Disease and Development Revisited: A Reevaluation of the Effect of Life Expectancy on Economic Growth

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Abstract

In an important recent paper Acemoglu and Johnson (2007) conclude that increased life expectancy causes decreases in income per capita rather than increases, both in the short and the long run. This is at odds with conventional wisdom, microestimates of the effect of life expectancy on income per capita and with the results of recent simulations of a neoclassical growth model by Ashraf et al. (2008).

We present a possible solution to this puzzle. We first rederive the theoretical relationship between life expectancy and income per capita implied by the model of Acemoglu and Johnson. We then redo their empirical analysis of the effect of changes in life expectancy on income per capita. We obtain results that indicate that the impact of changes in life expectancy on income per capita are very much in line with what standard neoclassical growth theory predicts. In particular, we obtain estimates of the short run effect that are very similar to Acemoglu and Johnson but we also obtain results of the dynamic effects that are very different from the conclusions in Acemoglu and Johnson. Instead, our estimates of the dynamic effects are very much in line with the simulation results of Ashraf et al.

1 Introduction

No one can deny the immense welfare benefits of better health and longer life expectancy especially for the poor of the world that are often deprived of both good health and a long life. But increased life expectancy may also have unintended consequences. In particular, a general improvement in the health of a population tends - at least in the short run - to generate population increases. The basic Solow model then predicts that increases in life expectancy may reduce income per capita through a capital dilution effect. Thus, even a one-time increase in population will lead to lower income per capita during the transition back to the pre-shock capital per capita stock. If the speed of transition back to steady state is slow this can imply large income losses.

Not that long ago, this possible deliterious effect of population increases was a big concern in the development community. The United Nations Development report for 1982 states that "Rapid population growth is a development problem." (United Nations, 1982, p.7). The report contends that "development may not be possible at all unless slower population growth can be achieved soon" (United Nations, 1982, p.iii). As a consequence of this conviction, in 1983, the United Nations gave its Population Award to the head of the Chinese government's campaign of forced sterilizations and abortions which was part of its one-child policy.

20 years later the conventional wisdom in the development community had changed drastically. The dire warnings from the basic Solow model had been cast aside and the economic profession had converged on a new conventional wisdom. At the turn of the millenium the new conventional wisdom held that better health and longer life spans lead to better economic outcomes. In addition to making people better off directly by improving their health and implying longer life spans, better health and longer life spans give indirect benefits in the form of higher productivity. In 2001 the World Health Organization put out a report stating that

> extending the coverage of crucial health services...to the worlds poor could save millions of lives each year, reduce poverty, spur economic development and promote global security (WHO, 2001, p.i)

Thus, in this view improvements in medical science are an unmitigated blessing. This new conventional wisdom is mostly based on a large number of microeconometric estimates in the literature that document positive effects of increases in health and life expectancy on a variety of individual level outcomes such as shooling attainment and wages. As such, these results do not seem to be more than manifestations of obvious common sense. In addition, a couple of macrolevel studies also find significant effects of improvements in health and life expectancy on economic outcomes (see for example Bloom and Sachs, 1998, and Gallup and Sachs, 2001). These latter studies though have been critisized for lack of an identification strategy implying that these estimates cannot be interpreted as causal effects of health on income per capita (see for example Weil, 2007).

With respect to the effects of longer life expectancy on income per capita in the aggregate, it turns out that things may not be as simple as either the pessimistic predictions of the basic Solow model or the newer and more optimistic microeconometric estimates would suggest. The basic Solow model does not take into account the productivity enhancing effects of increased life expectancy, and microeconometric estimates typically do not take into account general equilibrium effects of changes in life expectancy working through increases in population. In practice, both the negative and the positve effect are likely to operate.

A recent important insight is that in order to evaluate the effect of increases in life expectancy on income per capita we need a general equilibrium framework that can take into account both the direct positive effect on productivity and the indirect negative capital dilution effect working through an increase in population. Two recent papers try to quantify the effect of better health as proxied by increased life expectancy on income per capita in a general equilibrium context that take both factors into account (Acemoglu and Johnson, 2007, and Ashraf et al., 2008). This is as opposed to either the basic Solow model or the microeconomic estimates that are usually presented in the literature.

General equilibrium neoclassical growth theory that allows for productivity enhancing effects of increased life expectancy predicts that better health should lead to higher income per capita at least in the long run. But contrary to partial equilibrium analysis, in the short run the effect is theoretically ambiguous. If the temporary capital dilution effect is large, income per capita may fall in the short run. These considerations lead to some important questions. How large are the productivity enhancing effects, if any? How large is the capital dilution, if any, and how long is the transition to the new steady state? These questions in essence become a question of the whole dynamic path of income per capita caused by an increase in life expectancy, from the initial response to the new steady state.

Ashraf et al. (2008) attempt to give an answer to this question using simulation analysis. They perform simulations of a neoclassical growth model that incorporates both productivity enhancing effects and capital dilution effects in order to quantify the general equilibrium effect of increased life expectancy on income per capita. They find that in the short run increased life expectancy causes a significant decline in income per capita. The interpretation of this is that in the short run, increased life expectancy implies a larger population. With an inelastic capital supply this implies a capital shallowing effect that outweighs the positive effects of increased life expectancy on labor productivity. On the other hand the simulation results do imply a long-run increase in per capita real GDP as the capital dilution effect fades away.

Acemoglu and Johnson (2007) also ground their analysis in a standard neoclassical growth theory framework that is augmented to allow for positive effects of increased life expectancy on productivity. As such it is very similar to the model in Ashraf et al. Acemoglu and Johnson use data on the international epidemiological transition of the 1940s that implied large decreases in mortality from various infectuous diseases around the world to obtain identification of exogenous variation in life expectancy. Thus, their empirical results can plausibly be interpreted as causal effects of increased life expectancy on income per capita.

Given the similar theoretical framework it is something of a puzzle that Acemoglu and Johnson obtain very different and rather more pessimistic results than Ashraf et al. Based on their theoretical framework Acemoglu and Johnson derive an empirical model specification for analyzing the effect of increased life expectancy on income per capita. Employing first difference estimation of their model they then present results of 40 year first difference estimations of the model as short run effects and 60 year first difference estimates as long run effects. Their "short run" estimates based on 40 year first difference estimations show that increased life expectancy results in a large decline in income per capita. Although these results are dismaying they are not very surprising. Further, the short-run results are perfectly consistent with the theoretical framework and with the results of Ashraf et al. This seems to provide strong evidence of a negative effect of increases in life expectancy on income per capita in the short run.

The most interesting - and disturbing - result of the Acemoglu and Johnson paper is that their "long-run" estimates based on 60 year first difference estimations also show a strong long-run decline in per capita GDP as a result of the increase in life expectancy resulting from the international epidemiological transition. This is a very unexpected result and very different from the results obtained by Ashraf et al. (2009). This result is thus at variance both with other results obtained in the literature and with the conventional wisdom. At the very least it indicates that the long run macroeconomic effects of increases in life expectancy are still not firmly established.

In this paper we attempt to reconcile the results of these recent investigations that seem to come to such widely different conclusions. In particular, we present a possible solution to the puzzle of the disparities between the results of Ashraf et al. (2008) and Acemoglu and Johnson (2007). Based on a reevaluation of the theoretical analysis of Acemoglu and Johnson we reassess the effect of exogenous changes in life expectancy on income per capita. Specifically, we derive a different long run specification of the theoretical relationship between increases in life expectancy and income per capita.

We then argue that the solution to the puzzle of the disparities in the results between Acemoglu and Johnson (2007) on the one hand and Ashraf et al. (2008) on the other lies in recognizing that the empirical model specification employed in Acemoglu and Johnson (2007) does not allow for estimating long run effects. We argue that the correct interpretation of both their sets of estimates is in fact as estimates of the short run effect of shocks to life expectancy on income per capita. Specifically, we argue that both the 40 year and the 60 first difference estimation of the empirical model derived from their theoretical model yield estimates of the initial effect of changes in life expectancy on income per capita.

The theoretical long run relationship between increases in life expectancy and income per capita that we derive implies that in order to estimate the dynamic effects of exogenous shocks to life expectancy on income per capita a different empirical model specification is needed from the one that Acemoglu and Johnson (2007) employ. In particular, we argue that in order to obtain estimates of the dynamic effects of life expectancy on income per capita we need a new empirical specification which is built on the theoretical long run relationship that we derive.

We therefore estimate the effect of increases in life expectancy on income per capita using an empirical specification that is based on our theoretical derivation of the dynamic effects of increases in life expectancy on income per capita. For estimation purposes we construct a panel data set with decadal data from 1940-2000 based on the definition of a "global mortality" variable proposed by Acemoglu and Johnson (2007). This allows us to utilize more data on life expectancy and income per capita than is possible with the approach in Acemoglu and Johnson (2007). While Acemoglu and Johnson use long difference estimations only utilizing data for an initial and an end period our dataset allows us to use fixed effects estimation with the full dataset. This has the added advantage that it allows us to estimate the dynamic path of the response of income per capita to an increase in life expectancy.

We show that our estimate of the contemporaneous effect of life expectancy on income per capita is very similar to the estimates of Acemoglu and Johnson, i.e. we show that income per capita is estimated to decline substantially in the short run as a result of increases in life expectancy. More interestingly, we also estimate dynamic effects of a shock to life expectancy on income per capita based on our new empirical specification. We estimate a dynamic path of income per capita to a shock to life expectancy that is very different from the path implied by the results in Acemoglu and Johnson (2007). Specifically, our results indicate that income per capita recovers after the initial decline caused by the increase in life expectancy such that income per capita is back to its old level after approximately 30 years.

