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Evolution of recent economic-demographic modeling: A synthesis

Allen C. Kelley[1], **Robert M. Schmidt**[2]

[1] Duke University, Box 90097, Durham, NC, 27708-0097, USA
(e-mail: kelley@econ.duke.edu)
[2] Professor of Economics, Robins School of Business University of Richmond, Richmond, VA, 23173, USA (e-mail: rschmidt@richmond.edu)

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Abstract. This paper develops a flexible framework for modeling population's role in economic growth by assessing and extending a rendering suggested by several Harvard economists. Our framework includes a "productivity" model explaining output-per-worker growth and a "translation" model translating that growth into per-capita terms. We specify a core economic model and several "enriched" demographic variants that include dependency, size, and density. Regressions using a cross-country panel spanning the period 1960-1995 reveal that combined impacts of demographic change have accounted for approximately 20% of per capita output growth impacts, with larger shares in Asia and Europe.

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1. Introduction

Few issues in social history have attracted more attention than assessments of the economic consequences of rapid population growth. Debates have been vigorous and contentious. The primary evidence that has both stimulated and sustained these debates is cross-country regressions and simple correlations that expose the impacts of demographic variables on per capita output growth. A surprising result emerges: the overall impacts of demography are generally found to be small, especially for the decades of the 1960s and 1970s, although some negative impacts appear to emerge for the 1980s and possibly beyond (Kelley and Schmidt 1994). There are a number of reasons why the cross-country studies are inconclusive, not the least being their somewhat simple rendering of demographic processes.

Empirical analysis was enrichened in the 1990s with the emergence of a theoretical framework by Robert J. Barro that incorporates demography into convergence (or technology-gap) models. He and collaborators concluded that high fertility, population growth, and mortality all exert negative impacts on per capita output growth (Barro 1991, 1997; Barro and Lee 1994). Kelley and Schmidt (1994) extended this list to include population density and size, which revealed positive impacts, although a net negative assessment of combined demographic trends represented the bottom line.

The convergence modeling of demography evolved further in the late 1990s through a series of papers by several Harvard economists (e.g., Bloom and Williamson 1997, 1998; Bloom and Canning 2001, 2003; Radelet et al. 2001; and Bloom et al. 2000). Building on the Barro setup (albeit with a different choice of core variables), the Harvard framework focused on population impacts that take place due to imbalanced age-structure changes over the Demographic Transition. Their modeling compactly captured these impacts by just two variables: population growth (N_{gr}) and working-age growth (WA_{gr}). Such a specification neatly "translates" a traditional neoclassical model formulated in output per worker growth into a comparable model formulated in output per capita growth. While by construction such a translation derives from an identity, it is nevertheless a useful framework that provides a way of exposing some shorter-period "population impacts" within the usual long-run neoclassical framework. Such "translation" impacts of demography in numerous Harvard empirical papers are assessed to be sizeable, especially in East Asia.

Important to appraising these empirical findings is an understanding of the nature of the highlighted impacts of demographic translations. Although N_{gr} and WA_{gr} are introduced into these models primarily to translate per-worker into per-capita growth rates, they are often interpreted to play a role in the determination of the per-worker growth rate as well. Within the present paper, we build on the Harvard tradition by emphasizing the point that any per capita output growth rate can be separated into two components: an economic production (productivity) component and a translations component. We argue that these components are potentially separable and that clearer insights into the multi-faceted role of demography in economic growth can be gained by modeling them separately. In particular, such a rendering allows for the possibility that N_{gr} and WA_{gr} play little or no role in explaining productivity growth once the productivity component is modeled to include additional demographic variables. In this paper we take a hard look at these potentially separable components in a framework that provides reasonably clear, consistent, and interpretable empirical results with interesting policy implications.

The contributions of the present paper are several. First, we formulate an economic growth paradigm that highlights the separability of production and translations components. We identify quite distinct roles that demography might play within each component. We believe that this paradigm clarifies several specific ways in which economic and demographic change interconnect. We further believe that the modeling perspective developed in this paper need not be restricted to the particular empirical renderings chosen for this study. Indeed, our paradigm provides a potential platform for introducing alternative treatments of population into the modeling of economic growth.

Second, we evaluate this framework empirically using the Barro core. The results show that translations demography has little or no impact on economic production, *per se*, although the analysis of translations clarifies some welfare implications of demographic change. On net, demographic change elicits positive translations impacts over the full period in all regions. Such impacts, a byproduct of the Demographic Transition in many countries, are not uniformly positive over time. Our results indicate that the positive impacts relatively early in the Demographic Transition tend to turn negative during a later phase.

Third, we show that demography does matter within the productivity component, but primarily through linkages such as youth age structure, a variable highlighted in the literature of the 1950s–1980s. These demographic impacts on economic production, while notable, are not remarkable: Worldwide, demography accounts for around 8% of output per laborer, an impact with substantial regional variance spanning 3% in Africa to 28% in Asia. Demographic translations impacts are also sizeable (13%), but with smaller variance spanning 11% in South America to 16% in Asia. Overall, the results place demography's role as neither alarming nor benign. What has changed with the evolution of modeling in the 1990s is a clearer interpretation of the channels and sizes of demographic changes on the economy.

This paper has six sections. Section 2 provides an organizing framework that highlights the separability of impacts of demographic change on per-worker output growth from those of per-capita output growth. Section 3 assesses alternative ways of incorporating demography into the convergence model. Section 4 defends our preferred empirical paradigm that meshes the Barro core, the Harvard translations structure, and our own demographic enrichments. Section 5 examines the importance and alternative roles of demography in this framework; compares these results with other models in the literature; and arrives at empirical assessments that qualify the recent literature. Section 6 summarizes the paper's conclusions.

2. An organizing framework: Productivity and translations

We present in Eq. (1) an initial taxonomy for organizing an assessment of demographic change:

$$Y/N_{gr} \equiv \underbrace{Y/L_{gr}}_{\textit{Productivity Component}} + \underbrace{L_{gr} - N_{gr}}_{\textit{Translations Component}}, \tag{1}$$

which decomposes per capita output growth (Y/N_{gr}) into two components: (1) a labor productivity component (Y/L_{gr}) and (2) a translations component ($L_{gr} - N_{gr}$) that converts output growth per labor hour into output growth per person. Equation (1) derives from the identity, $Y/N \equiv (Y/L)(L/N)$. (See Bloom and Williamson 1998.)

Equation (1) is deceptively simple – it is, after all, an identity. We would argue, however, that recasting the Harvard model into separable productivity and translations components not only serves to clarify inconsistent demographic results found in previous empirical studies, but also provides a framework upon which further advances can be based. In this regard, note that this framework remains agnostic with respect to Eq. (1) the importance of the two components to per capita GDP growth rates and Eq. (2) the models chosen for either component. The present study builds upon, challenges, and enrichens the modeling of the Harvard studies. As such, we consider it a bridge between past and future demographic modeling. We begin by considering several candidates for the translations component.

2.1. Translations component

The translations component can take many forms. The one employed in most neoclassical theoretical modeling,

$$\textit{Translation I} \quad (L_{gr} - N_{gr}) = 0, \tag{2}$$

results in a focus on labor productivity due to the simplifying assumption that $L_{gr} = N_{gr}$. Population growth has no impact on per capita economic growth, *per se*, unless it has a direct impact on Y/L_{gr}. Such a framework is most relevant in the longer run (e.g., at or near a demographic steady state) or during conditions of slowly evolving demography, and less during conditions characterized by sizeable variations in L_{gr} and N_{gr} due to major changes in mortality and fertility.

A second translation takes full advantage of the components of labor change:

$$\textit{Translation II} \quad (L_{gr} - N_{gr}) = (L/LF)_{gr} + (LF/WA)_{gr} + WA_{gr} - N_{gr}, \tag{3}$$

where L = total labor hours, LF = laborers available for work, and WA = working-aged population. This expression reveals, in order, the impacts of changes in labor utilization rates (L/LF), labor force participation rates out of the working-age population (LF/WA), working ages (WA), and population (N). The last two terms represent demography, driven by changes in fertility, mortality, and migration. The other terms evolve from labor market conditions and household choices. While beyond the scope of this paper, this translation illuminates several potentially fruitful areas for future modeling, possibly within an endogenous framework. Consider the last three terms. While WA_{gr} is largely predetermined within our ten-year growth periods, changes in labor force participation out of the working ages [$(LF/WA)_{gr}$] as well as fertility and mortality changes (N_{gr}) need not be. An endogenous treatment of the interplay between fertility and female labor force participation could be intriguing in this context. Such modeling might incorporate macroeconomic renderings of the labor-leisure tradeoff as well as changes in public family planning programs and family structure over development.

