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Modeling the effects of health on economic growth

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Abstract

This paper investigates the effects of health indicators such as adult survival rates (ASR) on GDP growth rates at 5-year intervals in several countries. Panel data were analyzed on GDP series based on purchasing power adjustments and on exchange rates. First, we developed a framework for modeling the inter-relationships between GDP growth rates and explanatory variables by re-examining the life expectancy–income relationship. Second, models for growth rates were estimated taking into account the interaction between ASR and lagged GDP level; issues of endogeneity and reverse causality were addressed. Lastly, we computed confidence intervals for the effect of ASR on growth rate and applied a test for parameter stability. The results showed positive effects of ASR on GDP growth rates in low-income countries. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

The 20th century has seen remarkable gains in health. Average life expectancy in developing countries was only 40 years in 1950 but had increased to 63 years by 1990 (World Bank, 1993). Factors such as improved nutrition, better sanitation, innovations in medical technologies, and public health infrastructure have gradually increased the human life span. The relative contribution of these factors depends on the level of economic development; there are synergisms between the underlying factors operating in complex ways. Thus, for

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example, while recognizing various determinants of life expectancy, Preston (1976) emphasized economic development as the most important factor. However, since life expectancy is strongly influenced by child mortality, low-cost interventions such as the provision of ante natal care and vaccination programs in poor countries can be effective instruments for raising life expectancy. More generally, economic development depends on the level of skills acquired by the population and on capital formation. The former is influenced by child nutrition, educational infrastructure, and households' resources, including parents' physical health and cognitive attainment (e.g. Fogel, 1994; Scrimshaw, 1996; Bhargava, 1998, 1999). Capital accumulation depends on the savings rate that is also influenced by adult health.

Analyses of the inter-relationships between health and economic productivity can be conducted at the individual level, at regional levels within a country, and for aggregate data on countries. In developing countries, there are numerous micro studies in biological and social sciences showing benefits of better health on productivity (e.g. Basta et al., 1979; Spurr, 1983; Bhargava, 1997; Strauss and Thomas, 1998). Quantifying the relationship between health indicators and economic productivity is more subtle in developed countries. For example, the effects of disability on employment status have been investigated in The Netherlands (Stronks et al., 1997); the relationship was stronger in physically demanding occupations where earnings are typically low. The earnings of a large proportion of the population, however, depend on their general health and well-being, including mental health. While psychologists have investigated the decline with age in components of cognitive abilities (Horn and Hofer, 1992), the effects of such factors on individuals' productivity remain largely unknown.

Recently, aggregate data at the country level for the post-war period have become accessible (Penn world table (PWT), Summers and Heston, 1991; world development indicators (WDI), World Bank, 1998). Panel data on countries have been extensively used to elucidate economic relationships (e.g. Barro and Sala-i-Martin, 1995; Barro, 1997). Because many countries have experienced demographic and health transition in this period, studies can yield insights into the sources of economic growth. The quality of the data, however, can be poor especially in less developed countries, where many of the variables are 'projections' from statistical models. For example, the purchasing power parity indices commonly used for constructing the real GDP series in the PWT are based on the information on a subset of 68 countries. Further, most countries face different socio-economic and infrastructural constraints that are difficult to approximate in the analyses. Pooling data across countries can lead to spurious results, especially if the investigators fail to address stochastic properties of the dependent variable in econometric modeling (Sargan, 1964). Such problems are exacerbated in models explaining aggregate variables such as the GDP. Moreover, growth rates averaged over long time periods (e.g. 25 years) tend to describe economic activity in a way that is similar to the GDP. By contrast, the 5-year average growth rates analyzed in this paper show considerable variation but are less noisy than the annual growth rates.

The purpose of this paper is to model the proximate determinants of economic growth with emphasis on variables that approximate health of the population. In so doing, we develop an analytical framework within which issues of demographic transition, human development, and capital formation can be discussed. In addition, the models incorporate the stochastic properties of the GDP series and take into account the data limitations. Section 2 describes the data used in the analysis. The analytical framework for modeling the effects of health on economic growth is developed in Section 3.1. The econometric framework is outlined in Section 3.2. Issues of possible reverse causality from higher growth rates to the adult survival rates (ASR) are discussed in Section 3.3. A Wald type statistic for the stability of model parameters outside the sample period is developed in Section 3.4. In Section 4.1, average growth rates at 5-year intervals are modeled using a model similar to Barro (1997), but allowing for simultaneity and interactions between some regressors. Instrumental variables estimation methods were used and certain maintained hypotheses were tested (Bhargava, 1991a). In Section 4.2, we elaborate on the role of the interaction between lagged ASR and GDP from a policy standpoint. Stability of the estimated parameters is tested in Section 4.3 by a Wald test using out-of-sample observations for 1995 on GDP from the WDI. The conclusions and the need for collecting additional health statistics are discussed in Section 5.

2. The data

The data used in the analysis were primarily from the PWT (Summers and Heston, 1991) and the WDI (World Bank, 1998). The GDP series in the PWT are in "1985 international dollars" that were based on purchasing power parities for a subset of countries; the GDP series from the WDI was based on the official exchange rates using 1987 constant dollars. The WDI GDP series is likely to show greater variability, because exchange rate fluctuations can induce distortions especially for small countries. However, the PWT GDP series involves estimation of the purchasing power parity indices for countries where the data were not available (Summers and Heston, 1991; Ahmad, 1992). Conclusion from our analysis will be strengthened if GDP series based on purchasing power parities and exchange rates yield similar results.