Overall, we obtain results of the dynamic path of income per capita following an increase in life expectancy that is perfectly compatible with the predictions of a Solow type model that is augmented to allow for productivity enhancing effects of increases in life expectancy. Further, we find that the quantitative effects are similar to the results obtained by Ashraf et al. (2008). Thus we show that the results obtained by employing an empirical framework built on the model in Acemoglu and Johnson (2007) are compatible with rather than contradictory to the results obtained in Ashraf et al. (2008).

As the effect of changes in life expectancy on income per capita in a general equilibrium framework depends heavily on its effects on the size of the population we also reassess the impact of changes in life expectancy on the size of the population. Our estimates show a large contemporaneous effect of better health on population size almost identical to the results of Acemoglu and Johnson but we also find that the effect gets progressively smaller with time. This again makes the results obtained by using the model and the empirical methods in Acemoglu and Johnson (2008) more compatible with the results of Ashraf et al.

The rest of the paper is structured as follows. Section two reconsiders the theoretical framework and in particular derives the correct long run relationship between income per capita and life expectancy. Section 3 uses the results from section 2 to construct the proper empirical model specifications for the short run and long run relationships. Section 4 presents the data and gives details on the construction of the instrumental variable used for establishing causality. Section 5 presents the results of our empirical investigations and Section 6 concludes. An appendix gives details on the data used and in particular on the construction of the predicted mortality variable.

2 Theory

Acemoglu and Johnson construct a simple neoclassical growth model that incorporates both the producitivity enhancing effects of increased life expectancy and the capital diluting effects of a larger population. From this model they derive theoretical short run and long run relationships between life expectancy and income per capita. These relationships then motivate the empirical model specification that they estimate.

We start by reevaluating these derivations. Assume along with Acemoglu and Johnson (2007) a standard neoclassical production function of the form

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

where A_{it} is total factor productivity, $H_{it} = h_{it}N_{it}$ is human capital, K_{it} is physical capital, and L_{it} is land. Assume that land is in fixed supply such that we can set $L_{it} = L_i = 1$ for all i and t. Further, it is assumed that total factor productivity is given by

$$A_{it} = \overline{A}_i X_{it}^{\gamma} \tag{2}$$

while per capita human capital is determined according to

$$h_{it} \equiv \frac{H_{it}}{N_{it}} = \overline{h}_i X_{it}^{\eta} \tag{3}$$

Greater life expectancy leads to greater population both directly and through more females surviving to childbearing age, so that

$$N_{it} = \overline{N}_i X_{it}^{\lambda} \tag{4}$$

Suppose again along with Acemoglu and Johnson that we have a standard Solow type capital accumulation equation, i.e. suppose that physical capital accumulates according to

$$K_{it+1} = s_i Y_{it} + (1-\delta)K_{it} \tag{5}$$

This is a standard neoclassical model extended to allow for productivity enhancing effects of increased life expectancy. We depict the model for a generic country i in Figure 1 (in order to make this figure tractable we assume that $1-\alpha-\beta = 0$ which means that we disregard land as a factor of production). The production function is depicted as y_O, the saving function as sy_O and the depreciation schedule as δk.

Figure 1 here

Imagine that up to and including some date t_0 all variables are in long run equilibrium. In the initial steady state, when all variables are in long-run equilibrium we have

$$K_{it_0} = \frac{s_i Y_{it_0}}{\delta} \tag{6}$$

This equilibrium is determined in Figure 1 by the intersection of the saving function and the depreciation schedule. The resulting steady state per capita capital stock is then k_0 and steady state income per capita is y_0^*. This equilibrium is depicted as point A in Figure 1.

Now assume that in period t_1 there is a one-time increase in life expectancy. Specifically, assume life exptectancy jumps from the old equilibrium value X_{it_0} to a new value X_{it_1}at time t_1. As it is a one-time increase, life expectancy is fixed at this new value thereafter.

Also suppose that while life expectancy changes, the capital stock is initially fixed at its old equilibrium value. Using this new value of life expectancy and substituting relationships (2), (3) and (4) into equation (1) and taking logs we get that income per capita at time t_1 is determined as

$$y_{it_1} = \beta \log \overline{K}_{it_0} + \alpha \log \overline{A}_i + \alpha \log \overline{h}_i - (1-\alpha) \log \overline{N}_i + [\alpha(\gamma+\eta) - (1-\alpha)\lambda] x_{it_1} \tag{7}$$

where $x_{it_1} \equiv \log X_{it_1}$ and $y_{it_1} \equiv \log(Y_{it_1} /\!\!/ N_{it_1})$. This equation then shows that the initial impact of a change in life expectancy on income per capita, i.e. the change in income per capita at time t_1, which is caused by a change in life expectancy at that time, equals $\alpha(\gamma+\eta) - (1-\alpha)\lambda$ times the increase in life expectancy. This short run relationship is identical to the one derived in Acemoglu and Johnson (2007).

The positive contribution of an increase in life expectancy on income per capita, $\alpha(\gamma+\eta)$, comes from the productivity enhancing effects of increases in life expectancy on total factor productivity and human capital. The negative contribution of the increase in life expectancy on income per capita, $(1-\alpha)\lambda$, comes from the relationship postulated in equation (4). The increase in life expectancy implies an increase in the size of the population. As the capital stock is fixed in the short run this in turn implies that the capital stock per capita is diluted. As can be seen, the net effect of the increase in life expectancy on income per capita is then theoretically ambiguous and depends on whether $\alpha(\gamma + \eta) - (1 - \alpha)\lambda \gtreqless 0$.

The effect of the increase in life expectancy on income per capita in period t_1 is depicted in figure 1. The productivity enhancing effect is shown as a new production function, y_N, (and a new saving function, sy_N) that for any given per capita capital stock implies a larger income per capita than with the old production function. The negative capital diluting effect is shown as a decrease in capital per capita. The total effect is then a movement from point A to point B, with a capital stock at time t_1 of k_1 and income per capita of y_1. In the figure, the result is a decrease in income per capita, but the effect could be either positive or negative. This then shows the initial impact of a one-time increase in life expectancy on income per capita, with the total physical capital stock held fixed.

In the long run, the supply of capital is not fixed. The crucial thing to notice is that at time t_1, while life expectancy has reached its new long run value x_{it_1}, the capital accumulation equation implies that income per capita and the capital stock have not reached their new steady state value. As a result of the one-time increase in life expectancy, at time t_1 the economy as out of steady state. In Figure 1, this can be seen from the fact that at capital stock per capita, k_1, savings are larger than depreciation, implying that capital per capita will start to increase.

As we have seen, a change in life expectancy at time t_1 will from equation (7) above imply a change in income per capita in the same period. This will then according to the capital accumulation equation (5) in turn imply a change in the supply of capital at time $t_1 + 1$. The increase in the capital stock will then according to equation (6) increase further and this will again cause a change in income per capita at time $t_1 + 1$. This process then goes on until a new steady state is reached.

This gradual dynamic adjustment of capital and income per capita towards the new steady state is indicated in Figure 1 by the arrows going from point B to the new steady state equilibrium at point C. In any given time period, s periods after the increase in life expectancy, income per capita and the capital stock are given as

$$y_{it_1+s} = \beta \log \overline{K}_{it_1+s} + \alpha \log \overline{A}_i + \alpha \log \overline{h}_i - (1-\alpha) \log \overline{N}_i + \chi_s x_{it_1} \tag{8}$$

and

$$K_{it_1+s} = s_i Y_{it_1+s-1} + (1-\delta) K_{it_1+s} \tag{9}$$

A change in life expectancy at time t_1 will cause dynamic changes in both income per capita and the capital supply each period after t_1 towards a new long run equilibrium that is achieved at some time t_2. At time t_2 the capital stock per capita will reach its new steady state values at k_2 in Figure 1 where the new saving function sy_N intersects the depreciation schedule. Accordingly, the new steady state income per capita value reached at time t_2 is y_2^* in Figure 1.

In this new steady state at time t_2 the capital stock and income per capita are

$$K_{it_2} = \frac{s_i Y_{it_2}}{\delta} \tag{10}$$

and

$$y_{it_2} = \beta \log K_{it_2} + \alpha \log \overline{A}_i + \alpha \log \overline{h}_i - (1-\alpha) \log \overline{N}_i + [\alpha(\gamma+\eta) - (1-\alpha)\lambda] x_{it_1} \tag{11}$$

Inserting equation (10) into equation (11) and solving for income per capita we get

$$\begin{aligned} y_{it_2} = \tfrac{\alpha}{1-\beta} \log \overline{A}_i + \tfrac{\alpha}{1-\beta} \log \overline{h}_i + \tfrac{\beta}{1-\beta} \log s_i - \tfrac{\beta}{1-\beta} \log \delta \\ - \tfrac{1-\alpha-\beta}{1-\beta} \log \overline{N}_i + \tfrac{1}{1-\beta} [\alpha(\gamma+\eta) - (1-\alpha-\beta)\lambda] x_{it_1} \end{aligned} \tag{12}$$

as the new steady state value of income per capita.

The crucial thing to notice is that the new steady state is not attained when life expectancy reaches its new long run value. The new steady state is reached when the capital supply and income per capita attain their new long run values which, because of the dynamic interaction between the capital supply and income per capita, can be many periods after life expectancy reached its new long run value. Hence, the long run value of income per capita, i.e. the value of income per capita at time t_2, is a function of life expectancy at the time life expectancy reached its new long run value at date t_1. These considerations will be important in the next section as we will base our empirical specifications directly on the theoretical model.

In Acemoglu and Johnson's analog to our equation (12) income per capita and life expectancy have the same time index. This naturally leads them to an empirical specification of the long run in which the dependent and the independent variables have the same time index. Thus, because our derivation of the long of the long run effect of life expectancy on income per capita in equation (12) differs from that of Acemoglu and Johnson (2007) our empirical specification will also differ from theirs. This difference in the empirical specification of the long run effects of increases in life expectancy on income per capita may seem small but will turn out to be important for the empirical results and their interpretation.