A third translation, advanced by the Harvard scholars, focuses on the working age population (WA, say ages 15–64):

$$\textit{Translation III} \quad (L_{gr} - N_{gr}) = WA_{gr} - N_{gr}. \tag{4}$$

This formulation abstracts from labor force participation and employment rates. Because changes in the age distribution can be large and account for much of the variation in L, WA is a potentially useful proxy for labor force effects that occur over the Demographic Transition. We adopt this translation for the empirical work in this paper for two reasons. First, this translation provides a productive comparison between empirical results from the Harvard model and the extended model we propose. Second, and more important, within the ten-year growth periods employed in this paper, WA_{gr} is exogenous to the model while LF_{gr} is not. An endogenous modeling of labor force growth – and in particular one highlighting female labor force participation – is well beyond the scope of the present paper, especially given the problematic quality of labor force estimates.

Common to each of these specifications is the overriding lesson that the translations variables might have no impact on Y/L_{gr}. If that were the case, then their role would be mechanical in the sense that no econometric estimation would be necessary to estimate their net impact on Y/N_{gr} – it would be the unweighted difference between L_{gr} (however approximated) and N_{gr}. This does not imply that their quantitative impact need be small – their difference can be quite large, positive or negative, at various points during the Demographic Transition. However, we would argue that fuller modeling should include additional direct roles for demographic change on labor productivity growth – the variable highlighted in neoclassical growth theory. We expand on this distinction between direct “productivity” impacts and "translations" impacts in Sects. 3 and 4. Additionally, Sect. 4 provides empirical tests for productivity impacts of the translations variables while Sect. 5 presents estimates of the productivity and translations components on changes in Y/N_{gr}.

3. Expanding the theory: Elaborating the roles of demography

Prior to elaborating the roles of demography, Sect. 3.1 provides background on the convergence framework. Sect. 3.2 then assesses possible roles of demography in the productivity component of Eq. (1). Finally, Sect. 3.3 discusses another possible translations role that is not included in Eq. (1) – the translation of the convergence term itself from per worker into per capita terms.

3.1. The convergence framework for modeling productivity growth

The economic growth literature provides numerous ways to model productivity growth. We focus here on the “convergence” or “technology-gap” framework. Rooted in neoclassical growth theory, this paradigm explores the relationships between economic growth and the level of economic development. It focuses on the pace at which countries move from their current economic level to their long-run, or potential, or steady-state equilibrium level of output. (This section benefits from the presentation of Radelet et al. 2001 and Barro 1997).

The model begins by positing a convergence assumption:

$$Y/\mathrm{L}_{\mathrm{gr}_{\mathrm{it}}} = \mathrm{c}[\ln(\mathrm{Y/L_{it}})^* - \ln(\mathrm{Y/L_{it}})]. \tag{5}$$

Here the rate of output growth per worker ($\mathrm{Y/L_{gr}}$) is proportional to the gap between the logs of the long-run, steady-state $(\mathrm{Y/L})^*$ and the current (Y/L). The greater this gap, the greater are the gaps of physical capital, human capital, and/or technical efficiency from their potential levels. Large gaps allow for "catching up" through (physical and human) capital accumulation and technology creation and diffusion across, and within, countries.

The rate of convergence, c, is assumed to be independent of time and place. By contrast, potential output per worker $(\mathrm{Y/L_{it}})^*$ is specific to country (i) and time (t). This "conditional" convergence allows for the observed positive correlation between the level of development and economic growth rates. Were $\mathrm{Y/L}^*$ the same for all countries, the simple correlation would be negative. Were $\mathrm{Y/L}^*$ the same for all time periods, the world would eventually stop growing. Potential productivity is, of course, unobservable and must be modeled. Its log is modeled as a linear function of a vector of country- and time-specific characteristics:

$$\ln(\mathrm{Y/L_{it}})^* = \mathrm{a} + \mathrm{b}\,\mathrm{Z_{it}}. \tag{6}$$

The actual specification of the determinants of long-run labor productivity (i.e., the selection of Z's) varies notably, but the basic model, which combines Eqs. (5) and (6), is the same across scores of empirical studies:

$$Y/\mathrm{L}_{\mathrm{gr}_{\mathrm{it}}} = \mathrm{a}' + \mathrm{b}'\,\mathrm{Z_{it}} - c\,\ln(\mathrm{Y/L_{it}}), \tag{7}$$

where $\mathrm{a}' = \mathrm{ac}$ and $\mathrm{b}' = \mathrm{bc}$.

What types of Z variables should be included as determinants of long-run output per worker? Recognizing that a long-run, steady-state production function lies behind $\mathrm{Y/L^*_{it}}$, factors that influence long-run physical and human capital stocks, technology, and natural resource stocks should be considered. Barro (1997, Sect. I) additionally notes that endogenous growth theories that include the discovery and diffusion of new technologies suggest that $\mathrm{Y/L^*_{it}}$ depends upon "governmental actions such as taxation, maintenance of law and order, provision of infrastructure services, protection of intellectual property rights, and regulation of international trade, financial markets, and other aspects of the economy." Additionally, various authors have suggested access to ports, climate, education, health, and many other factors as possible influences.

More subtly, Eq. (5) provides additional insight. The invariance of the convergence parameter (c) across countries is consistent with a neoclassical view of efficient international capital markets. Simply stated, a neoclassical perspective models (physical and human) investment to flow fluidly within and across countries toward highest returns (e.g., to regions and countries with large gaps between potential and current Y/L). However, not all countries finance investment with equal ease. Thus, a second category of variables is added to the Z vector to "condition" the convergence rate, c. These variables include country- and time-specific factors that enhance or deter international capital flows, domestic saving, domestic investment, and/or migration. Included among these are, for example, restrictive licensing, the risk of expropriation, political conditions, the rule of law, migration regulations, and so forth.

Conspicuous by its absence from this list is the investment share in GDP. At first blush, investment might be the first variable one would think to include in a model of Y/L_{gr}. Indeed, Levine and Renelt (1992) surveyed numerous empirical growth studies to identify a common set of influential variables. They found investment rates to constitute the most robust variable. Rather than implying that the investment rate is a viable Z variable for predicting long-run capital-to-output ratios, however, its significance in a convergence model suggests an incomplete set of Z variables. If the convergence hypothesis is correct, the list of Z variables is complete, and factors enhancing or deterring the free flow of investment have been modeled, then the investment coefficient would be rendered largely moot. For a similar perspective see Bloom et al. (2000), Higgins and Williamson (1997), and Kelley and Schmidt (1994).

Finally, consider another subtlety of the model. Long-run, steady-state productivity is specified as being time-specific. Indeed, Radelet et al. (2001) develop the convergence model from an instantaneous growth perspective highlighting the idea that $(Y/L)^*_{it}$ changes for a country from one point in time to another. $(Y/L)^*_{it}$ might progress or regress as, for example, government tax policy changes. Since these models are estimated over a period of years, Z variables are typically calculated as period averages. (In some cases, beginning-of-period values are used as instruments for a variable, such as population size, which may be influenced by economic growth over a longer period). For greater depth on the technical details of convergence modeling, see Radelet et al. (2001).

3.2. Modeling the productivity component to account for demography

Are there roles for demography among the Z variables in the convergence model; or, put differently, how does demography influence the labor productivity component of definitional Eq. (1)? Consider first the translations variables themselves. Do N_{gr} and WA_{gr} influence productivity growth in addition to their role of translating productivity growth into per capita GDP growth? The potential for productivity effects of these variables has been advanced along several lines.

3.2.1. Measuring demographic impacts indirectly: N_{gr}, WA_{gr}

Within the neoclassical model, the steady-state levels of capital and output per worker depend upon the propensity to invest (or save in a closed economy), the growth rate of labor (or population if assumed to grow at the same rate), and the state of technology. In our context, this implies that WA_{gr} can play a role in the Z vector, holding the propensity to invest and technology constant. An economy can experience capital "deepening" when investment outpaces WA_{gr} or "shallowing" when WA_{gr} exceeds capital expansion. Can the economy attract sufficient investment to avoid capital shallowing in the face of a growing workforce? Some would argue that the answer to this question is driven largely by an institutional structure that facilitates entrepreneurial activity and the free flow of financial capital. For this reason, the Barro core of Z variables (discussed below) includes measures that represent his best efforts at proxying such impacts (government consumption, rate of inflation, a rule-of-law index, and a democracy index).