The total fertility rate, life expectancy, and population variables were available in the PWT and WDI data sets. In addition to life expectancy, we used the ASR (probability of surviving the 60th birthday after reaching the age 15 years; mean $= 0.702$, S.D. $= 0.14$) from Bos (1998). The ASR is less sensitive to child mortality rates and was constructed from World Bank demographic files containing mortality data on countries; figures for some countries were projections from demographic models. Typically, data on total fertility rate and ASR were compiled at irregular intervals. To reduce the effects of projections on the empirical results, we analyzed panel data that were separated by 5-year intervals, i.e. six time observations on the countries (in 1965, 1970, 1975, 1980, 1985, 1990) were used (first observation in WDI series was for 1966).

The education series (average years of education for population aged 15–60) for the six time periods were taken from Barro and Lee (1996). Data on geographical variables such as the area in the tropics, if the country is 'land-locked', and an index of openness to trade were from Gallup and Sachs (1998). Overall, the GDP data covered 125 countries in the PWT and 107 countries in the WDI. However, because of missing observations on explanatory variables, the sample sizes used in the estimation were lower for the models for GDP growth rates.

We note that while it is feasible to estimate aggregate production functions for the countries, the data on physical capital stock were available for only 58 countries in the PWT.

Collins and Bosworth (1996) and Nehru and Dhareshwar (1993) have imputed the data on physical capital for a larger number of countries under certain assumptions on depreciation rates. Because these assumptions are non-standard and because the focus of our analysis was on the relationship between health indicators and economic growth, we do not report the results for aggregate production functions in this paper.

3. A framework for modeling the effects of health on economic activity

3.1. The conceptual framework

Preston (1976) analyzed cross-country data on life expectancy and national incomes for the approximate periods 1900, 1930, 1960 and observed that the curves showed an upward shift over time. For a given income level, life expectancy was highest in 1960s. Moreover, per capita GDP above $600 (in 1963 prices) had little impact in raising the highest life expectancy (73 years) in the 1960s. While recognizing that shifts in the curves had multiple causes, Preston attributed approximately 15% of the gains in life expectancy to income growth, but was less optimistic about the role played by nutrition and literacy. However, recent analyses of historical data suggest larger benefits from improved nutrition (Floud et al., 1991; Fogel, 1994). Furthermore, public health programs reducing sicknesses have beneficial effects on health by preventing the loss of vital nutrients due to infection (Scrimshaw et al., 1959).

Life expectancy (or ASR) in a country is a broad measure of population health, though it need not accurately reflect the productivity of the labor force. For example, suppose that due to poor childhood nutrition, ability of individuals to perform productive tasks diminishes at an early age but, because of access to medical care, life expectancy is high (e.g. the Indian state of Kerala; International Institute of Population Sciences, 1995). Then productivity loss will be under-estimated if life expectancy was used as the sole indicator of health. Indices measuring disabilities of the working population in various occupations would be insightful for assessing productivity loss (e.g. Murray and Lopez, 1996).

At a general level, capital formation requires that a high proportion of the skilled labor force remains active for a number of years; experience is important for technical innovations that take years of investments in research and development. Because detailed information on such variables cannot be utilized in national comparisons, a broader view of health is helpful for interpreting the results. In particular, investments in education and training critically depend on survival probabilities; expenditure on children's education may be influenced by parents' subjective probabilities of child survival. All these factors are potentially important for explaining economic growth (e.g. Bloom and Canning, 2000).

Panel data on developing and developed countries provide an opportunity to disentangle some of the effects of demographic, health, and economic variables on growth rates, because the countries are at different stages of economic and social development. In certain developing countries, high fertility rates hamper investments in child health and education. Poor child health is likely to lead to reduced physical work capacity when the children turn into adults (Spurr, 1983). Thus, in the absence of natural resources, certain countries may not be able to escape from poverty traps. Because many developing countries have prospered during the sample period (1965–1990), while others have not, a model for the proximate determinants of economic growth can shed light on these issues.

The dependence of life expectancy on incomes up until a certain threshold suggests that it would be useful to model the GDP or growth rates using a flexible production function such as the trans-logarithmic function (Christensen et al., 1973; Sargan, 1971). Boskin and Lau (1992) estimated aggregated production functions for five developed countries using annual observations for the post-war period. Kim and Lau (1994) extended the analysis to cover four countries in the Pacific basin where good data on the physical capital stock were available. From the standpoint of modeling the effects of health on economic growth, the flexible functional form approach underscores the interaction between explanatory variables and the importance of squared terms in the model. While precise estimation of coefficients of high order terms would require large sample sizes, the work by Preston (1976) demonstrated the asymmetry in the life expectancy–incomes relationship. It is therefore likely that the impact of health indicators such as ASR on growth rates would depend on the level of GDP. Thus, ASR should be important for explaining economic growth at low levels of GDP. In more affluent settings, investments in education and training, and measures of health such as the decline in cognitive abilities with age, and age-specific disease prevalence rates, may be of greater importance.

3.2. The econometric framework for estimation of static random effects models containing endogenous regressors

The methodology used for the estimation of static random effects models for GDP growth rates in situations where some of the explanatory variables are endogenous was developed by Bhargava (1991a). Let the model be given by

$$y_{it} = \sum_{j=1}^{m} z_{ij}\gamma_j + \sum_{j=1}^{n_1} x_{1ijt}\beta_j + \sum_{j=n_1+1}^{n} x_{2ijt}\beta_j + u_{it} \quad (i = 1, \ldots, N;\ t = 1, \ldots, T) \tag{1}$$

where z is time invariant variables, x_1 and x_2, respectively, exogenous and endogenous time varying variables, and N the number of countries that are observed in T time periods. The slope coefficients are denoted by Greek letters. In the models estimated for GDP growth rates, for example, the proportion of area of a country in the tropics is a time invariant explanatory variable. Time varying regressors consist of (lagged) total fertility rate, investment/GDP ratio, ASR, interaction between ASR and GDP, and GDP.