The coefficients on life expectancy x_{it_1} in equations (7) and (12) show that according to the model we would expect the long run effect of a change in life expectancy to be larger (more positive) than the initial effect (that the effect of life expectancy on income per capita changes over time is the reason we use χ_s as the coefficient on life expectancy in equation (8)). If we are willing to assume - as we have done in Figure 1 - that $\alpha(\gamma + \eta) - (1 - \alpha)\lambda \leq 0$ so that income per capita is expected to decline initially, the derivations above can be summed up as Acemoglu and Johnson (2007) do thus:

> Increased life expectancy raises population, which initially reduces capital-to-labor and land-to-labor ratios, thus depressing income per capita. This initial decline is later compensated by higher output as more people enter the labor force and more capital is accumulated. This compensation can be complete and may even exceed the initial level of income per capita if there are significant productivity benefits from longer life expectancy.

This postulated dynamic path for income per capita is depicted in Figure 2.

Figure 2 here

Until time t_1, we are in the old steady state with income per capita at y_0^*. At time t_1, there is a change in income per capita as a result of the increase in life expectancy (here depicted as a fall in income per capita to be consistent with Figure 1). Thereafter there is a dynamic upward path for income per capita as a result of capital accumulation. At some time $\widetilde{t}$, income per capita recovers to its old steady state value. But because of the productivity enhancing effects of increased life expectancy, the new steady state value of income per capita is above the old steady state value. Therefore, the transition is not complete at time $\widetilde{t}$. Income per capita continues to rise as a result of continuing capital accumulation until a new steady state is reached at time t_2 and income per capita reaches its new steady state value of y_2^*.

According to equation (12) it is possible for the new steady state value of income per capita to be below the old steady state. This is because it is not possible to accumulate land as a factor of production. This means that after the increase in life expectancy and the implied increase in population size the land to labor ratio is permanently lower even though physical capital per capita has returned to its initial level and may even be higher. If land is an important factor of production this negative influence on income per capita may not be compensated for with the productivity enhancing effects of increased life expectancy.

If we assume that land is not a factor of production (as we have done in Figure 1) so that $1 - \alpha - \beta = 0$, the new steady state value of income per capita will necessarily be at least as large as the old steady state value. Whether the new steady state value is larger than the old steady state value and if so how much larger depends on the strength of the productivity enhancing effects of increased life expectancy through the term $\gamma + \eta$.

3 Estimating Framework

3.1 Specification and interpretation

Because their theoretical model specifications for both the short run and long run involve income per capita and life expectancy at the *same time period* Acemoglu and Johnson use the same empirical model specification for both the long run and the short run. Hence, the model specification follows directly from their equations (4) and (5) and is

$$y_{it} = \pi x_{it} + \zeta_i + \mu_t + Z_{it}^{'}\beta + \varepsilon_{it} \tag{13}$$

This corresponds to our equation (7). Acemoglu and Johnson claim that when there only are two data points per country, estimating equation (13) "is also equivalent to estimating the first differenced specification",

$$\Delta y_i = \pi \Delta x_i + \Delta \mu + \Delta Z_i' \beta + \Delta \varepsilon_i \tag{14}$$

Here Acemoglu and Johnson seem to mistake the empirical model specification, i.e. equation (13), for an estimating equation. Estimating equations cannot be equated with structural model specifications which are fundamentally different objects. Sometimes the structural model can be used directly as its own estimating equation but that is not the case here. Equation (13) is a structural model but is not an estimating equation because of the presence of the unobserved fixed effects ζ_i. To obtain estimates of the parameter of interest, i.e. π, a transformation is needed which turns the structural model into an estimable model. It is of course true that with only two data points per country, estimating the parameter of interest using a single cross-section in first-differences as in equation (11) is algebraically equivalent to fixed effect estimation of the parameter of interest in equation (10), i.e. the parameter estimates will be identical. But this does not imply that equation (10) and equation (11) are equivalent in any meaningful sense.

There are a variety of different transformations available that turn the structural model into an estimating equation, for example fixed effects estimation and first difference estimation. Taking first differences achieves the objective as the first differenced specification in equation (14) only involves observables and is therefore an estimating equation which can be used to obtain estimates of π. But the interpretation of the parameter estimates in any regression should be done from the structural equation (see Wooldridge 2002, pp.267, 279 and 283).

Equation (13) is the empirical model to be estimated, so the proper interpretation of the estimate of π is done from the structural conditional expectation $E(y_{it} \mid x_{it}, \zeta_i, \mu_t, Z_{it}') = \pi x_{it} + \zeta_i + \mu_t + Z_{it}' \beta$ (and its theoretical counterpart equation (7)). And as the empirical model specification in equation (13) specifies income per capita y_{it} and life expectancy x_{it} to have the same time subscript, equation (13) is appropriate as the empirical counterpart to the theoretical relationship postulated in equation (7). Therefore equation (13) shows that estimating equation (14) only gives a parameter estimate of the short run effect of changes in life expectancy on income per capita.

This can be understood intuitively from the economic theory above thus: The dynamics of capital accumulation imply that a change in life expectancy in any time period has an impact on income per capita in the same period and long after life expectancy has stopped changing. Therefore, it does not make sense to interpret the coefficient from a regression of changes in income per capita on changes in life expectancy *over the same time period* as long-run changes.

Our derivations above of the economic model show that if we want to estimate long run effects we first need a different empirical model specification that is different from the specification of the initial impact. In order to estimate the long run effect we need an empirical model specification that corresponds to equation (12). Unfortunately we do not know how many time periods there are between t_1 and t_2 so it is not possible to postulate a direct empirical counterpart to equation (12).

What we can do is specify an empirical model specification that corresponds to equation (8) which will allow us to estimate dynamic effects. We thus postulate an empirical specification like

$$y_{it+k} = \chi_k x_{it} + \zeta_i + \mu_t + Z'_{it}\beta + \varepsilon_{it} \tag{15}$$

where k indexes how many time periods we lead the dependent variable so that χ_k shows the partial effect of a shock to life expectancy at any point in time on income per capita k periods down the line. This is the direct empirical counterpart to equation (8).

To estimate the long run effect we need to relate life expectancy at the initial date to income per capita sufficiently far ahead in the future that χ_k has reached its new long run value. That is, as k becomes sufficiently large, χ_k will converge towards the long run value χ, and this will then be the long run effect of life expectation on income per capita. Fixed effects or first difference transformations can then be applied in order to estimate the parameter of interest, i.e. χ_k, in equation (12).

How large "sufficiently large" is for χ_k to be the "long run" effect, is an empirical question. What we will do is to use fixed effects estimation to estimate the parameter of interest in equation (8) for $k = 1, 2...$ and soforth as far ahead as our data will allow. As the time periods go by we expect the coefficients on life expectancy to change from the short run value to the long run value. If the coefficients seem to converge to some value we can interpret this value as the long run effect. But even if the estimated coefficients do not settle down within the time periods allowed by our data the estimates for $k = 1, 2...$ are valuable as they show the transitional dynamics of income per capita from the initial effect towards the new long run equilibrium as a result of an initial shock to life expectancy.

3.2 Instrumentation strategy

In order to be able to interpret our estimates as causal effects we need to control for possible reverse causality and time varying omitted variable bias. That means that we need an instrumental variable for life expectancy. With a suitable instrumental variable we can specify a first stage relationship between life expectancy and the instrumental variable of the form

$$x_{it} = \theta M_{it}^{I} + \widetilde{\zeta}_i + \widetilde{\mu}_t + Z_{it}^{'}\widetilde{\beta} + u_{it} \tag{16}$$

where M_{it}^{I} is the instrument. The crucial restriction for consistent estimation of the effect of increases in life expectancy on income per capita is then that cov(M_{it}^{I},u_{is})=0, for any t, s.

The major innovation of Acemoglu and Johnson's paper is the ingeneous instrumentation strategy. They propose to use data which record the dramatic decrease in mortality in many countries around the world - the socalled international epidemiological transition - which occurred during the 1940s to construct a "predicted mortality" variable.

Acemoglu and Johnson present a detailed discussion of why the proposed "predicted mortality" variable is plausibly valid as an instrument. In essence they argue that the decrease in mortality came about because of the worldwide spread of cheap new vaccines and pesticides, and because of WHO campaigns to "bring the benefits of up-to-date scientific medical knowledge to backward parts of the world" (McNeill, 1976). The "predicted mortality" variable is thus postulated to give variation in life expectancy that is exogenous to income per capita in any particular country and is therefore suitable as an instrumental variable for life expectancy in empirical investigations of the effect of changes in life expectancy on income per capita.

This instrumentation strategy is only likely to be entirely valid when we estimate the initial effect of life expectancy on income per capita, ie. when $k = 0$ in equation (15). After the initial period, were we estimate the system of equations (15) and (16) with $k > 0$, we are out of steady state so that the capital stock is changing. We don't have a measure of the capital stock included as a regressor so our Z vector is empty. The changes in the capital stock therefore are subsumed in the error term. Further, from the theoretical model we know that the omitted capital stock variable and the predicted mortality instrumental variable are correlated through life expectancy and income per capita. Therefore there is an omitted time-varying variable problem even when we instrument for life expectancy. And even if we did include a measure of the capital stock in each period as a regressor this would not help much as the capital stock is endogenous with respect to income per capita.