In a different vein, some analysts have justified the inclusion of (N_{gr} and WA_{gr}) to capture the impacts of "dependency" (the proportion of the population or work force in the youth and/or aged cohorts). Specifically, the impact of life-cycle consumption patterns on macroeconomic saving and investment levels can be large over the Demographic Transition due to swings in a country's age structure. Since the relative rates of N_{gr} and WA_{gr} influence dependency levels which in turn influence savings and investment which in turn influence the rate of an economy's productivity growth, then N_{gr} and WA_{gr} can indeed exert an effect on labor productivity. While true, an issue arises whether these two variables best capture such dependency effects. We argue probably not. The savings literature posits that it is the current level of youth and aged dependency that influences savings and investment rather than their rates of change. (See, for example, Kelley and Schmidt 1996; Higgins and Williamson 1997.) It would thus seem that while dependency effects are plausibly important, measuring their impacts directly, versus capturing them indirectly as correlates of the translations variables, represents a preferred empirical methodology, allowing, of course, for estimation of direct effects of the translations variables on labor productivity (if they exist) as well. This more direct approach to isolating the various impacts of demography is the tack we present below.

Some authors (e.g., Bloom and Canning 2001) have justified the inclusion of WA_{gr} for another reason: rapid labor force growth may result in a deterioration of labor force quality as workers with lower than average skills and experience are hired. Again, while true, an issue arises whether WA_{gr} is the best variable for capturing these impacts. For example, the Barro core already includes life expectancy and post-primary educational attainment of males ages 25 and over as human capital measures. Of course, it is arguable whether life expectancy primarily represents human capital. This issue is taken up in Sect. 4.1.

In short, various authors have advanced arguments for the inclusion of WA_{gr} among the Z variables; however, in at least two cases we would argue that other variables capture the posited effect more directly. We prefer to model those productivity effects explicitly and separately from the translations variables. Nevertheless, we agree with Bloom and Canning (2001) that the possibility N_{gr} and/or WA_{gr} exert an impact on Y/L_{gr} are hypotheses that can and should be tested directly. A pure translations role predicts coefficients of $+1$ and -1 for WA_{gr} and N_{gr}, respectively. Deviations from those values imply either an incomplete set of Z variables or productivity impacts. For example, each of the above arguments posits a negative productivity impact for WA_{gr}, implying a coefficient WA_{gr} lower than $+1$. This is a testable hypothesis.

On the other hand, if neither coefficient statistically differs from unity, we would prefer to constrain them to unity since this approach introduces clarity into the modeling of demography that has been absent from this literature. Indeed, a major contribution of the Harvard translations framework is to expose the "catch-all" nature of the N_{gr} variable included as the sole demographic measure in many studies. By introducing WA_{gr} (with N_{gr}) as a way of translating labor into per capita output growth, a clearer meaning for this variable is provided. However, to the extent that N_{gr} and WA_{gr} proxy additional demographic influences, the purity and usefulness of the framework is diminished. Such an outcome is minimized when those additional measures are explicitly included in the analysis. We next turn to some of these variables.

3.2.2. Measuring demographic impacts directly: D1, D2, N, Density

What demographic variables might have a direct (Z-variable) bearing on labor productivity growth? Of the various possibilities, three seem particularly promising. The first has already been mentioned. To the extent that a population's age structure (proxied here by dependency ratios: D1 = ratio of population aged 0–14 to those of working age 15–64 and D2 = ratio of population 65 + to those of working age) influences the rate of domestic saving (e.g., through life-cycle influences), then D1 and D2 can have both short- and long-run influences on productivity growth. The short-run influence is through facilitating or inhibiting the savings and investment necessary to close the gap of Eq. (5). The long-run influence is on Y/N^*. A basic lesson of the standard neoclassical growth model is that in long-run equilibrium, the savings level will affect the level of Y/N^* but not its rate of change. Modeling unobservable Y/N^* from currently observed variables is one challenge of convergence modeling, and dependency rates assist in this modeling.

Second, both the scale of production (population or labor force size), and density (population or labor force per unit of land), can exert an impact on long-run growth. It is in agriculture where the impacts of scale and density are most discussed. On the positive side, higher densities can decrease per unit costs and increase the efficiency of transportation, irrigation, extension services, markets, and communications. On the negative side, higher density may be associated with diminishing returns to land or deleterious effects of congestion. The predicted impact of rising population density on growth is ambiguous. We might note that the distribution of the population between urban and rural areas does not influence this density measure. Thus, the possibility of reverse causation where rapid economic growth encourages urbanization does not affect our density measure. With respect to population size, scale effects have been highlighted in earlier development studies, particularly with reference to specialization and diversification between firms. Recent endogenous growth models of technical change posit positive scale effects where an R&D industry produces a non-rival stock of knowledge. We predict a positive impact, holding density constant, of population size. Overall, evidence on scale and density effects is mixed and sparse.

3.3. Modeling a translations component for the convergence term

Equation (1) includes a component ($L_{gr} - N_{gr}$) that translates output growth from per-worker to per-capita terms. Equation (5) indicates that economic growth is slower the higher the initial level of labor productivity. Although theory dictates the specification of this "convergence" term in output per worker terms [$\ln(Y/L_{it})$], nearly all empirical models prefer to specify it in per-capita terms [$\ln(Y/N_{it})$]. To do so properly, however, the model should include another variable to translate the convergence term to per-capita terms. When completed, Eq. (5) would appear as Eq. (8).

$$Y/L_{gr_{it}} = c\ \ln(Y/L_{it})^* - c\ \ln(Y/N_{it}) + c\ \ln(L/N_{it}) \tag{8}$$

Thus, another translations term, $\ln(L/N_{it})$, must be included when the convergence term is specified in per-capita units. Surprisingly few empirical studies include such a term. To our knowledge the first study to do so was Bloom et al. (2000).

Having said that, however, we prefer not to employ the per-capita variant of Eq. (8) for our primary rendering, opting for the per-laborer variant of Eq. (5) instead. The two variants are equivalent unless $\ln(L/N_{it})$ plays a role beyond translations. While we can think of no compelling rationale for inclusion of $\ln(L/N_{it})$ in the productivity component of the model, we can for two of its correlates. Specifically, we argued previously that youth and aged dependency rates are plausible Z variables to the extent that they influence the domestic savings rate. Were Eq. (8) estimated without the dependency rates, the estimated coefficient for $\ln(L/N_{it})$ would include both translations and dependency impacts. Were we to include the dependency rates as well, we would introduce severe multicollinearity unnecessarily. (The simple correlations between WA/N, our variant of L/N, and D1 or D2 are −0.98 and 0.78, respectively). Equation (5)'s rendering coupled with dependency rates as Z variables thus provides clean translations and labor productivity interpretations of age-structure effects. We will return to this issue when we examine the empirical results in Sect. 4.2.

4. Toward an empirical rendering of demography and growth

Our preferred theoretical model is presented as Eq. (9), derived by substituting Eq. (7) into definitional Eq. (1). This formulation highlights two sets of Z variables – an "economic" core (Z_e) and a "demographic" core (Z_d) – that determine output per worker (Y/WA) in the long run. The rationale for selecting specific Z_d variables is considered in Sect. 3. Here we present the rationale for selecting specific Z_e variables; describe the data; set out estimation procedures; and present the results of alternative models that estimate the impacts of demography on growth.

$$Y/N_{gr_{it}} = a' + \underbrace{b'(Z_e + Z_d)_{it} - c\ln(Y/L_{it})}_{Productivity\,Model} + \underbrace{L_{gr_{it}} - N_{gr_{it}}}_{Translations\,Model} + d\kappa_i + e\tau_t + \varepsilon_{it}; \tag{9}$$

where κ_i provides for regional fixed effects, τ_t represents a period fixed effect allowing for exogenous shocks and ε_{it} represents an error term following the classical assumptions.

4.1. *Specifying Z_e's, data, and estimation*

Since the impact of demography on the economy can be influenced by the choice of Z_e variables, we are cautious in selecting the Z_e's. Furthermore, an extensive literature already exists in this area, including the pioneering work of Robert Barro (1997), whose core economic variables we elect to adopt without notable modification. While one can easily imagine alternative variables, suffice it to say that Barro's empirical inquiries have been expansive.