It is important to distinguish between two sets of assumptions for the potential endogeneity of the time varying variable x_2. First, x_2 may be correlated with the errors u_{it} in a general way, i.e. x_2 are 'fully' endogenous variables. Thus, x_{2jt} must be treated as different variables in each time period. Let X_1 and X_2 be, respectively, the $n_1 \times 1$ and $n_2 \times 1$ vectors containing the exogenous and endogenous time varying variables ($n_1 + n_2 = n$), and let Z be the $m \times 1$ vector of time invariant variables. We can write a reduced form equations for the fully endogenous variables X_2 as

$$X_{2it} = \sum_{j=1}^{T} F_{tj} X_{1ij} + F_t^* Z_i + U_{2it} \tag{2}$$

where F_{tj} $(t = 1, \dots, T;\ j = 1, \dots, T)$ and F_t^* $(t = 1, \dots, T)$ are, respectively, $n_2 \times n_1$ and $n_2 \times m$ matrices of reduced form coefficients; U_{2it} the $n_2 \times 1$ vector of errors.

The reduced form Eq. (2) is a general formulation for correlation between the time varying endogenous variables and errors u_{it} affecting model (1). Thus, for example, lagged GDP has often been included as an explanatory variable in models for growth rates (Barro and Sala-i-Martin, 1995; Barro, 1997). Caselli et al. (1996) have stressed that lagged GDP should be treated as endogenous. Because the error terms affecting Eq. (1) may have a complex structure (Sala-i-Martin, 1996), it is appealing to treat lagged GDP as a fully endogenous variable in the estimation. Similarly, one might postulate that the investment/GDP ratio is a fully endogenous variable; transitory components of u_{it} may be correlated with short-term fluctuations in the investment/GDP ratio. Moreover, one can test the hypotheses that GDP and the investment/GDP ratio are exogenous variables using sequential procedures.

As noted in Section 2, variables such as ASR and total fertility rate are typically compiled in a country at a certain points of time; the yearly values tabulated in PWT and WDI are often projections from simple statistical models. Extrapolation of a variable such as ASR implies that it cannot be treated as a fully endogenous variable; the time observations on ASR are likely to be systematically related. This will violate the rank condition for parameter identification in models where ASR is assumed to be a fully endogenous variable.

An alternative assumption for endogeneity of variables such as ASR is to assume that only the country-specific random effects δ_i are correlated with x_{2ijt}.

$$x_{2ijt} = \lambda_t \delta_i + x^*_{2ijt} \tag{3}$$

where x^*_{2ijt} are non-correlated with δ_i, and δ_i are randomly distributed variables with zero mean and finite variance. This correlation pattern was invoked by Bhargava and Sargan (1983) and is in the spirit of the commonly used random effects models. Endogenous variables represented by Eq. (3) have sometimes been referred to as 'special' endogenous variables (Bhargava, 1991b). While Eq. (3) may seem to be a restrictive formulation, it allows countries to possess unobserved 'permanent' characteristics that in turn could influence the levels of explanatory variables. For example, countries with high saving rates may invest greater resources in health and education sectors. This will cause the errors on the model for growth rates to be correlated with variables such as the education levels attained by the population. Furthermore, such assumptions are implicit in random effects models that decompose the errors u_{it} as

$$u_{it} = \delta_i + v_{it} \tag{4}$$

where v_{it} are independently distributed random variables with zero mean and finite variance. Eq. (4) is a special case of the general formulation for the errors on model (1), which only assumes that the variance covariance matrix of u_{it} is positive definite.

The main advantage in assuming the correlation pattern (3) is that deviations of the x_{2ijt} from their time means.

$$x^+_{2ijt} = x_{2ijt} - \bar{x}_{2ij} \quad (t = 2, \dots, T;\ j = n_1 + 1, \dots, n;\ i = 1, \dots, N) \tag{5}$$

where

$$\bar{x}_{2ij} = \sum_{t=1}^{T} \frac{x_{2ijt}}{T} \quad (j = n_1 + 1, \ldots, n; i = 1, \ldots, N) \tag{6}$$

can be used as $[(T-1)n_2]$ additional instrumental variables to facilitate parameter identification and estimation (Bhargava and Sargan, 1983). An efficient three-stage least squares type instrumental variables estimator will be used to estimate Eq. (1), assuming the two types of correlation patterns for x_{2jt} given by Eqs. (2) and (3), and without restricting the variance covariance matrix of u_{it}.

Further, in contrast to ordinary time series case, where mis-specification tests have been applied to test the overidentifying restrictions (Sargan, 1958), it is possible to test the validity of exogeneity assumption for explanatory variables in the panel data framework. As shown in Bhargava (1991a), one can sequentially test exogeneity assumptions using statistics based on instrumental variables estimates, because the correlation pattern for special endogenous variables in Eq. (3) is nested within the general formulation (2), where the x_2 are fully endogenous. The sequential Chi-square test for exogeneity would first test the validity of the special correlation pattern (3). If n_2 time varying variables are postulated to be endogenous, then under the null hypothesis, the first test statistic is asymptotically distributed (for large N and fixed T) as a Chi-square variable with $[T(T-1)n_2]$ d.f. If the null hypothesis cannot be rejected, then we can further test if the time means of x_2 given by Eq. (6) are non-correlated with the random effects δ_i. The test statistic for the second set of hypotheses is asymptotically distributed as a Chi-square with Tn_2 d.f. (for details, see Bhargava, 1991a). The overall size of sequential tests can be based on several considerations (e.g. Anderson, 1971; Sargan, 1980).

