of this estimation are provided in Appendix Table A1.

The two columns of this table correspond to alternative moment restrictions, with Panels A and B again showing results for the periods 1940-1980 and 1940-2000 respectively. Column 1 reports results using a sparse set of moments (at most two lags of predicted mortality and GDP per capita). Column 2, in the same spirit as Arellano and Bond's full GMM, uses all lags of predicted mortality and twice or more lagged GDP per capita.

The results are very close to the baseline estimates in AJ (2006, 2007). In the first column for 1940-1980 (Panel A), we have $\hat{\pi} = -1.261$, with a standard error of 0.801; and for 1940-2000 (Panel B), we have a more precisely estimated $\hat{\pi} = -1.548$, with a standard error of 0.644. The results in column 2 are similar, with the Panel B results showing larger (i.e., more negative), more precise, and more statistically significant estimates.

The similarity of these results to our baseline estimates can be seen by noting that, as pointed out in footnote 6 in the text, π in this specification corresponds precisely to the parameter π in our equation (1), which measures the impact over a 40 or 60 year horizon. This can be verified by setting $\Delta y_{it} = \Delta x_{it} = 0$ in equation (3) — so that the dynamics have worked themselves out — in which case the equation implies $y_{it} = \pi x_{it}$. Therefore, estimates of π can be directly compared to the estimates in Table 9 of AJ (2007), which range from -1.21 to -2.70.

In short, nonlinear estimation using BCF's own specification produces estimates within the range of our baseline results.

Table 1

Effect of life expectancy on GDP per capita, controlling flexibly for the impact of life expectancy in 1900 and convergence dynamics, using panel data

	Dependent variable is log GDP per capita				
	2SLS				GMM
	(1)	(2)	(3)	(4)	(5)
	Baseline specification	Including life expectancy in 1900, interacted with time dummies			
	A. 1940-1980 balanced panel				
Lagged GDP per capita				0.552	0.414
				(0.080)	(0.296)
Life expectancy	-1.307	-0.100	-0.270	-0.478	-0.171
	(0.455)	(0.421)	(0.522)	(0.443)	(0.393)
Countries	47	47	47	47	47
Periods	5	5	5	5	4
Moments					25
Hansen p-value					0.29
AR2 p-value					0.22
	B. 1940-2000 balanced panel				
Lagged GDP per capita				0.817	0.821
				(0.047)	(0.144)
Life expectancy	-1.394	-0.928	-1.317	-0.965	-0.598
	(0.362)	(0.486)	(0.627)	(0.425)	(0.234)
Countries	47	47	47	47	47
Periods	7	7	7	7	6
Moments					44
Hansen p-value					0.31
AR2 p-value					0.43

Note. Two-Stage Least Squares specifications (columns 1, 2, 3, and 4) include a full set of country and year fixed effects. Columns 2, 3, 4, and 5 include a full set of year dummies interacted with life expectancy in 1900. Regressions in column 3 also include a full set of year dummies interacted with the log of GDP per capita in 1940. Arellano and Bond's GMM estimator (column 5) removes country fixed effects by taking first differences (hence the lower number of time periods), and then constructs moment conditions using all predetermined lags of GDP per capita and predicted mortality as instruments. It is estimated in two steps and thus is optimally weighted. Robust standard errors corrected for arbitrary serial correlation (clustered) at the country level are reported in columns 1, 2, 3 and 4, and robust standard errors are reported in column 5. Panel A contains estimates using a balanced panel of 47 countries from 1940 to 1980. Panel B contains estimates using a balanced panel of the same 47 countries from 1940 to 2000. See Acemoglu and Johnson (2007) for the construction of the predicted mortality instrument, definitions, and data sources.

Table 2

Effect of life expectancy on GDP per capita controlling directly for the impact of life expectancy in 1940 and convergence dynamics, using long differences

	Dependent variable is change in log GDP per capita							
	A. Long differences between 1940 and 1980							
	κ = 0.3		κ = 0.4		κ = 0.5		κ = 0.6	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Change in life expectancy	-0.820	-1.008	-0.655	-0.855	-0.489	-0.703	-0.324	-0.551
	(0.331)	(0.757)	(0.325)	(0.746)	(0.319)	(0.736)	(0.313)	(0.726)
GDP per capita 1940		-0.051		-0.054		-0.058		-0.061
		(0.169)		(0.167)		(0.164)		(0.162)
	B. Long differences between 1940 and 2000							
Change in life expectancy	-1.111	-2.894	-0.979	-2.774	-0.848	-2.654	-0.716	-2.534
	(0.395)	(1.058)	(0.394)	(1.053)	(0.392)	(1.048)	(0.391)	(1.042)
GDP per capita 1940		-0.604		-0.608		-0.612		-0.616
		(0.266)		(0.264)		(0.263)		(0.261)

Note. Two-Stage Least Squares estimates of equation (8), from the text, assuming different values for κ. Columns 1 and 2 show estimates with κ = 0.3, columns 3 and 4 show estimates with κ = 0.4, columns 5 and 6 show estimates with κ = 0.5, and columns 7 and 8 show estimates with κ = 0.6. In all models, the change in life expectancy is instrumented using the change in predicted mortality during the corresponding time period. Robust standard errors are in parentheses. Panel A contains estimates for a cross-sectional regression with data for 47 countries in 1940 and 1980. Panel B contains estimates for a cross-sectional regression with data for the same 47 countries in 1940 and 2000. See Acemoglu and Johnson (2007) for the construction of the predicted mortality instrument, definitions, and data sources.

Table A1

Effect of life expectancy on GDP per capita: estimates for the parameters of equation (3), using panel data

	Dependent variable is log GDP per capita	
	(1)	(2)
	A. 1940-1980 balanced panel	
π	-1.261	-0.815
	(0.801)	(0.461)
λ	0.031	-0.001
	(0.028)	(0.021)
Countries	47	47
Moments	14	20
Hansen p-value	0.22	0.22
	B. 1940-2000 balanced panel	
π	-1.548	-1.965
	(0.644)	(0.546)
λ	0.040	0.044
	(0.017)	(0.011)
Countries	47	47
Moments	22	42
Hansen p-value	0.25	0.55

Note. Optimally weighted two-step GMM estimates of the model in equation (3) from the text. Robust standard errors are in parentheses. In column 1, the second lag of GDP per capita and the first and second lags of predicted mortality are used as instruments for every year. In column 2, the second and all longer lags of GDP per capita, and the first and all longer lags of predicted mortality are used as instruments for every year. All models include a full set of year dummies which are also used as instruments. Panel A contains estimates using a balanced panel of 47 countries from 1940 to 1980. Panel B contains estimates using a balanced panel of the same 47 countries from 1940 to 2000. See Acemoglu and Johnson (2007) for the construction of the predicted mortality instrument, definitions, and data sources.