4.1.1. The economic Z_e's.

A brief justification of the economic variables follows; see Barro (1991, 1997) for more detail. Growth in output per capita is held to be positively related to:

(1) A lower initial level of productivity [*ln(Y/WA)*]. This convergence is posited to be more rapid in countries with higher levels of schooling attainment [*ln(Y/WA) •Ed*].
(2) Higher educational attainment for males ages twenty-five and over [*Ed*], which facilitates the absorption of new technologies.
(3) Higher life expectancy [$ln(e_0)$], a proxy for better health and human capital in general (Barro 1997). Note that the mortality patterns underlying life-expectancy calculations can influence life-cycle saving: e.g., rising e_0 can impact saving due to the financing of earlier or later retirement. (See Bloom et al. 2003, and Lee et al. 2001.) Note also that while life expectancy is a traditional demographic variable, it can still largely represent "health" if the demographic correlates of e_0 (e.g., N_{gr} versus WA_{gr}, youth and elderly dependency ratios) are held constant in the empirical modeling. We lean toward this *ceteris paribus* interpretation, but are open to reclassifying the impacts of e_0 between "economic" and "demographic" impacts in Sect. 5.
(4) Improvement in terms of trade [*TT% chg*], posited to generate added employment and income.
(5) A lower rate of inflation [*Inflation*], leading to a more stable investment climate and to better decisions with predictable price expectations.
(6) A lower government consumption share netted of education and defense spending [*Gcons/Y*], posited to release resources for more productive private investment.
(7) Stronger democratic institutions [*Democracy*] at low levels of democracy, which promote market activity by loosening autocratic controls. However, stronger democracies at high levels can dampen growth by the government exerting an increasingly active role in redistributing income. *Democracy* is thus entered in quadratic form, posited to rise and then fall.
(8) A stronger rule of law [*Rule Law*] which stimulates investment by promoting sanctity of contracts, security of property rights, etc.

4.1.2. The demographic Z_d's

As justified in Sect. 3, two demographic variables are posited as having negative impacts [*lnD1* and *lnD2,* youth and aged dependency ratios, respectively], one an uncertain impact [*Density* (1000 population per square kilometer)], and one a positive impact [*Size* (lnN)] on output growth per worker.

4.1.3. The data

The data comprise 86 countries and four growth periods (1960–70, 1970–80, 1980–90, 1990–95), resulting in a panel with 344 observations. Included countries have (a) market economies, (b) a production structure that is not dominated by raw material exports, (c) a population of at least one million in

1970, and (d) reasonably reliable data. Descriptive Statistics, data sources, and a country listing are presented in the Appendix.

4.1.4. Measuring L

We follow the Harvard studies and proxy L with WA (working-aged population, ages 15–64). The rationale for this choice is provided above in the discussion of Eqs. (3) and (4).

4.1.5. Estimation procedures

Following Barro (1991, 1997) we employ two-stage least-squares estimation, running period-specific first-stage regressions for *ln(Y/WA)*, *ln(Y/WA) •Ed*, *Inflation*, *Gcons/Y*, and *Democracy*. All rates of change are calculated as continuous rates over the period. *ln(Y/WA)*, *ln(Y/WA)•Ed*, *Ed*, $ln(e_0)$, *lnN*, and *Density* are beginning-of-period values. *Gcons/Y*, *Democracy*, *Rule Law*, *lnD1*, and *lnD2* are period averages. We include regional binaries for North and Central America, South America, Europe, Asia, and Oceania (with Africa in the intercept) to allow for possible cross-sectional fixed effects. A country listing by region is included in the appendix. Finally, we include period binaries for the 1970s, 1980s, and 1990s (i.e., period fixed effects with the 1960s in the intercept) to allow for exogenous shocks. Additional technical detail is provided in the Appendix.

4.2. Empirical results: Choosing among alternative specifications

Table 1 presents five alternative regression models that account for per capita output growth. Each shares the Barro Z_e economic core and each illustrates an alternative demographic setup designed to distinguish between Z_d variables (productivity impacts of demography) and translations variables.

(1) Model 1, termed *Simple Demography*, substitutes N_{gr} for the TFR in Barro's core. Using this model, we can ask: how do the impacts of population growth (N_{gr}) change with alternative modeling embellishments, and why?

(2–3) Models 2 and 3, termed *Translations Demography*, append a translations component in the manner of Harvard. Both models include lnWA/N and lnWA/N•Ed to translate the theoretical convergence terms (lnY/WA and lnY/WA•Ed) into the analogues typically used in estimation (lnY/N and lnY/N•Ed). Additionally, model 2 includes N_{gr} and WA_{gr} to translate per worker growth rates (Y/WA_{gr}) into its more typical per capita variant (Y/N_{gr}). Thus, demography is not explicitly modeled as having long-run productivity impacts. However, any of these coefficients could deviate from its translations' prediction (e.g., WA_{gr} and/or N_{gr} could deviate from 1 or −1) if it either has direct long-term impacts, or if the model is specified incompletely (e.g., if the translations variables are correlated with omitted impacts of demography).

By contrast, model 3 specifies Y/WA_{gr} as the dependent variable (model 2 employs Y/N_{gr}). Having removed their translations role, Model 3's inclusion

Table 1. Empirical results for five demographic specifications

Dep. var.	Simple demography	Translations demography		Enriched demography	
	Y/N_{gr} (1)	Y/N_{gr} (2)	Y/WA_{gr} (3)	Y/WA_{gr} (4)	Y/WA_{gr} (5)
Productivity model					
Convergence					
lnY/ N (1–3)	−1.19***	−1.18***	−1.18***	−1.31***	−1.26***
lnY/WA (4–5)	(4.27)	(4.30)	(4.30)	(4.63)	(4.47)
lnWA/N		11.56***	11.56***		
		(4.77)	(4.77)		
ln(Y/N)•Ed (1–3)	−0.04	0.00	0.00	−0.08	−0.03
ln(Y/WA)•Ed (4-5)	(0.30)	(0.02)	(0.02)	(0.51)	(0.18)
lnWA/N•Ed		0.27	0.27		
		(0.14)	(0.14)		
Z_e: Economic core					
TT %chg	0.16***	0.15***	0.15***	0.14***	0.15***
	(5.13)	(5.16)	(5.16)	(4.92)	(5.20)
Gcons/Y	−0.11**	−0.06	−0.06	−0.07*	−0.07*
	(2.01)	(1.17)	(1.17)	(1.35)	(1.40)
Inflation	−0.04***	−0.04***	−0.04***	−0.04***	−0.04***
	(4.80)	(4.51)	(4.51)	(4.63)	(4.77)
ln(e_0)	6.51***	4.49***	4.49***	4.40***	5.22***
	(4.92)	(3.56)	(3.56)	(3.14)	(3.99)
MaleEduc	0.38	0.17	0.17	0.23	0.20
	(1.50)	(0.71)	(0.71)	(0.95)	(0.83)
Rule law	2.42***	1.93**	1.94**	2.04**	2.03**
	(2.50)	(2.15)	(2.15)	(2.18)	(2.13)
Democracy	7.99***	5.15**	5.16**	5.68***	6.28***
	(3.33)	(2.31)	(2.31)	(2.49)	(2.69)
Democracy ˆ2	−8.41***	−6.11***	−6.12***	−6.57***	−7.10***
	(3.79)	(2.94)	(2.95)	(3.03)	(3.20)
Z_d: Demographic core					
lnD1				−2.95***	−2.17***
				(3.45)	(2.99)
lnD2				0.01	−0.32
				(0.01)	(0.58)
Dns				0.14	0.15
				(0.66)	(0.69)
lnN				0.10	0.10
				(0.99)	(1.04)
Translations model					
	N_{gr}	−0.29**	−1.12***	−0.12	0.13
	(1.71)	(3.63)	(0.40)	(0.40)	
WA_{gr}		1.51***	0.51*	0.23	
		(4.96)	(1.68)	(0.75)	
Exogenous influences					
Regional fixed effects					
N&C Amer	−0.01	0.26	0.26	0.34	0.22
	(0.01)	(0.62)	(0.62)	(0.78)	(0.51)
SAmerica	1.24**	1.24**	1.24**	1.29***	1.32***
	(2.37)	(2.57)	(2.57)	(2.61)	(2.61)
Europe	0.91	1.12**	1.12**	0.76	0.70
	(1.55)	(2.04)	(2.04)	(1.32)	(1.20)
Asia	1.47***	1.35***	1.35***	1.27***	1.21***
	(3.78)	(3.72)	(3.72)	(3.39)	(3.19)