This means that we cannot be certain that our estimates of the dynamic effects are consistent estimates because we cannot be certain that the restriction that cov(M_{it}^I,u_{is})=0, for any t, s holds. All we can do is to do the estimations and hope that the likely violation of the restriction that cov(M_{it}^I,u_{is})=0, for any t, s does not imply that the omitted variable causes the estimates to be significantly biased. In the end, we therefore have to rely on our economic model in order to ascertain whether the estimates of the dynamic effects are reasonable or not.

With this said, we still believe that estimating the dynamic effects through estimation of the system of equations (14) and (16) will give us a good picture of the dynamic effects of an increase in life expectancy on income per capita. In the next section we turn to the instrumental variable and give some details on how it is constructed.

4 Data

Acemoglu and Johnson do most of their regressions using a "baseline" predicted mortality variable that is based on mortality data for 15 specific diseases. It utilizes the interaction between these disease specific mortality rates in 1940 and international intervention dates for these diseases. For most diseases - and in particular for the 3 diseases responsible for most deaths, i.e. tuberculosis, malaria and pneumonia - the intervention dates are in the 1940s so that predicted mortality falls almost to 0 in 1950. This implies that there is very little variation in the predicted mortality variable after 1950. This variable might therefore be expected to perform relatively poorly in a setting where we use the full data set with decadal data rather than a "before and after" approach where only 1940 as a beginning date and either 1980 or 2000 is used as an end date.

As an alternative measure of predicted mortality rates which does not have this weakness they propose constructing a slightly different variable which they call the "global mortality" variable. The "global mortality" instrumental variable is defined as

$$M_{it}^{I} = \sum_{d \in D} \frac{M_{dt}}{M_{d1940}} M_{id1940} \tag{17}$$

This definition of "predicted mortality" exploits the interaction between the disease specific mortality rate before the global interventions and the relative change in world wide average mortality over time. This coincides with the "predicted mortality" variable for the year 1940 but differs afterwards as it predicts a more gradual reduction in mortality rates after 1940 than does the baseline "predicted mortality" variable of Acemoglu and Johnson which sets the predicted mortality rate from a specific disease to 0 after the intervention date.

We use the "global mortality" variable rather than the "baseline" predicted mortality instrument in our regressions. We do this because this variable has variation over the entire time span and thus allows us to utilize the full dataset in our estimations rather than just data for a beginning date and an end date.

As can be seen from the formula for constructing this variable, it is necessary to have complete coverage for every country and every disease for the year 1940. For the periods covered after 1940 it is also necessary to have data on all included diseases but it is not absolutely essential to have data for every country subsequent to 1940 as we only use the average for each disease across countries. But it is of course necessary to have data for enough countries such that the average calculated over the countries that we have data for is not very different from what it would have been if we had data for all countries.

We collect data such that we can construct a panel data set with decadal observations for each country from 1940 to 2000. As data on mortality rates - especially for the early period - is not available for many countries, while data on the other variables used are widely available, the country coverage will be restricted to those countries for which we can find data sucht that the predicted mortality variable can be constructed. Under the restrictions mentioned above we have been able to collect data and construct a "global mortality" instrumental variable with coverage from 8 diseases for 51 countries (the diseases are: tuberculosis, malaria, pneumonia, typhoid, measles, influenza, smallpox and whooping cough). The countries included are the same ones as are included in the "base sample" of Acemoglu and Johnson plus another 4 countries, namely The Dominican Republic, Egypt, Japan and Mauritius. These 51 countries then constitute our sample. More details on the construction of the data set can be found in the appendix to this paper.

Figure 3 shows the evolution of the predicted mortality variable for two countries at opposite extremes of the predicted mortality spectrum in 1940, Sweden at the low end and Guatemala at the high end.

Figure 3 here

Two noticable features stand out. First, as can be seen for these two countries and which is true more generally in the sample, there is strong convergence in predicted mortality rates. In 1940 the predicted mortality rates differ by a factor of more than 7, while in 2000 the predicted mortality rates differ by a factor of slightly less than 2. Second, there is a strong downward trend in the mortality rates especially in the period right after

1940. The predicted mortality rate in Sweden falls from a high of 142 per 100 thousand population in 1940 to 16 per 100 thousand population in 2000 while the predicted mortality rate in Guatemala falls from a high of 1026 in 1940 to a low of 31 in 2000.

Data on life expectancy for 1940 are from United Nations (1948). Data for 1950 and forward are from UN's World Population Prospects available on the internet. Data on population and GDP per capita are from Maddison (2006) - these data are available on his homepage. For 1940, population data for a few countries are missing in the Maddison data. These gaps have been filled with data from WHO (1951). For GDP per capita we use 5 year averages to smooth out business cycles so that the data points for 1950 for example are averages over the years 1948-1952.

5 Results

5.1 OLS results

We start with OLS regressions. Column (1) in Table 1 shows the contemporaneous conditional correlation between changes in life expectancy and income per capita.

Table 1 here

The coefficient estimate of -0.65 points to a relatively large negative correlation that is statistically significant at the 1% level. Still, the estimate is somewhat smaller in numerical value than the estimate of -0.81 that Acemoglu and Johnson obtain with their 40 year first difference estimation. Columns (2)-(4) display the results when we lead the dependent variable, i.e. set $k = 1, 2$ and 3 in equation (15). We see that the coefficient estimates get progressively smaller in numerical value. After 10 years the negative correlation has contracted to -0.48 which is still statistically significant at a 5% level. After 20 years the coefficient is -0.16 and after 30 years the coefficient has contracted to -0.10 which is economically and statistically insignificant. These are not estimates of causal effects, only conditional correlations, but they do point to a difference between short run and long run effects. Interestingly, they seem to indicate that the long run effects are more positive (less negative) than the initial effect. This is very different from Acemoglu and Johnson's conclusions where they point to a more negative long run effect as the coefficient from the 60 first difference estimation is -1.14 and so is even more negative than the result from the 40 year difference estimation.

Table 2 presents the OLS estimates for the size of the population.

Table 2 here

Column (1) shows a positive and statistically strongly significant conditional correlation between life expectancy and size of population with an estimate of 1.60. This is very close to Acemoglu and Johnson's 40 year first difference estimate of 1.62. Columns (2)-(4) show that the correlations for the dynamic specifications gets progressively smaller. After 10 years the correlation is down to 1.41, after 20 years it is 1.14 and after 30 years the correlation is down to 0.84 or about one half of the contemporaneous correlation. This points to a smaller long run effect than short run effect. Again, this is very different from the conclusions one gets from Acemoglu and Johnson. Their long run estimate obtained from 60 year first difference estimation is 2.01 which is larger than the 40 year first difference estimate and two and a half times larger than our 30 year lead estimate.

That our estimates of the contemporaneous conditional correlations are very similar to the 40 year first difference estimates of Acemoglu and Johnson is no surprise as these are estimates of the same parameter using similar data. But the estimates from our dynamic specification suggest very different dynamic effects than the long run effects estimated by Acemoglu and Johnson.

These OLS estimates are not necessarily causal though, so the true effect of increases in life expectancy on income per capita may be smaller or larger than the estimates shown in Table 2. We therefore turn to IV estimation to investigate this possibility.

5.2 IV results

5.2.1 First-stage estimates

Given that Acemoglu and Johnson obtain data for 15 diseases while we only have data on 8 diseases one could worry that the predictive power of our instrumental variable could be severely diminished. Table 3 below shows that this turns out not to be the case. Even with only 8 diseases included in the construction of the instrumental variable the first stage t-statistic is 9.89 in absolute value which is very large. In fact, the predictive power of the "predicted mortality" variable is largest when we only include 5 of the diseases in the construction of the variable. As columns (2)-(4) show, pneumonia, influenza and smallpox do not have any predictive power for life expectancy.

Table 3 here

Column (5) shows that when these three diseases are excluded from the construction of the "predicted mortality" variable the t-statistic increases from 9.89 to 12.49 in absolute value. We will therefore use the predicted mortality variable constructed from the 5 diseases, tuberculosis, malaria, measles, typhoid and whooping cough in our main regressions below. We will also report results from robustness that show that using the predicted mortality variable constructed from all 8 available diseases will not change the results materially.

5.2.2 Preexisting trends

Before we turn to the main empirical analysis we will discuss a potential concern with the identification strategy. The identification strategy is predictated on the assumption that the changes in mortality rates from the 1940s and forward was a truly exogeneous shock. Therefore there should be not correlation between changes in life expectancy and changes in life expectancy or either of the independent variables, income per capita and population, before the epidemiological transition. We therefore investigate the possibility of preexisting trends in life expectancy, income per capita and population being correlated with the changes in predicted mortality. For the purpose of these regressions we extend the data set backwards to include values for life expectancy, income per capita and population for the year 1900, so we can check for trends before the international epidemiological transition being correlated with changes in predicted mortality after 1940.

Table 4 shows the results of regressing changes in life expectancy, income per capita and population over the period 1900-1940 on changes in predicted mortality over the period 1940-2000.

Table 4 here

Column (1) shows that there is no correlation between changes in life expectancy before 1940 and changes in predicted mortality after 1940. The estimate of -0.04 is economically and statistically far from significant. Likewise, there is no correlation between changes in income per capita before 1940 and changes in predicted mortality after 1940. The estimate of 0.39 is economically and statistically insignificant. This gives us confidence that the predicted mortality variable is useful as an instrumental variable in the context of investigating the effect of increases in life expectancy on income per capita.

Column (3) indicates that there is some evidence of a correlation between changes in population size before 1940 and changes in predicted mortality after 1940 as the estimate of -0.48 is statistically significant at the 10% level. This is a potential problem when investigating the effect of increases in life expectancy on population size. The IV results regarding the relationship between life expectancy and population size will thus have to be interpreted with this caveat in mind.

5.2.3 Main results

Table 5 shows the effect of increased life expectancy on income per capita.