To summarize the modeling strategy used in the analysis, we proceed by assuming that lagged GDP is a fully endogenous variable and estimate the parameters using an efficient instrumental variables estimator. It is likely that the exogeneity null hypothesis will be rejected for the lagged GDP variable. We can also test whether lagged investment/GDP ratio should be treated as a fully endogenous variable. Due to the potentially low predictive power of the instrumental variables in explaining the endogenous variables in panel data models (Bhargava and Sargan, 1983, p. 1654), we also report the adjusted R-squared for the reduced form equations for lagged GDP in each of the five time periods.

Further, because of extrapolation of variables such as ASR, it would be inappropriate to formulate that ASR and the interaction between ASR and GDP are fully endogenous variables. Instead, we treat these regressors as special endogenous variables as in Eq. (3) and test if their time means given by Eq. (6) are non-correlated with the country specific random effects δ_i. We recognize that it would be desirable to use additional time varying variables not included in model (1) as instruments. However, the identification conditions for such formulations in the presence of cross-equation restrictions on the parameters have not been fully worked out. Furthermore, simulation evidence suggests that it is important to incorporate the serial covariance structure of the errors affecting panel data models and select good instruments for producing reliable parameter estimates. Thus, in Section 3.3, we also develop a formulation for testing reverse causality, i.e. if lagged growth rates affect the current ASR. The results will be helpful in interpreting the outcome of the exogeneity tests in the models for growth rates.

3.3. A formulation for investigating reverse causality from GDP growth rates to adult survival rates

As noted in Section 3.1, Preston (1976) emphasized the likely effects of GDP *level* on life expectancy using cross-country data. By contrast, the recent literature explains GDP growth rates using lagged life expectancy as an explanatory variable. It is therefore important not only to treat lagged GDP level as a fully endogenous variable in model (1), but also to investigate possible reverse causation, i.e. if higher GDP growth rates in the previous period may be the 'cause' of higher ASR. Such an investigation would be in the spirit of Fisher (1973). Cochrane (1965) and Cox (1992) discuss certain aspects of interpreting associations in observational data as causal effects.

While one can apply the approach commonly used in time series analysis for testing the significance of lagged values of ASR in the model for GDP growth rate to investigate reverse causality, this procedure would suffer from certain drawbacks. First, as noted above, ASR is based on demographic data collected at a few points in time and the remaining values are projections; the lagged values of a slowly evolving variable such as ASR will be highly correlated with current values. Second, ASR may be correlated with the country specific random effects δ_i in model (1) for growth rates thereby making it more likely that the coefficients of lagged ASR will be significantly different from zero. Third, because our sample size consists of six time observations at 5-year intervals and some explanatory variables are endogenous, the purely time series approach is perhaps unappealing.

The approach used in our analysis is based on developing a model for ASR and investigating whether lagged GDP growth rates are significant predictors of ASR, after controlling for many confounding factors. Because the relationship between life expectancy and GDP *level* is well-established, we include lagged GDP level as an explanatory variable in the model for ASR and expect it to be a significant predictor. However, this need not be true for lagged GDP growth rates. In the spirit of the discussion in Section 3.1, we also include an interaction term between lagged GDP level and growth rates. Thus, if the coefficient of lagged GDP growth rates is a significant predictor of current ASR, and ASR is also a significant predictor of growth rates in model (1), then causality could run in either direction, i.e. from GDP growth rates to ASR or from ASR to GDP growth rates. By contrast, if the coefficient of GDP growth rates is not statistically significant in the model for ASR, then causality is more likely to run from ASR to GDP growth rates. Because of the panel nature of the data, we can tackle some of the issues of simultaneity in the estimation of models for GDP growth rates and ASR.

3.4. A Wald type test for parameter stability outside the sample period

A Wald type statistic can be developed in the random effects framework to test if the parameters remain constant outside the sample period. Assuming that the number of countries (N) is large, this statistic would be asymptotically equivalent to the appropriate likelihood ratio test. The Wald statistic can be computed by estimating the model for the N out-of-sample observations in time period $(T+1)$. Coefficients estimated from model (1), using the observations in the first T periods, are substituted as parameter values under the null hypothesis. Formally, apart from the intercept term, let b be the $(k \times 1)$ vector of efficient estimates of the unknown coefficients in Eq. (1) and let b^* be the corresponding estimates from the cross-section regression for time period $(T + 1)$. Then, defining the variance covariance matrix of b^* by $V(b^*, b^*)$, the Wald statistic for parameter stability is given by

$$W = (b^* - b)' = [V(b^*, b^*)]^{-1}(b^* - b) \quad (7)$$

Under the null hypothesis of parameter stability, W is distributed (for large N) as a Chi-square variable with k d.f.

4. Empirical results

4.1. Empirical results for models for GDP growth rates

Table 1 presents the empirical results for GDP growth rates for 92 countries at 5-year intervals using the PWT GDP series; the stochastic properties of the GDP series are discussed in Bhargava (2000), where it was found preferable to model growth rates. The model is similar in spirit to Barro (1997) but, as will be apparent from the discussion, it differs in a number of important respects. Specification 1 treats the explanatory variables as exogenous; the lagged GDP was a fully endogenous variable in specification 2. The estimation method used for specification 2 was also applied under the additional assumption that lagged investment/GDP ratio was a fully endogenous variable. However, the appropriate Chi-square statistic reported in Table 1 accepted the exogeneity null hypothesis for investment/GDP

Table 1
Estimated slope coefficients from static random effects models for real per capita GDP growth rates 1965–1990 at 5-year intervals using data from PWT[a]