Table 1 (continued)

Dep. var.	Simple demography	Translations demography		Enriched demography	
	Y/N_{gr} (1)	Y/N_{gr} (2)	Y/WA_{gr} (3)	Y/WA_{gr} (4)	Y/WA_{gr} (5)
Oceania	0.87	0.61	0.61	0.96	0.89
	(1.23)	(0.92)	(0.92)	(1.44)	(1.31)
Period fixed effects					
Pd:70–80	−0.47	−0.91***	−0.91***	−0.98***	−0.91***
	(1.36)	(2.68)	(2.68)	(2.91)	(2.76)
Pd:80–90	−1.83***	−2.37***	−2.37***	−2.47***	−2.37***
	(4.81)	(6.41)	(6.40)	(6.65)	(6.44)
Pd:90–95	−2.27***	−2.84***	−2.84***	−2.87***	−2.83***
	(5.80)	(7.48)	(7.48)	(7.47)	(7.35)
Intercept					
Constant	−23.95***	−9.80	−9.79	−3.78	−9.03
	(4.59)	(1.83)	(1.83)	(0.54)	(1.41)
R Squared	0.55	0.61	0.60	0.59	0.58
Adj R-Sq.	0.53	0.58	0.57	0.56	0.56
Std error	1.88	1.74	1.74	1.76	1.78
# of Obs	344	344	344	344	344

* Denotes 10% significance, ** denotes 5% significance, and *** denotes 1% significance for the appropriate 1- or 2-tailed test. t-values are in parentheses. Descriptive statistics, the country sample, and estimation details are provided in the appendix. Note that the change of dependent variable between models 2 and 3 eliminates the need for "translations". By definition, the coefficients for N_{gr} and WA_{gr} in model 3 are those of model 2 minus the translations values of −1 and +1, respectively. Within the limits of estimation precision, all other coefficients and t-values are identical.

of N_{gr} and WA_{gr} provides an explicit test for direct productivity impacts. A statistically significant coefficient for N_{gr} and/or WA_{gr} would indicate a role beyond translations, perhaps for one of the reasons discussed in Sect. 3 above.

(4–5) Models 4 and 5, termed *Enriched Demography*, append four demographic variables (Z_d = lnD1, lnD2, Density, lnN) that have the potential for influencing long-run output per worker. Additionally, Model 4 constrains two translations parameters (lnWA/N and lnWA/N•Ed) to their theoretical expectations in a translations framework while Model 5 constrains all four (also N_{gr} and WA_{gr}).

4.2.1. Overall fit and economic core results

The convergence framework appears to be a reasonable paradigm for assessing the roles of demography. The models fit the data satisfactorily with R^2's ranging from 55% to 61%. All economic core variables are of the expected sign and nine of those twelve variables are significant at the five-percent level in each of the five variants. Over half of the coefficients are significant at the one-percent level. Two variables are never significant (the convergence term's interaction with education and the education variable itself) and one variable (government consumption's share in GDP) is significant at the 5% level in the simplest demographic variant and at the 10% in the enriched demographic variants. For the most part, the Z_e

variables are not particularly sensitive to the demographic specification either in coefficient magnitude or in statistical significance.

4.2.2. Demography results: Translations

Considering first Model 1, we observe that population growth (N_{gr}) has a negative impact on per capita output growth which almost quadruples (it declines from −0.29 to −1.12) when working age growth (WA_{gr}) is taken into account (see Model 2). Presumably WA_{gr}'s positive impacts are incorporated into the estimated coefficient on N_{gr} in Model 1, muddying the measurement of population's impact (see also Bloom and Williamson 1997). Such a result plausibly accounts for the mixed results of N_{gr} across numerous empirical studies. Thus, while in those studies population growth may well have mattered, impacts were offsetting because the frameworks were excessively parsimonious. Kelley (1988, p. 1701) observes that such results "…provide little *prima facie* information about the size and nature of the net impact…". Kelley and Schmidt (1995, p. 545) further argue that the non-significant result "…does not mean that demographic processes are unimportant; … may imply that strong intertemporal demographic effects are offsetting."

Turning to the Harvard translations model (Number 2 in Table 1) in which N_{gr} and WA_{gr} are included to translate per worker into per capita growth, note that N_{gr} does not play a role beyond pure translation. That is, its coefficient is not statistically different from −1 at the 10% level (the *p-value* from that test, not included in the table, is 0.689). By contrast, WA_{gr}'s coefficient of 1.51 is notably larger than the pure translations coefficient of +1 and that discrepancy is significant at the 10% level (*p-value* of 0.094). Model 3 makes these points more directly since it eliminates the need for such translation by using Y/WA_{gr} rather than Y/N_{gr} as the dependent variable. In this variant, the coefficient on N_{gr} does not differ significantly from zero while that for WA_{gr} is positive (0.51) and significant at the 10% level.

This latter result is quite surprising in light of the discussion of Sect. 3.2.1 that provides three separate rationales for including WA_{gr} in the labor productivity model. While each of those arguments implied a negative impact on productivity growth, the estimated impact here is positive, quantitatively notable, and statistically significant at the 10% level. We believe this perverse outcome to be the result of omitted variable bias. We argued in Sect. 3.2.1 that the savings influence attributed to WA_{gr} might be captured better by direct measures of the age-structure. We have done that in model 4 which enriches the Harvard model by adding youth and elderly dependency ratios, lnD1 and lnD2, as well as density (Dns) and population size (lnN). In model 4, the perverse estimate disappears – the coefficient for WA_{gr} drops to 0.23 and it is insignificant at the 10% level (t-value of 0.75). In model 4, neither N_{gr} nor WA_{gr} plays any significant role beyond translations.

A surprising story emerges as well for the translations variable lnWA/N, included in models 2 and 3, to translate the convergence term from lnY/WA to lnY/N. Its coefficient (11.56) differs statistically and substantively from its translations prediction of the negative of the convergence term (–1.18). Although this result is not new to the literature (see for example Bloom et al. Malaney 2000), the striking disparity between the coefficients has not been explained satisfactorily. As was the case with WA_{gr}, we would argue that this disparity is likely the result of omitted variable bias rather than an impact of WA/N on long-run, steady-state productivity.

We have suggested a theoretical reason in Sect. 3 for including two correlates of lnWA/N, the youth and elderly dependency ratios (lnD1 and lnD2), in the productivity model. We believe that their omission from the model has resulted in a coefficient estimate for lnWA/N that is dramatically different from the convergence coefficient. Unfortunately, we cannot include all three variables in the model due to the high correlations between lnWA/N and lnD1 (–0.96) as well as lnD2 (0.79). We have taken a different tack. Models 4 and 5 utilize lnY/WA as the convergence term rather than lnY/N in conjunction with lnWA/N. Neither variant is preferable theoretically and to our knowledge no empirical growth model has included lnWA/N among Z vector influences on the steady-state productivity level. Having eliminated the need for inclusion of lnWA/N, models 4 and 5 do include youth and elderly dependency ratios as well as additional demographic variables.

4.2.3. Demography results: Z_d variables

We turn finally to the productivity roles demography might play in the Barro convergence model. Models 4 and 5, denoted as enriched demography, append four demographic variables to the list of variables influencing an economy's long-term productivity level. This Z_d vector includes lnD1, lnD2, Density, and lnN. While each carries its predicted sign, only lnD1 is significant (at the 1% level). Moreover, the coefficients on lnD1 appear to be large. Of course, the relative importance of the various variables cannot be determined solely by reference to their coefficients. As a result, Sect. 5 assesses the magnitude of these impacts in the context of the world's experience.

Before turning to that, however, consider again the key theoretical insight of Sect. 3 and an empirical lesson of Sect. 4. Demography plays multifaceted roles in the economy. Certain influences are negative while others are positive; and some are felt immediately while others are felt with lags of 10, 15, 20 or more years. But all are interrelated. Consequently, modeling demographic effects by any single variable such as N_{gr} is overly simplistic and potentially misleading. Moreover, these influences are separable into two distinct categories – a translations set (N_{gr} and WA_{gr}) and a productivity set (in our rendering, lnD1, lnD2, Density, and lnN). Furthermore, this dichotomy is pure in the sense that the results from Models 3 and 4 demonstrate no productivity influence of the translations variables. Indeed, the more demographic detail incorporated into the model, the more sharply separable are the two models.