Table 5 here

The first column shows the initial impact. The coefficient estimate of -1.19 shows a large decline in income per capita as a result of increased life expectancy. The coefficient estimate is very close in numerical value to the estimate of Acemoglu and Johnson of -1.21 using the "global mortality" instrument (but somewhat smaller than the estimate of -1.32 they obtain using the "baseline" predicted mortality instrument). That the estimates are of similar magnitude is not surprising given that we have shown that these two estimates are estimates of the same parameter, namely the initial impact of increased life expectancy on income per capita.

Columns 2-4 show the dynamic effects of increased life expectancy on income per capita. Column 2 shows that the coefficient estimate on life expectancy on income per capita 10 years after the shock to life expectancy has increased from -1.19 to -0.61. After 20 years the impact on income per capita is -0.24 and after 30 years the impact of a shock to life expectancy on income per capita has turned positive with a coefficient estimate of 0.12. This corresponds nicely with the simulation results in Ashraf et al. (2008) where income per capita recovers to its old steady state level between 30 and 35 years after an initial decline as a result of an increase in life expectancy.

The initial decline in income per capita and subsequent recovery is illustrated in Figure 4 which shows the point estimates together with the estimate of Acemoglu and Johnson.

Figure 4 here

The dynamic path illustrated in Figure 4 corresponds nicely to the predictions of the theoretical model. The close resemblance between the theoretical predictions about the path of income per capita as a result of an increase in life expectancy and our estimates becomes particularly obvious if one compares Figure 4 with Figure 2. We take this resemblance between theory and empirics as an indication that our estimates give a good picture of the true effect of increases in life expectancy on income per capita.

This dynamic path for income per capita as a response to a shock to life expectancy points to a very different long run effect of changes in life expectancy on income per capita than in Acemoglu and Johnson. In Acemoglu and Johnson the estimation of equation (14) with 60 years between the beginning and end dates of -1.51 is interpreted to imply that the effect is negative even in the long run and actually more negative than the short run effect. As pointed out above though we do not believe the estimate of -1.51 to be an estimate of the long run effect. Rather, in our view it is another estimate of the contemporaneous effect of life expectancy on income per capita.

The available data do not allow us to estimate the effect of shocks to life expectancy on income per capita more than 30 years ahead. The coefficient estimates do not seem to converge to a fixed value within the 30 year range that we can estimate. But there does not seem to be any reason to believe that upward trend over time after the initial decline will be reversed. On the contrary, the dynamic path of income per capita in response to a shock to life expectancy seems to follow a similar path to what Ashraf et al. (2008) find in their simulations. If we take this as an indication that the simulations of Ashraf et al. give a reasonable picture of the dynamic path of income per capita all the way to the new long run equilibrium we would expect to find that the coefficient estimate has increased further if we were to redo the estimations when data for the next decade become available.

In the early working paper versions of their paper Acemoglu and Johnson do estimate versions of our equation (15). Their results for $k > 0$ are very different from our results. In particular, the coefficient on life expectancy is consistently statistically negative. This is in stark contrast to our results that show a sharp initial negative effect of greater life expectancy on income per capita but that the dynamic effect becomes increasingly more positive so that after 30 years income per capita is back at its initial level. It is difficult to pinpoint where the difference stems from as we do not have data on mortality from all the diseases that they use in constructing the instrumental variable. Therefore we have not been able to replicate the values for the instrument that Acemoglu and Johnson present in their Appendix A.

Table 6 presents the estimates of the effects of changes in life expectancy on the size of the population.

Table 6 here

Column (1) presents the contemporaneous effect. The estimate of 1.74 is very close to the estimate of 1.70 that Acemoglu and Johnson obtain with 40 year difference estimation with the global mortality instrument. They interpret this as their short-run estimate.

The results in columns 2-4 show that the dynamic effects tend to get progressively smaller with time. After 10 years the estimated effect is 1.65, after 20 years it is 1.54 and after 30 years it is down to 1.36. This again seems to suggest that the long run effect is smaller than the contemporaneous effect. This presumably because as life expectancy increases the birth rate starts to decline which dampens the large initial response of the population size. Acemoglu and Johnson's estimate using 60 year differences of 1.96 is larger than the estimate of the initial effect. They present this as a long run estimate implying that the long run effect is larger than the short run effect. But as was the case for income per capita we think that it is better to interpret this estimate as another estimate of the short run effect.

Figure 5 shows the evolution of the effect of changes in life expectancy on population size together with the 40 year difference estimate of Acemoglu and Johnson (2007).

Figure 5 here

5.2.4 Robustness check

As a robustness check below we present results of regressions where we include all 8 diseases in the construction of the instrumental variable.

Table 6 here

Table 6 shows that including all 8 diseases in our instrumental variable gives a slightly worse fit in the first stage regressions as the first stage F-statistic is somewhat lower than in Table 4. This change in the instrumental variable does not change the estimated coefficients in the second stage materially. The effect of the contemporaneous effect is very slightly larger with an estimate of -1.23 rather than the estimate in Table 4 of -1.19. The other columns also show similar coefficient estimates to the corresponding ones in Table 4. In Column (4) the effect after 30 years is estimated to be positive with a coefficient of 0.18, which is somewhat higher than the estimate of 0.12 in Table 4. We conclude that our estimates of the effect of increases in life expectancy on income per capita seem to be robust with respect to the construction of the instrumental variable.

Table 7 displays the result of estimating the effect of life expectancy on population size using all 8 available diseases in the construction of the instrumental variable.

Table 7 here

The results are again similar the corresponding results in Table 5 where we used the 5 diseases that were statistically significant in the regression of life expectancy on the individual diseases, even though the dynamic trajectory is somewhat flatter than what we estimated in Table 5. Specifically, the estimate of the contemporaneous effect is now 1.70 which is very slightly smaller than the estimate of 1.70 we obtained with the 5 disease instrument and the coefficient estimate of the effect after 30 years is now estimated to be 1.45 rather than 1.36. These small differences though do not change the main conclusion that the effect gets smaller over time. So again, we conclude that the results seem to be robust with respect to the construction of the instrumental variable.

6 Conclusion

In addition to have the potential to improve productivity at the individual level increases in life expectancy likely have an effect on population size. In general equilibrium therefore the effect of increases in life expectancy on income per capita is ambiguous. This is particularly the case in the short run but potentially also in the long run.

This insight is at the core of the important recent papers by Acemoglu and Johnson (2007) and Ashraf et al. (2008). These papers construct standard neoclassical growth models extended to incorporate productivity enhancing effects of increased life expectancy as well as capital diluting effects of increased life expectancy working through an increase in population. Acemoglu and Johnson (2007) exploit the "quasi-natural" experiment of the international epidemiological transition to obtain empirical estimates of the effect of increases in life expectancy on income per capita. Ashraf et al. (2008) perform simulations, which allows them to estimate the dynamic path of income per capita from the initial response through to the new steady state as a result of an increase in life expectancy.

These two papers reach similar results with regard to the short run effect of an increase in life expectancy. Surprisingly, they come to very different conclusions with regard to the long run effects of an increase in life expectancy on income per capita. Ashraf et al. (2008) find that the most plausible long run scenario is a modest increase in income per capita. Acemoglu and Johnson on the other hand find that the long run effect of an increase in life expectancy is an even larger decrease in income per capita than in the short run. Given the similarity of the theoretical framework in the two papers, these diverging results are something of a puzzle. Further, they would seem to indicate that the net effect of an increase in life expectancy on income per capita - at least in the long run - is still very much an unsettled question.

This paper attempts to present a possible solution to this puzzle. Specifically, we attempt to show that the analysis of Acemoglu and Johnson on the one hand and Ashraf et al. on the other can be reconciled. The key to the solution lies in rederiving the model predictions of Acemoglu and Johnson. This leads specifically to a new prediction about the theoretical long run relationship between increases in life expectancy and income per capita. The new theoretical prediction can then be used to specify a new empirical model for the relationship between life expectancy and income per capita.

We redo the empirical analysis basing the empirical framework on the relationship between life expectancy and income per capita derived from the postulated theorectical model. As a necessary preliminary step to the estimations we construct a panel dataset for the period 1940-2000 by utilizing the recipe for constructing a "global mortality" variable as an instrument proposed by Acemoglu and Johnson to control for reverse causality and time-varying omitted variable bias. With the constructed panel dataset it is possible to estimate the initial impact of exogenous changes in life expectancy on income per capita and the impact 3 periods, i.e. 30 years, forward.

We show that when we apply the estimation framework that we base on the derived model predictions of changes in life expectancy on income per capita the results are consistent with what standard neoclassical growth theory predicts. The initial effect of an increase in life expectancy is estimated to be a large decline in income per capita. In fact, the estimate is very similar to the estimates of Acemoglu and Johnson. But our estimates of the dynamic effects are very different from the results in Acemoglu and Johnson. Our estimates of the dynamic effects show a trend towards recovery of income per capita after 30 years and perhaps even an increase compared to the initial situation.

In this respect, a very interesting aspect of our results is their close resemblance to the simulation results of Ashraf et al. who find that income per capita declines initially and then recovers to its old steady state leval 30 to 35 years after the increase in life expectancy. Our estimates of the dynamic path of income per capita also suggest that income per capita recovers to its old steady state level about 30 years after an initial decline due to the increase in life expectancy. In this respect, our results are quantitatively very similar to the dynamic path found in the simulations of Ashraf et al.

(2008). Thus, with a reevaluation of the Acemoglu and Johnson paper, we can reconcile to the results obtained with the methods used in that paper with the results obtained in Ashraf et al.