Variable	Specification 1	Specification 2[b]
Constant	0.274 (0.041)	0.407 (0.069)
Tropics	−0.011 (0.004)	−0.012 (0.004)
Openness	0.026 (0.005)	0.028 (0.005)
Logarithm of fertility rate lagged 5 years	−0.015 (0.006)	−0.028 (0.008)
Logarithm of investment/GDP ratio lagged 5 years	0.014 (0.002)	0.014 (0.002)
Logarithm of adult survival rate lagged 5 years	0.181 (0.075)	0.358 (0.114)
Interaction between lagged adult survival rate and GDP	−0.024 (0.011)	−0.048 (0.016)
Logarithm of GDP lagged 5 years	−0.026 (0.004)	−0.041 (0.008)
GDP at which partial derivative of GDP growth rate with respect to lagged adult survival rate is zero	2123	1714
Chi-square (20) test for exogeneity of lagged GDP	63.89	
Chi-square (20) test for exogeneity of investment/GDP ratio	18.28	
Chi-square (15) test for exogeneity of means of lagged investment/ GDP ratio, ASR, and interaction of ASR and GDP	15.22	
Number of countries	92	92
Number of time observations	5	5

[a] Asymptotic standard errors are in parentheses.
[b] Specification 1 treats the time varying variables as exogenous; specification 2 treats lagged GDP as a fully endogenous variable.

ratio, conditional on the treatment of lagged GDP as a fully endogenous variable. Next, the investment/GDP ratio, ASR and interaction between ASR and GDP were treated as special endogenous variables, i.e. correlated with the country specific random effects δ_i. Another Chi-square statistic reported in Table 1 accepted the exogeneity null hypothesis, conditional on the treatment of lagged GDP as a fully endogenous variable. The variance covariance matrix of the errors was unrestricted in the estimation and testing procedures.

The main results can be summarized as follows.

1. The coefficient of the percentage of area of a country in the tropics was estimated with a negative sign that was statistically significant. Openness of the economy was positively associated with growth rates; the magnitude of the coefficient was robust to the use of alternative definition of openness in the PWT. The log of total fertility rate was negatively associated with GDP growth rates and was statistically significant. High fertility rates are common in developing countries and increase the demand on resources for health care and education; the work force does not increase equi-proportionately with the population. Also, high fertility rates in developing countries often reflect unwanted fertility that adversely affects households' resource allocation decisions (Bhargava, 2002). For example, the ratio of skilled to unskilled labor is likely to be negatively associated with total fertility rate due to diminished resources available for education; total fertility rate is thus likely to be negatively associated with growth rates.
2. The lagged investment/GDP ratio had a positive coefficient that was statistically significant; economic growth was affected by investments in physical capital. The fact that the coefficient of the investment/GDP ratio was small, suggests that one should not dismiss proximate determinants of growth rates because of their small magnitudes. Of course, coefficients should be statistically significant and robust to changes in model specification. However, the extent to which one can investigate adequacy of models for growth rates is limited by difficulties such as the large variation in growth rates, modest number of countries in the sample, measurement errors in the explanatory variables, etc. For example, one might have expected a variable such as the average years of education of the population (Barro and Lee, 1996) to be positively associated with growth rates. This was not the case in the present models, perhaps because variation in this variable was relatively small for a number of developing countries.
3. The lagged ASR and interaction between ASR and GDP were the significant predictors of economic growth. The impact of ASR was positive at low levels of GDP and, for example, approached zero in specification 1 when the per capita GDP was 2123 in 1985 international dollars. We discuss this issue in greater detail in Section 4.2. The empirical results were similar when ASR was replaced by life expectancy, though the model where ASR was included provided a better fit. This was perhaps not surprising since life expectancy is strongly influenced by child mortality. Because child mortality is itself affected by unwanted fertility in developing countries, the total fertility rate and ASR are better indicators of the health infrastructure.
4. The estimated coefficient of lagged GDP was negative showing a tendency of regression towards the mean. While the results in specifications 1 and 2 were close, the level of GDP at which the effect of ASR on growth rate was zero was estimated to be 1714 in 1985 international dollars due to the treatment of lagged GDP as an endogenous variable.

Table 2
Estimated slope coefficients from static random effects models for real per capita GDP growth rates 1965–1990 at 5-year intervals using data from WDI[a]

Variable	Specification 1	Specification 2[b]
Constant	0.220 (0.033)	0.310 (0.048)
Tropics	−0.014 (0.004)	−0.016 (0.005)
Openness	0.041 (0.006)	0.047 (0.007)
Logarithm of fertility rate lagged 5 years	−0.023 (0.007)	−0.034 (0.008)
Logarithm of investment/GDP ratio lagged 5 years	0.009 (0.003)	0.008 (0.003)
Logarithm of adult survival rate lagged 5 years	0.192 (0.061)	0.333 (0.084)
Interaction between lagged adult survival rate and GDP	−0.029 (0.010)	−0.052 (0.014)
Logarithm of GDP lagged 5 years	−0.022 (0.004)	−0.034 (0.006)
GDP at which partial derivative of GDP growth rate with respect to lagged adult survival rate is zero	684	580
Chi-square (20) test for exogeneity of lagged GDP	62.41	
Chi-square (20) test for exogeneity of investment/GDP ratio	13.23	
Chi-square (15) test for exogeneity of means of lagged investment/ GDP ration, ASR, and interaction of ASR and GDP	3.04	
Number of countries	73	73
Number of time observations	5	5

[a] Asymptotic standard errors are in parentheses.
[b] Specification 1 treats the time varying variables as exogenous; specification 2 treats lagged GDP as a fully endogenous variable.