Finally, the finding of a strong and significant coefficient for lnD1 provides insight into the interpretation of the translations demography in convergence modeling. Specifically, in terms of theory, the impacts of the age-distribution on the saving rate (S/Y), and thus Y/N_{gr}, are typically specified in terms of the age-structure *levels*, such as dependency rates or similar summary measures. Thus, while dependency is correlated with the *growth rates* of population and the working-age population, the appropriate analytical connection is arguably better measured as dependency levels. This point is made most forcefully for WA_{gr}. Its productivity impact when lnD1 is excluded (col. 3) is estimated to be 0.51 and significant at the 10% level, two-tail. That impact falls to 0.23 and insignificance with the inclusion of the extended demography (col. 4). In short, adding lnD1 in the Barro core tends to provide more plausible estimates of the translations variables. For further elaboration of saving's role, see Mason (1988), Higgins and Williamson (1997), and Lee et al. (2001).

5. Demography matters: But how, and by how much?

A common methodology for assessing impacts within a regression model is to apply estimated coefficients to period means of the corresponding variables. However, assessing the "importance" of demographic trends must account not only for the size of the coefficients and mean levels of the variables, but also for changes in the variables over time. Such a reckoning is compiled in Table 2 which applies the regression coefficients from model 5 of Table 1 (our preferred rendering) to *changes* in mean values across decades, thereby estimating impacts on interdecade changes in Y/N_{gr}.

Table 2 groups impacts into broad categories denoted as "productivity model" (convergence, Z_e: economic core, and Z_d: demographic core), "translations model," or "exogenous influences" (period fixed effects). The table presents these results first for our "world" sample as well as for five regions (North and Central America, South America, Europe, Africa, and Asia) as described in the appendix. Given the extensive results in Table 2, we focus initially in Sect. 5.1 on net impacts of the major components of the model. Section 5.2 provides additional detail by assessing contributions from the variables within those components. Finally, Sect. 5.3 summarizes the major lessons and provides bottom line estimates of the relative contributions of the various influences.

5.1. Broad conclusions from the world and regional samples

Table 2 provides some interesting insights into trends during the last four decades of the twentieth century and in the process provides a warning against over-aggregation. For example, were we to focus exclusively on the world's "average" column (the equivalent of estimating from a single 35-year cross-section) and the five variable groupings, we would conclude that both the core demographic trends (0.18) and the demographic translations (0.14) have dominated the impact of the economic trends (0.08) on Y/N_{gr} changes. Furthermore, at –0.94, exogenous shocks have had several times the impact of the economic and demographic core variables. These conclusions hold across all regions except Asia where economic impacts (0.55) dominated the demographic core (0.28) and translations (0.14). While interesting, these generalizations conceal considerable variability across the individual decades and regions.

Consider first, time patterns in the global aggregates. Worldwide, positive economic impacts (Z_e) between the 1980s and 1990s (0.58) reversed two decades of growth-inhibiting trends (0.05 and –0.29). By contrast, demographic trends have been consistently growth enhancing. Thus, while Y/N_{gr} declined notably between the 1960s and 1970s and again between the 1970s and 1980s, those declines would have been even larger without the ameliorating impacts of favorable demographic trends. While the positive impacts of changes in the demographic core (Z_d) displayed no obvious trend over time (0.09, 0.26, 0.18),

Table 2. Accounting for changes in Y/N_{gr} over time: Impacts of interdecade change

	World sample				North & Central America				South America			
	1960s to 70s	1970s to 80s	1980s to 90s	Avg	1960s to 70s	1970s to 80s	1980s to 90s	Avg	1960s to 70s	1970s to 80s	1980s to 90s	Avg
Change in Y/N_{gr}	**−0.84**	**−1.73**	**0.28**	**−0.77**	**−1.15**	**−2.44**	**1.02**	**−0.86**	**0.27**	**−3.58**	**3.31**	**0.00**
						Productivity model						
Convergence	**−0.38**	**−0.26**	**−0.03**	**−0.22**	**−0.36**	**−0.18**	**0.14**	**−0.13**	**−0.28**	**−0.27**	**0.17**	**−0.13**
Z_e: Economic core	**−0.05**	**−0.29**	**0.58**	**0.08**	**−0.38**	**−0.75**	**1.48**	**0.12**	**−0.26**	**−1.82**	**1.56**	**−0.17**
Financial	−0.34	−0.66	0.19	−0.27	−0.67	−1.03	0.83	−0.29	−0.71	−2.03	1.30	−0.48
Human K: $\ln(e_0)$	0.37	0.35	0.28	0.33	0.45	0.36	0.34	0.38	0.32	0.35	0.29	0.32
Human K: Male Educ	0.06	0.09	0.07	0.07	0.06	0.11	0.08	0.08	0.02	0.09	0.04	0.05
Political	−0.13	−0.07	0.04	−0.05	−0.22	−0.19	0.23	−0.06	0.12	−0.23	−0.07	−0.06
Z_d: Demographic core	**0.09**	**0.26**	**0.18**	**0.18**	**0.16**	**0.34**	**0.22**	**0.24**	**0.15**	**0.26**	**0.19**	**0.20**
lnD1	0.08	0.24	0.17	0.17	0.14	0.32	0.21	0.22	0.13	0.24	0.18	0.18
lnD2	−0.02	−0.01	−0.01	−0.01	−0.01	−0.01	−0.01	−0.01	−0.01	0.00	−0.01	−0.01
Dns	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
lnN	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02
						Translations model						
Demographic translations	**0.40**	**0.02**	**0.01**	**0.14**	**0.62**	**−0.03**	**−0.02**	**0.19**	**0.46**	**−0.09**	**0.07**	**0.15**
N_{gr}	0.13	0.14	0.19	0.15	0.29	0.23	0.05	0.19	0.24	0.26	0.17	0.22
WA_{gr}	0.27	−0.12	−0.17	−0.01	0.33	−0.25	−0.06	0.00	0.22	−0.35	−0.10	−0.08
						Exogenous influences						
Period fixed effects	**−0.91**	**−1.47**	**−0.46**	**−0.94**	**−0.91**	**−1.47**	**−0.46**	**−0.94**	**−0.91**	**−1.47**	**−0.46**	**−0.94**

Table 2. (continued)

	Europe				Africa				Asia			
	1960s to 70s	1970s to 80s	1980s to 90s	Avg	1960s to 70s	1970s to 80s	1980s to 90s	Avg	1960s to 70s	1970s to 80s	1980s to 90s	Avg
Change in Y/N_{gr}	**−1.55**	**−0.48**	**−1.21**	**−1.08**	**−0.90**	**−2.30**	**−0.81**	**−1.34**	**−0.23**	**−0.84**	**0.74**	**−0.11**
						Productivity Model						
Convergence	**−0.53**	**−0.33**	**−0.24**	**−0.37**	**−0.28**	**−0.16**	**0.14**	**−0.10**	**−0.47**	**−0.41**	**−0.33**	**−0.40**
Z_e: Economic core	**−0.39**	**0.38**	**0.09**	**0.03**	**−0.15**	**−0.26**	**−0.07**	**−0.16**	**0.77**	**0.07**	**0.82**	**0.55**
Financial	−0.67	0.21	−0.13	−0.20	−0.20	−0.80	−0.47	−0.49	0.20	−0.43	0.32	0.03
Human K: $\ln(e_0)$	0.14	0.18	0.15	0.16	0.46	0.43	0.28	0.39	0.43	0.41	0.38	0.41
Human K: Male Educ	0.12	0.17	0.08	0.12	0.02	0.03	0.05	0.03	0.06	0.10	0.10	0.09
Political	0.01	−0.18	−0.01	−0.06	−0.43	0.08	0.06	−0.09	0.08	−0.02	0.01	0.03
Z_d: Demographic core	**0.06**	**0.43**	**0.23**	**0.24**	**−0.04**	**0.03**	**0.09**	**0.03**	**0.22**	**0.36**	**0.26**	**0.28**
lnD1	0.10	0.44	0.24	0.26	−0.06	0.01	0.06	0.00	0.20	0.33	0.25	0.26
lnD2	−0.05	−0.01	−0.02	−0.03	0.00	0.00	0.00	0.00	−0.02	−0.02	−0.03	−0.02
Dns	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02
lnN	0.01	0.01	0.00	0.01	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02
						Translations model						
Demographic translations	**0.34**	**0.18**	**−0.26**	**0.08**	**0.24**	**0.10**	**0.21**	**0.18**	**0.53**	**−0.14**	**0.03**	**0.14**
N_{gr}	0.19	0.21	−0.13	0.09	−0.11	−0.11	0.50	0.09	0.18	0.31	0.18	0.23
WA_{gr}	0.14	−0.03	−0.13	−0.01	0.35	0.22	−0.29	0.09	0.34	−0.46	−0.15	−0.09
						Exogenous influences						
Period fixed effects	**−0.91**	**−1.47**	**−0.46**	**−0.94**	**−0.91**	**−1.47**	**−0.46**	**−0.94**	**−0.91**	**−1.47**	**−0.46**	**−0.94**