The estimated value of the coefficient on life expectancy does not seem to converge to a new long run value within the 30 year time period our data allows us to investigate. Thus, with the panel data only spanning 60 years at present it is not possible to obtain estimates of the long run effect of an increase in life expectancy on income per capita. Therefore the results that we present seem to be only the first part of the transition towards a new equilibrium value for income per capita as a result of a change in life expectancy. For the same reason, it seems that for the time being at least, estimates of long-run effects must rely on the simulation results of the sort that Ashraf et al. present.

A Appendix

Most of the data on population and GDP per capita are taken from Angus Maddison's "Statistics on World Population, GDP and Per Capita GDP, 1-2006 AD" available at www.ggdc.net/maddison/. Data for population in 1940 for Egypt, Bangladesh, and Pakistan are from WHO (1951). Data on GDP per capita for Bangladesh, Pakistan and Panama are from Acemoglu and Johnson (2007). For GDP per capita we use 5 year averages, so we use e.g. the average over 1948-1952 for 1950.

Life expectancy in 1900 used in the falsification test are from Gapminder Foundation (2008), complemented with data from Riley (no date), Kinsella (1992) and Maddison (2001, table 1-5a). Data on life expectancy for 1940 is taken from various UN Demographic Yearbooks, particularly the 1948 and the 1949 versions. We calculate the unweighted average of male and female life expectancy. Life expectancy for 1950 onwards is downloaded from the online UN demographic database. The data are presented in 5 year intervals, so we use 1950-1955 for 1950 on soforth.

Acemoglu and Johnson (2007) provide a lengthy discussion of choice of diseases to include in the construction of the predicted mortality variable. We follow their lead and gather data on death rates by disease for as many of the diseases from their list of 15 diseases as we can. We have been able to collect data death rates by disease on 8 of the 15 diseases for the period 1940-2000 for 51 countries. The 51 countries are the same as in the "base sample" of Acemoglu and Johnson, plus The Dominican Republic, Egypt, Japan, and Mauritius. The 8 diseases we have data for are: tuberculosis, malaria, pneumonia, influenza, smallpox, whooping cough, typhoid, and measles.

The main sources of data for death rates by disease in 1940 are Summary of International Vital Statistics, 1937-1944, published by the Federal Security Agency (1947) of the U.S. government, and WHO (1951). For a couple of countries we have had to substitute death rates from neighbouring countries or areas: death rates for China are from Hong Kong, death rates for Indonesia are from Singapore and death rates for South Korea are from Japan. For some diseases we have also substituted death rates from Puerto Rico for death rates for The Dominican Republic. For some countries death rates for 1940 are only available for specific cities. For Bangladesh, India and Pakistan, we use the death rates reported for Calcutta, New Delhi and Karachi respectively.

Even when these substitutions are made, these two sources leave some gaps, especially for tuberculosis and malaria. The gaps have been filled from a wide variety of sources. For death rates from tuberculosis in Asian countries we have found data in various issues of Tubercle. The death rate from tuberculosis in China is from the homepage of the Tuberculosis and Chest Service, Department of Health, The Government of the Hong Kong Special Administrative Region. Gaps for death rates for malaria have been filled by consulting various documents obtained from the "Books and Documents" homepage of the Office of Medical History of the Office of the Surgeon General of The US Army which is available on the internet, especially from Volume VI of the Clinical Series about the Medical Department of the United States Army in World War II.

Death rates by disease from 1950-1980 are from various issues of UN Demographic Yearbooks. Death rates for 1990 and 2000 are from the online WHO Mortality Database, and the online WHO Causes of death database.

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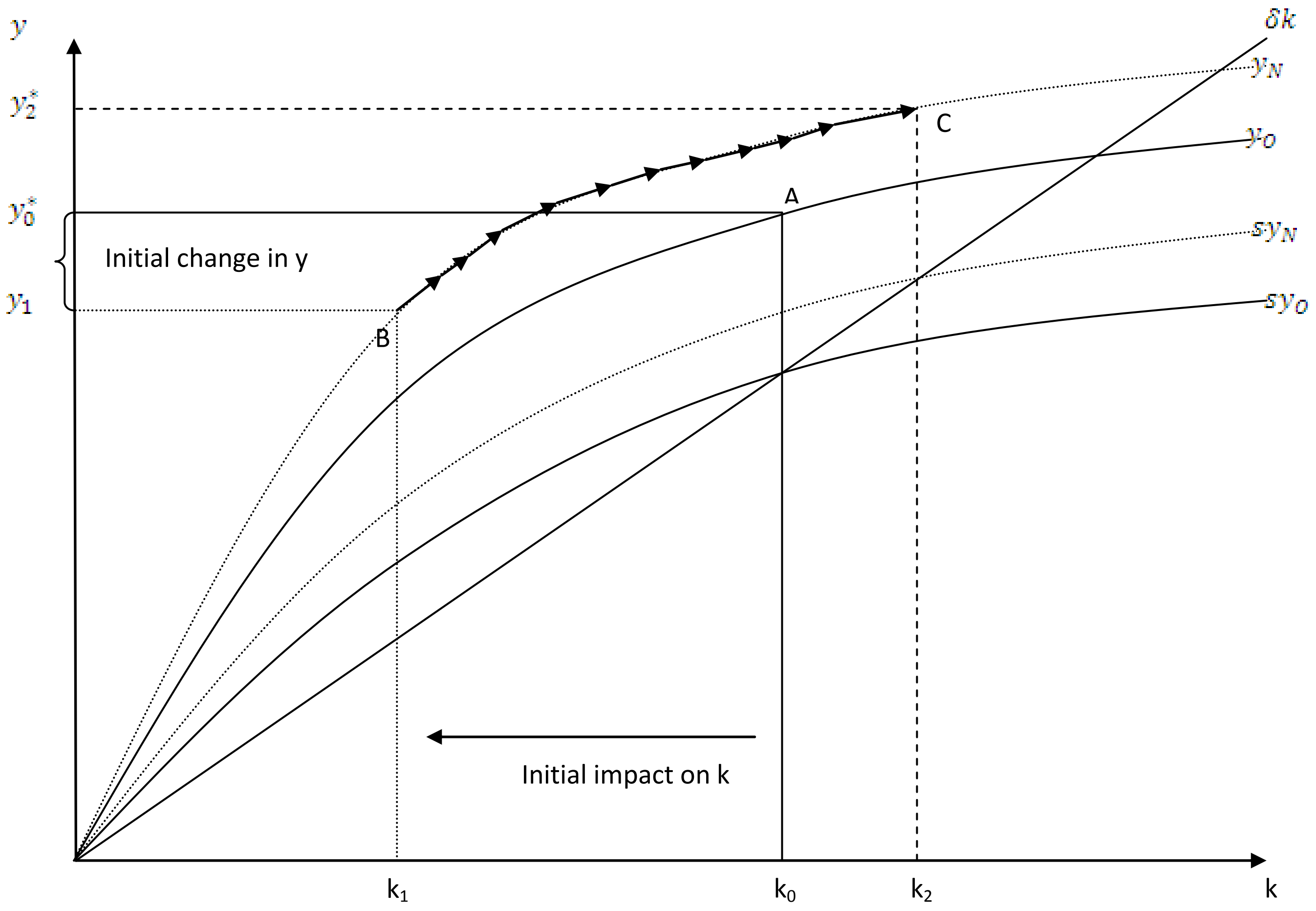
Figure 1



y
δk
y_N
y_2^*
C
y_O
A
y_0^*
sy_N
Initial change in y
y_1
sy_O
B
Initial impact on k
k_1
k_0
k_2
k