Because the Chi-square specification test indicated that lagged GDP should be treated as a fully endogenous variable, the *R*-squared values were computed from reduced form equations regressing lagged GDP on the explanatory variables; the adjusted *R*-squared for the five time periods were 0.78, 0.80, 0.81, 0.83, and 0.85, respectively. While it is possible to develop a rigorous statistical test for the rank condition underlying the instrumental variable estimation, the adjusted *R*-squared values suggest that the rank condition is satisfied in this model.

The empirical results for GDP growth rates based on official exchange rates from the WDI are shown in Table 2. The results in Tables 1 and 2 were similar for most explanatory variables except that the level of GDP at which the effect of ASR on growth rate was zero in specifications 1 and 2 were 684 and 580, respectively, in constant 1987 dollars. These estimates were substantially lower than the corresponding figures for the PWT data when converted from 1985 international dollars to 1987 constant dollars (an 1985 international dollar is approximately equal to 1.25 constant 1987 dollars). The specification test again indicated that lagged GDP should be treated as a fully endogenous variable; the adjusted *R*-squared for the five reduced form equations were 0.74, 0.75, 0.77, 0.79, and 0.80, respectively. Because the WDI data were not interpolated for most countries, there was greater variation in the GDP series. Thus, one would expect the *R*-squared values to be slightly lower in the reduced form equations for the WDI GDP series. The effects of smoothing procedures will be further apparent in Section 4.2, where we investigate the net effect of ASR on GDP growth rates.

4.2. The net impact of adult survival rates of GDP growth rates

The ASR for a country is likely to be influenced by economic development, access to and quality of medical care, and the public health infrastructure. However, beyond a certain threshold, increases in ASR are difficult to achieve and will increase the proportion of the elderly in the economy. By contrast, for countries at low levels of GDP, one would expect significant effects of ASR on economic growth due to the contribution of labor in prime years. Thus, models for growth rates should allow some forms of non-linearities. Because of the modest number of countries in the data set and because the average life expectancy in the sample was around 60 years, only the interaction between lagged ASR and GDP was found to be statistically significant. For illustrative purposes, we rewrite the net effect of a change in ASR on growth rate as

$$b_1 = b_2 + b_3(\text{GDP}) \tag{8}$$

where b_2 and b_3 are, respectively, the (partial) coefficients of the logarithm of ASR and interaction between logarithms of ASR and GDP in the model (1). The net effect b_1 can be computed at different levels of GDP and the asymptotic confidence intervals can be approximated from

$$A\text{var}(b_1) = A\text{var}(b_2) + A\text{var}(b_3)(\text{GDP})^2 + 2A\text{cov}(b_2, b_3)(\text{GDP}) \tag{9}$$

Thus, we can tabulate the effects of a unit change in ASR on growth rates and the corresponding confidence intervals for the countries at mean GDP levels. The results for

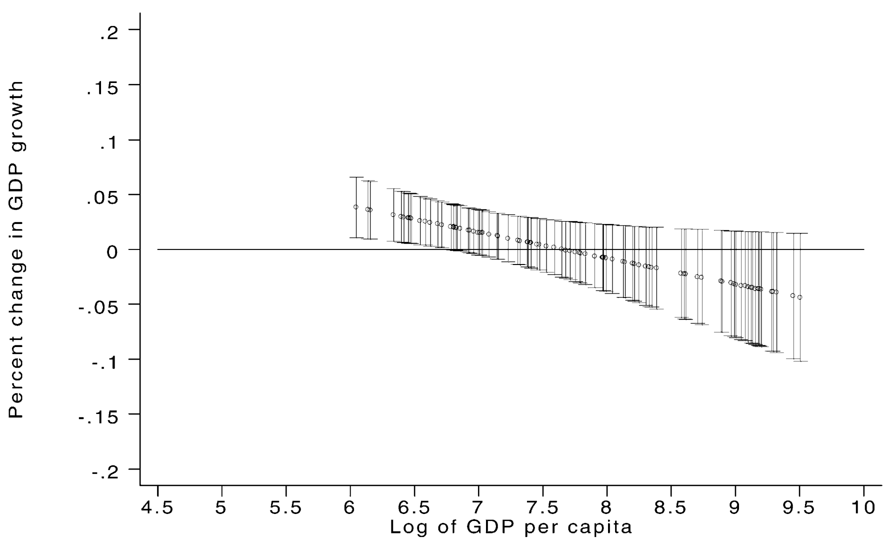

Fig. 1. Net effect and confidence intervals for a percent change in ASR on GDP growth rate using PWT GDP data and assuming exogenous explanatory variables.

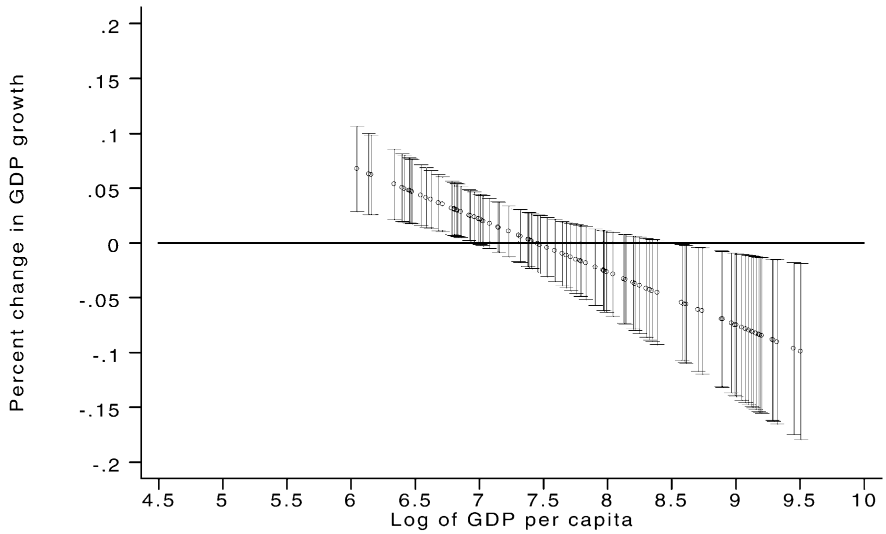

Fig. 2. Net effect and confidence intervals for a percent change in ASR on GDP growth rate using PWT GDP data and assuming GDP is a fully endogenous explanatory variable.