Notes: "Convergence" includes initial economic level and its interaction with education; "Financial" includes terms of trade, government consumption share, and inflation; separate "Human Capital" rows are included for the reader who prefers to treat life expectancy as a demographic variable; and "Political" includes rule of law and democracy. Exogenous impacts include only period fixed effects and are the same for all regions since the regional fixed effects and the intercept are constant across decades. By definition, regression impacts will add up (except for rounding) to "Change in Y/N_{gr}" for each World sample column but not for the regional columns. The calculations are based on col. 5, table 1, augmented by the theoretically specified coefficients for Ngr and WAgr, −1 and +1, respectively. While Oceania is not included as a separate region in this table, its three countries are included in the worldwide sample.

a favorable net trend in the demographic translations variables was largely exhausted in the 1970s (0.40, 0.02, 0.01), a fascinating finding.

How do these global conclusions fare across the regions of the world? The Americas follow the worldwide Z_e pattern with South American countries experiencing the largest negative (–1.82) and positive (1.56) impacts. While Africa suffered negative Z_e impacts throughout, positive impacts were enjoyed in Europe in two periods and in Asia in all three periods. By contrast, the regions followed global demographic patterns quite well. Trends in the Z_d variables contributed positively and notably to growth throughout the period in four of the five regions. As is the case worldwide, favorable impacts from the translations variables were largely exhausted in the 1970s in the same four regions. Indeed, in each of those regions, translations impacts were negative in at least one of the last two periods. Africa displays demographic impacts different from the other regions because of stubbornly high fertility rates throughout most of the period. Correspondingly, translations impacts are smaller initially but remain positive and are nearly as large in the last period as in the first (0.24, 0.10, 0.21). On the other hand, Zd impacts are quite small in Africa, starting out negative but rising gradually (–0.04, 0.03, 0.09).

Finally, briefly consider the impacts of "convergence" and exogenous influences. Since the log level of per worker income (lnY/WA) is inversely related to Y/N_{gr}, the estimated convergence impact will be negative between any two decades of growth in lnY/WA and positive after a decline. For the world as a whole and in three of the five regions, convergence had a negative impact during the first two periods because economic growth dictated higher lnY/WA in 1970 than 1960 and 1980 than 1970, but a positive impact due to the widespread decline over the 1980s resulting in a lower Y/WA in 1990 than 1980. Europe and Asia bucked this trend, enjoying growth in every decade – implying negative convergence impacts in all three periods. Humbling to the growth literature is the role played by the largely unexplained exogenous factors. They exert the largest influences in Table 2 and they are consistently negative. (Note that exogenous impacts are the same across all regions because regional fixed effects are held constant across all periods and thus drop out when interdecade changes are calculated.)

5.2. Digging deeper into components of Z_e, Z_d, and translations

A review of the components of these broad categories enriches this analysis further, both temporally and spatially. Within the economic core, trends in human capital (life expectancy and education) have been strongly growth inducing globally (0.43, 0.44, 0.35) as well as in every region. That consistency is not found in the financial (terms of trade, government consumption, and inflation) and political (rule of law and democracy) components whose combined negative impacts more than offset these gains in the first two periods before enhancing the gains with favorable impacts in the last period. This worldwide trend (–0.34, –0.66, 0.19) was largely followed in North and Central America (–0.67, –1.03, 0.83) and South America (–0.71, –2.03, 1.30), but not in Africa which suffered throughout (–0.20, –0.80, –0.47) or in Europe (–0.67, 0.21, –0.13) and Asia (0.20, 0.43, 0.32) which enjoyed positive impacts in one of the earlier periods. The largest negative *and* positive financial impacts were experienced in South America, followed by North and Central

America (acknowledging that this model is not designed to fully capture the Asian monetary crisis of the late 1980s). While the political component is the least influential worldwide (–0.13, –0.07, 0.04), this is the net result of advances and retreats regionally. For example, while South America made strides in the political arena between the 1960s and 1970s, this region fell back in the latter two periods (0.12, –0.23, –0.07). Africa demonstrated the opposite pattern (–0.43, 0.08, 0.06) following the ending of the colonial era in Africa.

Turning to demography, several interesting results emerge. First, youth dependency (lnD1) strongly dominates other components of the demographic core (lnD2, lnN, Dns) in influence on Y/N_{gr} trends, and its impact has been consistently positive. This is true in every region of the world with the exception of Africa where, because of delayed fertility declines, youth dependency has remained high throughout the latter half of the twentieth century. By contrast, aged dependency has had a negligible effect to date. The impacts of aging may well reveal themselves as the twenty-first century progresses. Large youth dependency ratios have already been observed and their impacts can therefore be estimated. By contrast, the largest elderly dependency ratios lie in the future and those effects cannot be estimated well from this sample.

Second, the positive economic impacts of the demographic core could be enhanced considerably in all regions and in all periods depending upon how much of the gains from rising life expectancy one ascribes to demography rather than to human capital. As we argued earlier, we believe that the demographic side of life expectancy impacts is largely controlled for within this model by other demographic indicators. On the other hand, were an analyst to disagree and impute all life expectancy impacts to demography, the effect on Z_d impacts would be substantial.

Third, within the Translations Model, declining population growth (N_{gr}) positively impacted trends in Y/N_{gr} relative to Y/WA_{gr} throughout the last four decades of the twentieth century worldwide and in three of the five regions of Table 2. The exceptions are Africa in the first two periods for reasons discussed above and Europe in the last period. Trends in the growth of the working-age population (WA_{gr}) enhanced Y/N_{gr} change six times in the first two periods but not a single time since.

In short, the prevailing pattern throughout the world of a positive and strong net translations impact between the 1960s and 1970s followed by small and even negative net impacts in the latter two periods has to date been driven largely by initially strong but eventually declining growth rates of the working age population. Again, the notable exception is Africa where, subject to the ravages of HIV-AIDS, such a period might lie ahead as these countries pass through the various phases of the Demographic Transition.

5.3. Summary lessons and bottom-line calculations

What lessons can be learned from the rich regional detail of Table 2? First, demography can and has exerted quantitatively large impacts on changes in Y/N_{gr}, especially if one combines the impacts of both core and translations demography (and even more if one includes life expectancy in the demographic core).

Second, the translations impacts trace out a fairly consistent pattern following a fertility boom and decline (for example, over the course of the

Demographic Transition) of: 1) strong positive impacts (as N_{gr} declines from lower fertility while WA_{gr} rises from earlier high fertility), 2) small impacts, and possibly negative impacts (as N_{gr} stabilizes and WA_{gr} eventually slows due to earlier fertility declines). This result both qualifies and elaborates the renderings of the recent literature. The magnitude and timing of these impacts can vary dramatically across countries and regions. Africa (with a delayed transition and positive impacts throughout the period) and Asia (with a rapid transition in key countries and negative impacts by the second period) provide stark contrasts in this regard. Third, the demographic core variables, especially youth dependency, change more slowly and therefore exert their influences over longer periods than do the translations variables. For this reason, we argue the importance of a richer modeling of demographic change to an improved understanding of economic change.

Having said all of this, we remain curious about the relative contributions of the various influences to variability in Y/N_{gr} changes around the world. Table 2 is inadequate for this task since Y/N_{gr} changes derive from variables that have both positive and negative impacts. As a result, Y/N_{gr} change can be quite small by comparison to its component influences. (See, for example, the 1980s to 1990s in Table 2.) The net value masks considerable "economic activity" which can be negative as well as positive. As an alternative approach, we have computed component shares in total "movements" – the sum of the unsigned impacts of all variables (including the exogenous variables that result from period shifts in events like OPEC, debt overhang, etc.). These movements are shown in Table 3. For the world sample, core demography accounts for 8% of total movements across the interdecade periods. Amongst the other factors, human capital (education, health) and financial/economic factors have the most important impacts (16% and 15% respectively), followed by demographic translations (13%), the convergence adjustments (9%), and politics (4%). As previously noted, exogenous factors dominate interdecade changes (36%).