Figure 2

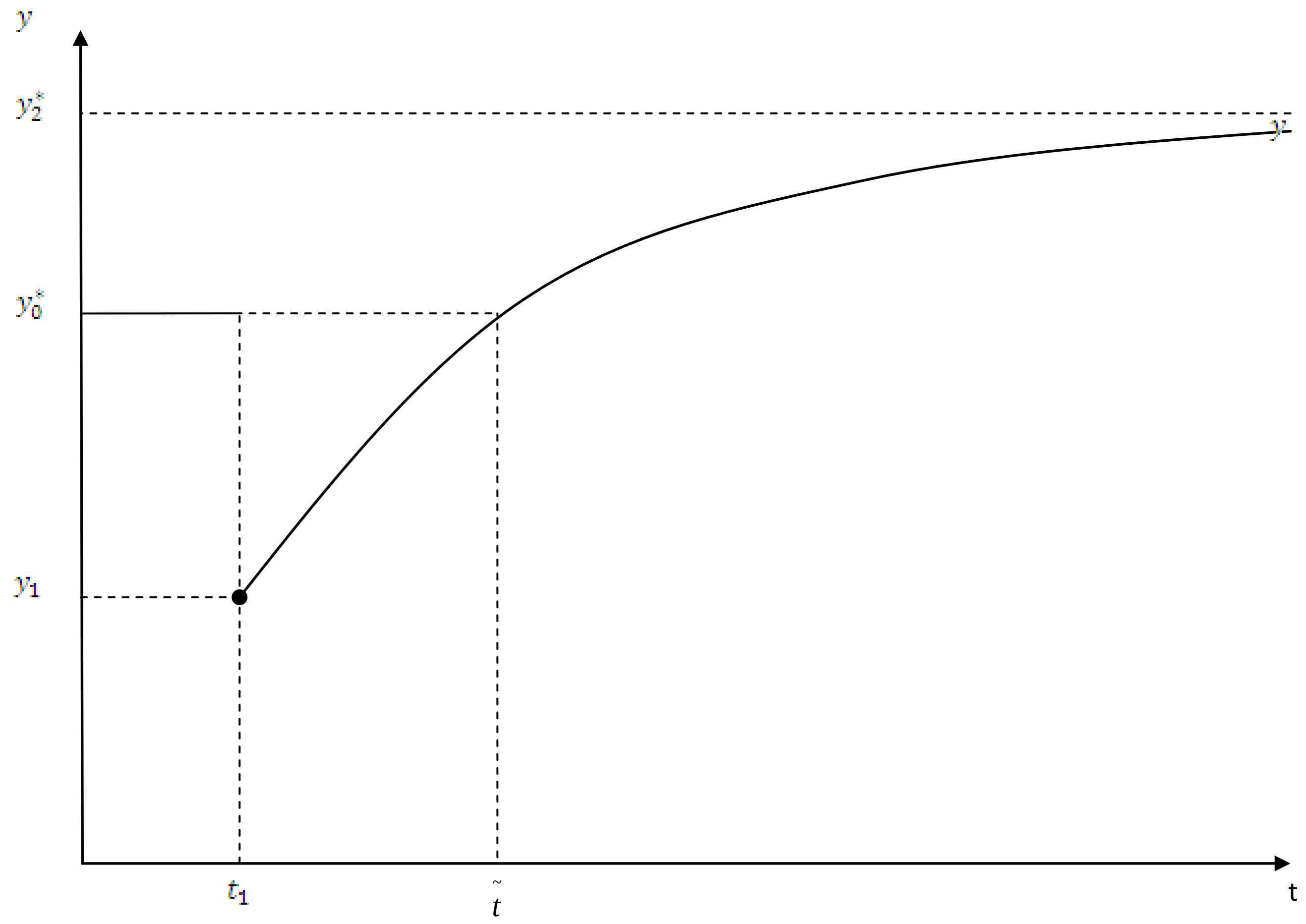


Figure 3

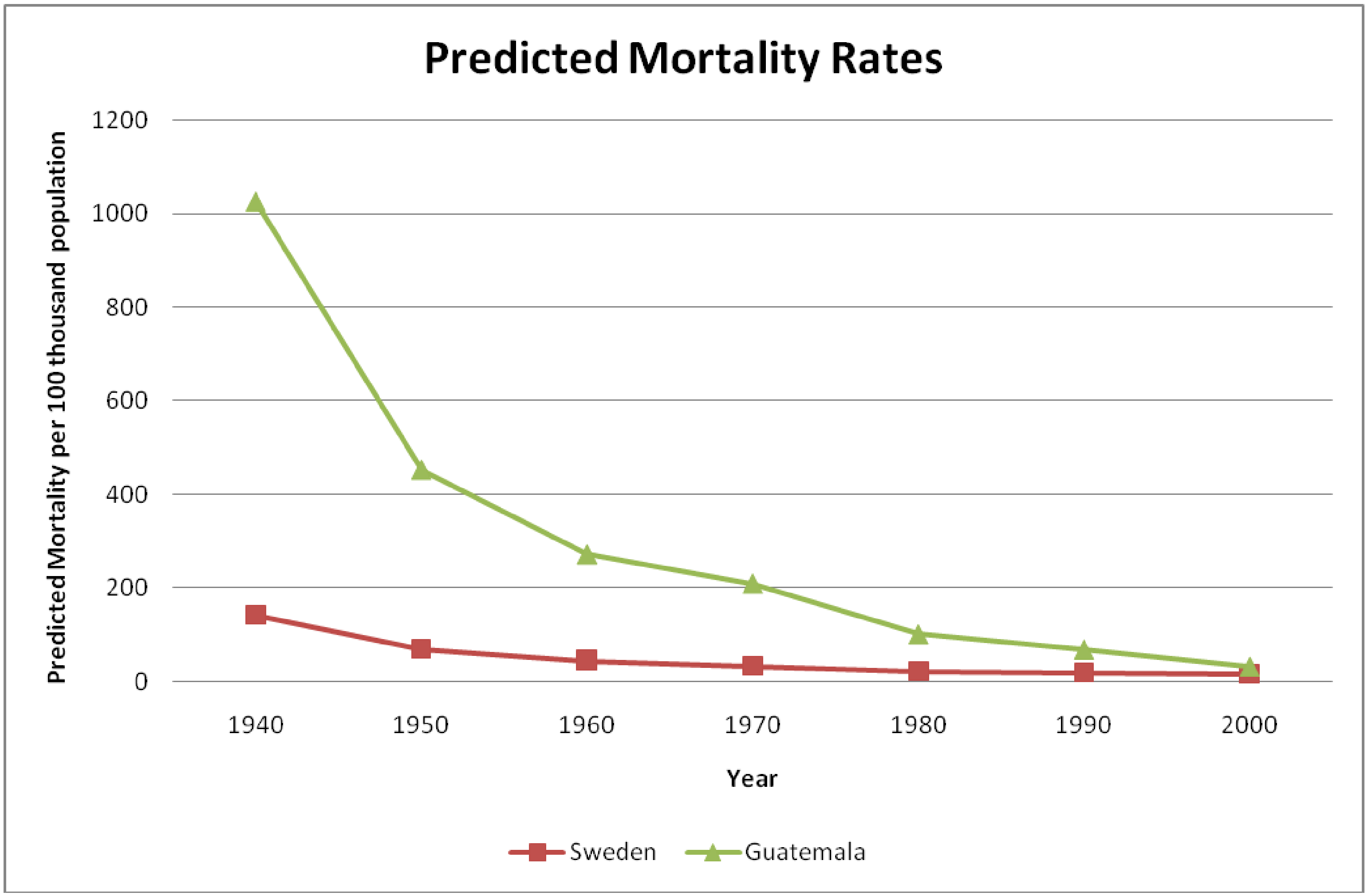

Predicted Mortality Rates
Predicted Mortality per 100 thousand population
1200
1000
800
600
400
200
0
1940
1950
1960
1970
1980
1990
2000
Year
Sweden
Guatemala

Figure 4

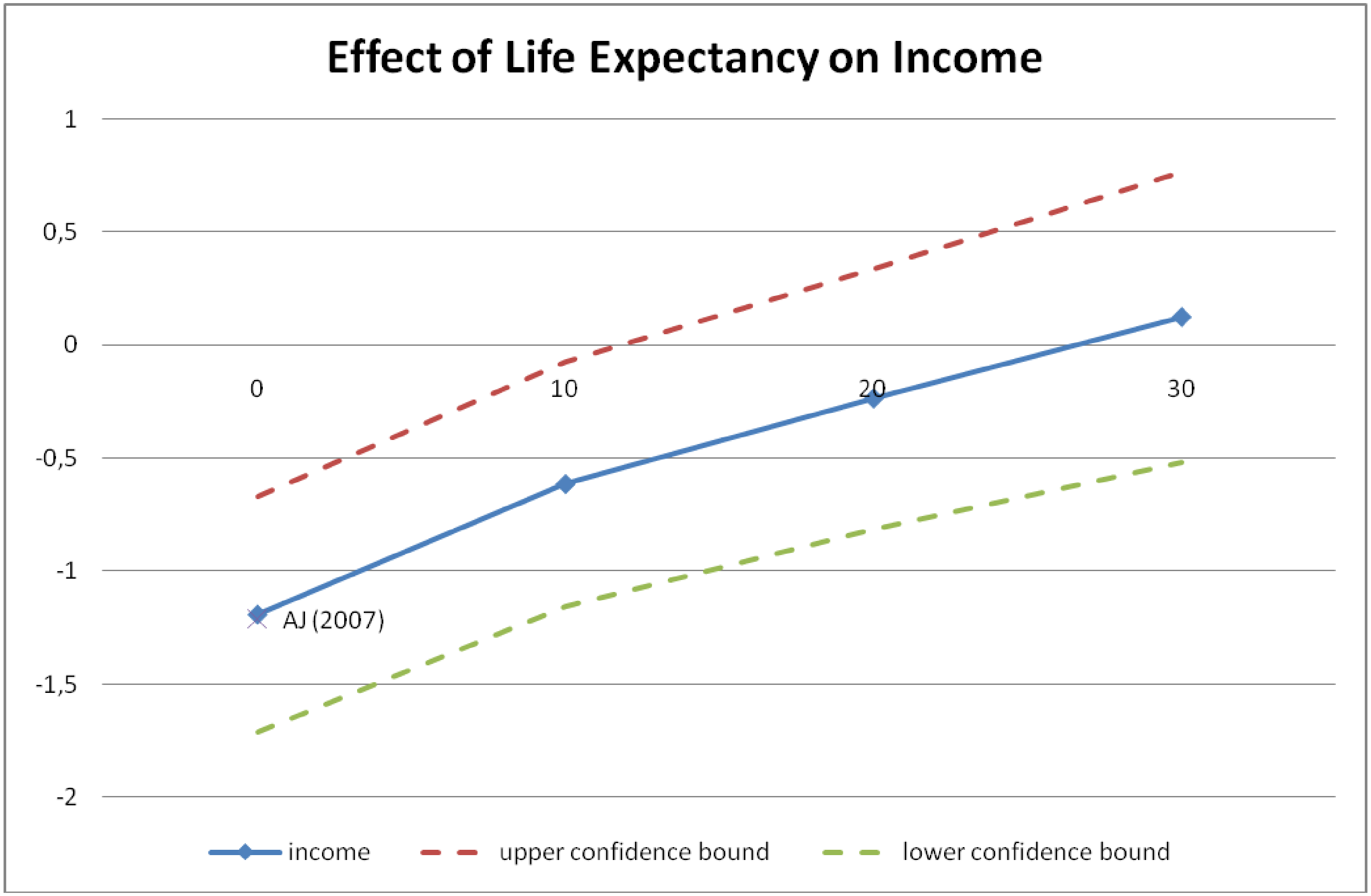
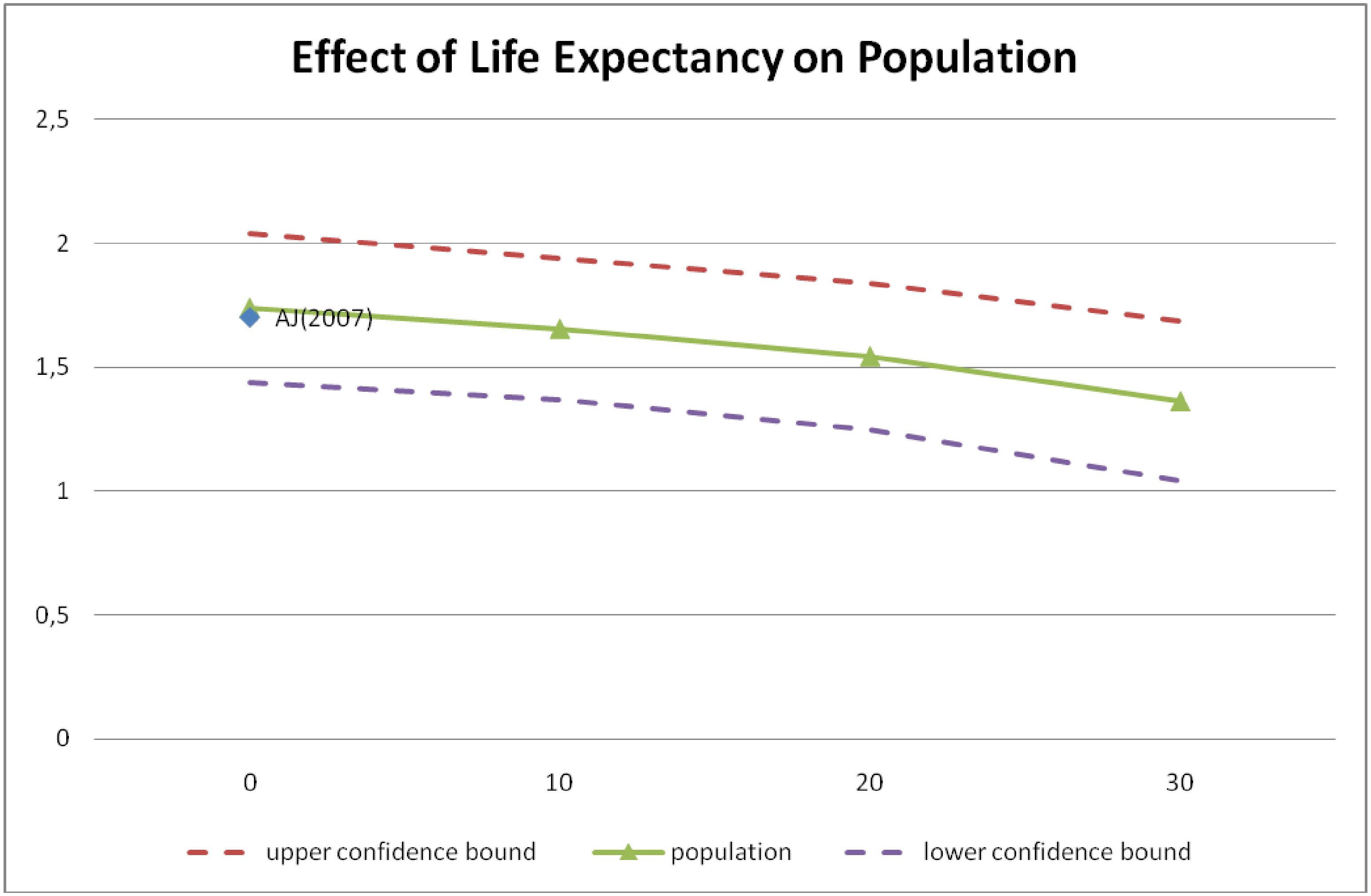