the PWT data are presented in Figs. 1 and 2, where Fig. 2 plots the results for the case where lagged GDP was treated as a fully endogenous variable. The effect was plotted against mean of the logarithm of GDP of countries in the sample period. Corresponding results for the WDI data are in Figs. 3 and 4.

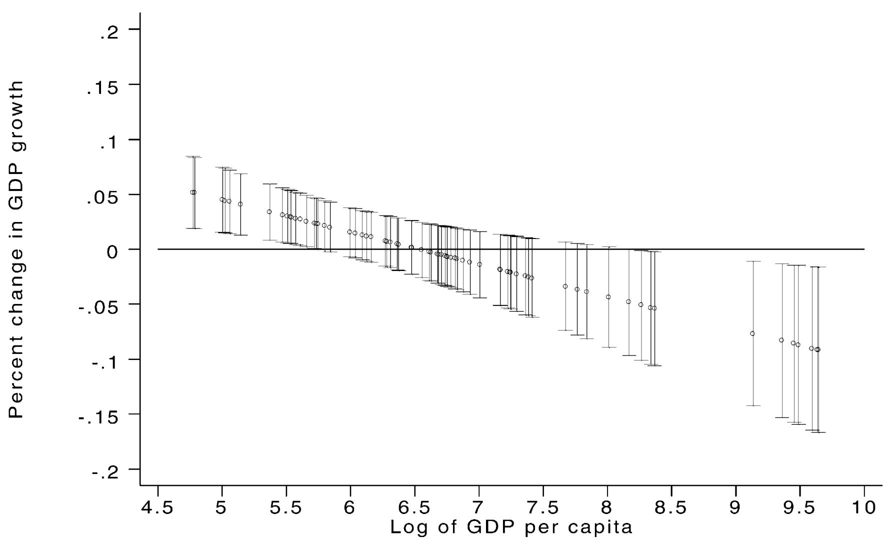

Fig. 3. Net effect and confidence intervals for a percent change in ASR on GDP growth rate using WDI GDP data and assuming exogenous explanatory variables.

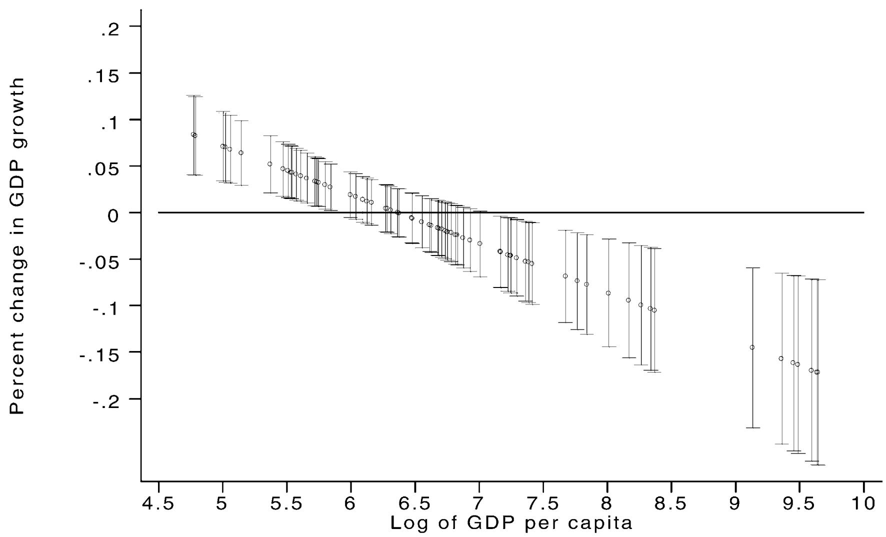

Fig. 4. Net effect and confidence intervals for a percent change in ASR on GDP growth rate using WDI GDP data and assuming GDP is a fully endogenous explanatory variable.

The results from PWT in Fig. 1 showed significant positive effects of ASR on growth rates until the logarithm of the GDP was approximately 6.81 (907 in 1985 international dollars); the corresponding estimate from specification 2 in Fig. 2 was very close. Once these points were crossed, the net effect of ASR approached zero and subsequently assumed negative values. Note, however, that the negative effects of ASR on growth rates were not statistically different from zero in Fig. 1. However, this was not true in Fig. 2, where the net effect was negative and significant for a few countries with high GDP levels.

The results using WDI GDP series in Figs. 3 and 4 were similar for low income countries, except that the threshold where the impact of ASR was zero, was reached earlier. Once the net effect of ASR turned negative, it was statistically significant for certain countries at the high end of the income distribution in Figs. 3 and 4. However, as noted in Section 3.1, this should not be construed as implying harmful effects of ASR on growth rates. Rather, some of the affluent countries, especially in Europe, had achieved high ASR while experiencing slower growth rates in the sample period, due to historical and institutional reasons. As discussed in Section 5, it would be useful to compile additional health indicators providing elaborate information especially in affluent settings.