As can be seen in Table 3, these figures vary notably by region. (They can also vary over time and by the degree of disaggregation, justifying caution in interpreting the results.) However, the general conclusion that "demography matters is beyond dispute and holds everywhere: in the aggregate it varies from 8% of "movements" in the demographic core, to 21% if translations

Table 3. Accounting for changes in Y/N_{gr} over time: Percentage shares in total movements

	World Sample	N & C America	South America	Europe	Africa	Asia
		Productivity model				
Convergence	**9**	**7**	**6**	**13**	**7**	**12**
Z_e: Economic core	**35**	**46**	**55**	**35**	**43**	**34**
Financial	15	25	35	16	21	13
Human K: $\ln(e_0)$	13	11	8	5	13	12
Human K: Male Educ	3	2	1	4	1	3
Political	4	7	10	9	8	7
Z_d: Demographic core	**8**	**8**	**5**	**24**	**3**	**28**
		Translations model				
Demographic translations	**13**	**12**	**11**	**10**	**17**	**16**
		Exogenous influences				
Period fixed effects	**36**	**28**	**23**	**33**	**31**	**28**

impacts are included and to 34% if life expectancy is interpreted not as a proxy for health but rather as largely a demographic variable.

6. Conclusion

This paper examines various ways in which demography has been incorporated into "convergence modeling," as pioneered by Robert J. Barro and extended by Harvard scholars and others. Our interpretation of this literature distinguishes somewhat sharply between the impacts of Harvard translations additions and the more traditional demographic impacts on the economy. We propose, and find in our empirical analysis, that the impacts of translations demography are best viewed as largely "neutral" on economic production, although the translations framework nicely exposes effects on potential consumption (and welfare) and, importantly, significantly clarifies the roles of other demographic variables (e.g., dependency, size, density,).

These demographic impacts (deriving mainly from declining birth and death rates) combine to exert positive contributions to trends in per capita GDP growth. Worldwide, the combined impacts of demographic change have accounted for approximately 20% of per capita output growth impacts, with larger shares in Asia and Europe. And, in the not too distant future, demographic change (this time deriving from low and stable death and birth rates) will likely exert negative impacts on growth. To see how these results can materialize, we propose that future modeling should build on the type of demographic disaggregation illustrated in this paper where greater distinction is made between demographic change that affects output growth per worker and that which translates such growth into per capita terms. A theoretical modeling perspective that synthesizes the Barro convergence framework, augmented to include several traditional demographic variables like population age structure and size, and unified within the Harvard translations framework, provides a promising and relatively clear structure for revealing the roles of demographic change on the economy.

Appendix

Appendix. Variable definitions, sources, descriptive statistics, country sample, and estimation details

Variable	Description	Source	Mean	Std Dev	Min	Max
Y/Ngr	Per capita GDP (PPP) growth rate	Trans	1.65	2.69	−10.77	8.64
Y/WA_{gr}	Per working-age GDP (PPP) growth rate	Trans	1.46	2.66	−11.14	7.94
lnY/N	Per capita GDP (PPP, log)	SH	0.85	1.03	−1.35	2.89
lnY/WA	Per working-age GDP (PPP, log)	SH, UN	1.42	0.96	−0.72	3.31
lnWA/N	Ratio of working-age to total pop. (log)	UN	−0.57	0.10	−0.76	−0.32
Ln(Y/N)•Ed	Interaction: lnY/N • MaleEduc	Trans	0.95	1.48	−0.84	10.98
ln(Y/WA) •Ed	Interaction: lnY/WA • MaleEduc	Trans	0.86	1.36	−0.91	10.14
lnWA/N•Ed	Interaction: lnWA/N • MaleEduc	Trans	0.09	0.14	−0.14	0.83
TT %chg	Terms-of-trade, percentage change	WB	−0.43	3.54	−13.73	19.25
Gcons/Y	Pct share of gov't consumption in GDP	WB, BL93	7.27	3.60	0.01	27.19

Appendix. (continued)

Variable	Description	Source	Mean	Std Dev	Min	Max
Inflation	Inflation rate	WB	15.71	28.71	0.74	317.10
$\ln(e_0)$	Life expectancy at birth (log)	WB	4.07	0.21	3.46	4.37
MaleEduc	Avg years post-primary educ, Males 25+	BL96	1.29	1.19	0.02	6.67
Rule Law	Index: Law & order tradition	ICRG	0.56	0.24	0.10	1.00
Democracy	Democracy (political rights index)	G	0.58	0.33	0.00	1.00
Ngr	Population growth rate	Trans	2.02	1.01	−2.18	4.06
WAgr	Working-age population growth rate	Trans	2.21	1.05	−1.81	4.23
lnD1	100 • Ratio of ages 0–14 to 15–64 (log)	UN	4.14	0.41	3.14	4.67
lnD2	100 • Ratio of ages 65+ to 15–64 (log)	UN	2.14	0.51	1.21	3.31
Dns	Density: 1,000 population per Sq. Km	WB	0.17	0.61	0.00	5.77
lnN	Population size (log)	WB	9.37	1.26	7.06	13.65

Notes: Additional definitional details are found in Kelley and Schmidt (2001). Data fills and extrapolations were made by imposing rates of change from an alternative data set with more complete series. For SH, WB was the primary filling source with UN and IMF as alternatives. WB was generally filled from earlier versions, UN sources, or SH. Fills for ICRG and G are too complicated to describe here; a description is available upon request.

The "Source" column from the appendix table uses the following key for data sources:

BL93 Barro and Lee's data set used in Barro and Lee (1993).
BL96 Barro and Lee (1996) update of their education attainment series.
G Gastil (1991).
ICRG International Country Risk Guide.
SH Summers and Heston Penn World Tables, version 5.6.
Trans Transformation of variable described elsewhere in table.
UN United Nations (1996).
WB World Bank's 1997 (and later) *World Development Indicators* CD-ROM.

Following Barro (1991, 1997), we use a panel with ten-year growth periods. Our sample, grouped by region, includes the following 86 countries. **Africa (26)**: Algeria, Benin, Cameroon, Central Africa, Ivory Coast, Egypt, Ethiopia, Ghana, Kenya, Madagascar, Malawi, Morocco, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Tunisia, Uganda, Zaire, Zambia, Zimbabwe. **North and Central America (12)**: Canada, Costa Rica, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, United States. **South America (10)**: Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela. **Asia (18)**: Bangladesh, Hong Kong, India, Indonesia, Iran, Israel, Japan, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Singapore, South Korea, Sri Lanka, Syria, Taiwan, Thailand. **Europe (17)**: Austria, Belgium, Denmark, Finland, France, Greece, Germany, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom. **Oceania (3)**: Australia, New Zealand, Papua-New Guinea.

Barro employs three-stage least-squares estimation, with the third-stage correcting for possible serial correlation. Since he found little evidence of serial correlation, we opted for two-stage estimation instead. Following Barro, the first-stage equations include all exogenous or predetermined variables together with five-year lags of ln(Y/N), ln(Y/N)'s interaction with contemporaneous education, Gcons/Y, Democracy, and Democracy's squared term . Finally, binaries for former colonies of Spain and Portugal and former colonies of Great Britain and France are included as instruments for inflation. The first-stage equations are run separately for each period. The second-stage equation is pooled but includes period-specific binaries.

Problems of reverse causation may plague demographic variables as well, although here the case is less clear. On the one hand, fertility rates are likely to be more sensitive to the level than to the growth of income. On the other hand, the length of the observations used in empirical studies ranges from five to twenty-five years, resulting in periods sufficiently long that the levels can change notably through growth. Our estimation uses an intermediate period of ten years. Consequently, we assessed the need to instrument key demographic variables (WAgr, Ngr, lnD1) through the Durbin-Wu-Hausman test (appending lagged demographic variables to the above list of instruments). In no demographic variant was that test significant at the 5% level. This result is consistent with that of Brander and Dowrick (1994) who present one of the most econometrically-intensive analyses in the literature using instrumental variables for birth rates in a production function setup. They conclude that, "there is no evidence that the demographic variables are endogenous with respect to income growth rates" (p. 18). As a result, we do not instrument any of the demographic variables in the estimation presented in this study. As a sensitivity experiment, we ran an additional set of 2SLS regressions that included first-stage regressions for WAgr, Ngr, and lnD1 (thought to be most sensitive to fertility changes). Coefficient estimates changed negligibly.

A more thorough explanation and rationale for our estimation procedures can be found in Barro (1997) and Kelley and Schmidt (2001).

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