Effect of Life Expectancy on Income
1
0,5
0
-0,5
-1
-1,5
-2
0
10
20
30
AJ (2007)
income
upper confidence bound
lower confidence bound

Figure 5



Effect of Life Expectancy on Population
2,5
2
1,5
1
0,5
0
AJ(2007)
0
10
20
30
upper confidence bound
population
lower confidence bound

Table 1: Effects of Life Expectancy on GDP per Capita, OLS

	(1) No lead	(2) 10 year lead	(3) 20 year lead	(4) 30 year lead
	Dependent Variable is log GDP per Capita			
Life Expectancy	-0.65 (0.19)***	-0.48 (0.20)**	-0.16 (0.23)	-0.10 (0.28)
Countries	51	51	51	51
Observations	354	306	255	204

OLS estimation in all columns. The dependent variable is log GDP per Capita (1990 International Geary-Khamis dollars). The explanatory variable is life expectancy at birth. Robust standard errors are reported in parentheses. Full set of country fixed effects and time dummies included in all columns.

Table 2: Effects of Life expectancy on Population, OLS

	(1) No lead	(2) 10 year lead	(3) 20 year lead	(4) 30 year lead
	Dependent Variable is log Population			
Life Expectancy	1.60 (0.13)***	1.41 (0.12)***	1.14 (0.13)***	0.84 (0.13)***
Countries	51	51	51	51
Observations	357	306	255	204

OLS estimation in all columns. The dependent variable is log Population. The explanatory variable is life expectancy at birth. Robust standard errors are reported in parentheses. Full set of country fixed effects and time dummies included in all columns.

Table 3: Predicted Mortality Rates and Life expectancy

	(1) Log Population	(2) Log Population	(3) Log Population	(4) Log Population	(5) Log Population
Tuberculosis		-0.56	-0.56	-0.57	
		(0.24)**	(0.24)**	(0.23)**	
Malaria		-0.70	-0.70	-0.69	
		(0.12)***	(0.12)***	(0.11)***	
Influenza		-0.17	-0.16		
		(0.62)	(0.60)		
Typhoid		-2.60	-2.60	-2.55	
		(1.10)**	(1.10)**	(1.10)**	
Whooping cough		-0.82	-0.82	-0.85	
		(0.25)***	(0.25)***	(0.22)***	
Measles		-0.98	-0.98	-1.01	
		(0.52)*	(0.52)*	(0.49)**	
Smallpox		0.12			
		(0.91)			
Pneumonia		-0.09	-0.09	-0.09	
		(0.28)	(0.28)	(0.28)	
Predicted Mortality	-0.58				
	(0.06)***				
Predicted Mortality					-0.82
					(0.06)***
Countries	51	51	51	51	51
Observations	357	306	255	204	204

OLS estimation in all columns. The dependent variable is life expectancy at birth. Robust standard errors are reported in parentheses. Full set of country fixed effects and time dummies included in all columns.

Table 4: Preexisting trends

	(1) Change in Log Life Expectancy, 1900-1940	(2) Change in Log GDP per capita, 1900-1940	(3) Change in Log Population, 1900-1940
Change in Predicted Mortality, 1940-2000	-0.04	0.39	-0.48*
	(0.08)	(0.31)	(0.25)
Observations	32	34	47
R^2	0.01	0.03	0.07

OLS in all columns. Dependent variable is indicated in each column separately. Robust standard errors are reported in parentheses.

Table 5: Effects of Life expectancy on GDP per Capita, 2SLS

	(1) No lead	(2) 10 year lead	(3) 20 year lead	(4) 30 year lead
	Dependent Variable is GDP per Capita			
Life Expectancy	-1.19 (0.27)***	-0.61 (0.28)**	-0.24 (0.29)	0.12 (0.33)
Countries	51	51	51	51
Observations	354	306	255	204
First-stage F-value	256.96	219.34	163.07	103.02

2SLS estimation in all columns. The dependent variable is GDP per Capita (1990 International Geary-Khamis dollars). The explanatory variable is life expectancy at birth. Instrument used is predicted mortality. Standard errors are reported in parentheses. Full set of country fixed effects and time dummies included in all columns.

Table 6: Effects of Life expectancy on Population, 2SLS

	(1) No lead	(2) 10 year lead	(3) 20 year lead	(4) 30 year lead
	Dependent Variable is log Population			
Life Expectancy	1.74 (0.15)***	1.65 (0.15)***	1.54 (0.15)***	1.36 (0.16)***
Countries	51	51	51	51
Observations	357	306	255	204
First-stage F-value	274.56	219.34	163.07	103.02

2SLS estimation in all columns. The dependent variable is log Population. The explanatory variable is life expectancy at birth. Instrument used is predicted mortality. Standard errors are reported in parentheses. Full set of country fixed effects and time dummies included in all columns.

Table 7: Effects of Life expectancy on GDP per Capita, 2SLS

	(1) No lead	(2) 10 year lead	(3) 20 year lead	(4) 30 year lead
		Dependent Variable is GDP per Capita		
Life Expectancy	-1.23 (0.27)***	-0.57 (0.28)**	-0.23 (0.31)	0.18 (0.36)
Countries	51	51	51	51
Observations	354	306	255	204
First-stage F-value	236.24	195.72	138.77	80.28

2SLS estimation in all columns. The dependent variable is GDP per Capita (1990 International Geary-Khamis dollars). The explanatory variable is life expectancy at birth. Instrument used is predicted mortality. Standard errors are reported in parentheses. Full set of country fixed effects and time dummies included in all columns.

Table 8: Effects of Life expectancy on Population, 2SLS

	(1) No lead	(2) 10 year lead	(3) 20 year lead	(4) 30 year lead
	Dependent Variable is log Population			
Life Expectancy	1.70 (0.16)***	1.65 (0.15)***	1.58 (0.16)***	1.45 (0.18)***
Countries	51	51	51	51
Observations	357	306	255	204
First-stage F-value	251.54	195.72	138.77	80.28

2SLS estimation in all columns. The dependent variable is log Population. The explanatory variable is life expectancy at birth. Instrument used is predicted mortality. Standard errors are reported in parentheses. Full set of country fixed effects and time dummies included in all columns.