4.3. Results for the test for reverse causality and parameter stability outside the sample period

The results for the model explaining ASR using the GDP data from PWT and WDI are presented in Table 3, under alternative exogeneity assumptions on lagged GDP levels and growth rates. The proportion of the area in the tropics and total fertility rate were significantly and negatively associated with ASR. Openness of the economy and the investment/GDP

Table 3
Tests for reverse causality based on the slope coefficients from static random effects models for log ASR in the period 1965–1990 at 5-year intervals using the data from PWT and WDI[a,b]

Variable	PWT		WDI	
	Specification 1	Specification 2	Specification 1	Specification 2
Constant	−0.852 (0.134)	−0.746 (0.211)	−0.435 (0.133)	−0.447 (0.237)
Tropics	−0.089 (0.028)	−0.091 (0.030)	−0.063 (0.032)	−0.060 (0.033)
Logarithm of fertility rate lagged 5 years	−0.058 (0.021)	−0.081 (0.030)	−0.126 (0.031)	−0.144 (0.048)
Logarithm of GDP lagged 5 years	0.087 (0.014)	0.078 (0.022)	0.050 (0.013)	0.055 (0.025)
Interaction between lagged GDP and growth rate	0.001 (0.070)	−0.025 (0.232)	−0.041 (0.101)	−0.382 (0.377)
Growth rate lagged 5 years	−0.258 (0.529)	−0.033 (1.765)	0.233 (0.680)	2.593 (2.578)
Chi-square (24) test for exogeneity of lagged GDP and growth rate	14.82		7.31	
Chi-square (8) test for exogeneity of means of lagged GDP and growth rate	4.83		3.02	
Number of countries	92	92	73	73
Number of time periods	4	4	4	4

[a] Specifications 1 and 2 treat lagged GDP and growth rate as exogenous and fully endogenous variables, respectively.
[b] Asymptotic standard errors are in parentheses.

ratios were not significant predictors of ASR; these variables were dropped from the model to reduce multi-collinearity. As expected, lagged GDP level was a significant predictor of ASR. By contrast, lagged GDP growth rate and the interaction between GDP level and growth rate were not statistically significant. The Chi-square statistics for the exogeneity null hypothesis of lagged GDP level and growth rate accepted the null. Overall, the results in Table 3 support the view that lagged GDP growth rates do not influence the current ASR, at least in the short time frame of 5 years. Consequently, the positive associations between ASR and GDP growth rates reported in Tables 1 and 2 are more likely to reflect causality running from ASR to growth rates for low income countries.

Further, because GDP data were available in the WDI for 1995 (the PWT data for 1995 are not as yet available), we applied the statistic W given in Eq. (7) to test the constancy of coefficients of the variables tropics, openness, lagged total fertility rate, investment/GDP ratio, ASR, interaction between ASR and GDP, and GDP in two situations. First, as in specification 1, these variables were assumed to be exogenous. In the second case, lagged GDP was treated as a fully endogenous variable (specification 2). The sample criteria for the W statistics in the two cases were 16.53 and 15.07, respectively. For a Chi-square variable with 7 d.f., the critical values at 5 and 2.5% are 14.1 and 16.0, respectively. Thus, the test assuming exogeneity of lagged GDP would reject the null hypothesis of parameter constancy at the conventional 5% level. The null would also be rejected using the parameter estimates from specification 2, though the sample criterion for the W statistics is somewhat closer to the 5% critical limit.

5. Conclusion

This paper modeled the proximate determinants of economic growth at 5-year intervals using panel data on GDP series based on purchasing power parities from the PWT and on exchange rate conversions from the WDI. In the conceptual framework of the analysis, the demographic literature relating life expectancy to income (Preston, 1976) was integrated with models commonly specified for economic growth (Barro and Sala-i-Martin, 1995). Appropriate econometric estimators and test procedures were used in the analysis to draw inferences. Although the health of individuals in a country can only be roughly approximated in national averages, the models showed significant effects of ASR on economic growth rates for low income countries. Thus, for example, for the poorest countries, a 1% change in ASR was associated with an approximate 0.05% increase in growth rate. While the magnitude of this coefficient was small, a similar increase of 1% in investment/GDP ratio was associated with a 0.014% increase in growth rate. A novel aspect of the analysis was that we estimated the threshold point beyond which ASR had typically negligible effects on growth rates; confidence intervals for the net impact of ASR highlighted the asymmetries for poor and rich countries (Figs. 1–4). Thus, for example, using the GDP data for 1990 from the PWT, the parameter estimates imply large positive effects of ASR on growth rates for countries in the sample such as Burkina Faso, Burundi and the Central African Republic. The positive effects were also significant for India, Ivory Coast and Nigeria. For highly developed countries such as USA, France and Switzerland, the estimated effect of ASR on growth rates was negative. These empirical findings in part result from the choice of the functional form, explanatory variables available for the analysis, and the standard errors of the estimated parameters.

From a conceptual standpoint, it is important that future research compile more elaborate data on health indicators. Thus, for example, ASR in poor countries reflects the levels of nutrition, smoking prevalence rates, infectious diseases, health infrastructure, and factors such as accidents leading to premature deaths. By contrast, differences in ASR in middle and high income countries may be influenced by genetic factors and by access to and costs of preventive and curative health care. Because investments in skill acquisition in poor countries depend on the ASR, the years for which skilled labor remains productive is likely to be important for explaining economic productivity. Furthermore, it would be useful to augment statistics such as percentages of skilled and unskilled labor compiled for countries (International Labour Organization, 1999) by measures of physical and mental health. For example, productivity loss due to ill health can be estimated from augmenting employment surveys with a health module. Measures of cognitive function in different age cohorts may also be useful for explaining economic performance of countries. Analyses based on elaborate data sets would afford sharper insights into the likely impact of health on economic growth.

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