Forecasting long run economic growth with probabilistic demographic projections: an application to India*

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Abstract

During recent years there has been an increasing awareness of the explanatory power of demographic variables in economic growth regressions. We use results from this literature and demonstrate that demographic changes have not only shaped the past but accounting for uncertainty in the future evolution can guide projections of economic variables. We apply recent probabilistic demographic projections based on expert opinion for India to derive the uncertainty of predicted economic growth caused by the uncertainty in demographic developments.

1 Introduction

As is now well-known, OECD countries stand on the threshold of enormous population aging. The most predictable challenge posed by population aging

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is the fiscal burden. During recent years there has been an increasing awareness of a direct influence of population age structure on the macroeconomy. Significant age structure effects were found for economic growth, inflation and savings in OECD countries ([19], [20], [21]).[1] Recently, [5] argue that a falling youth dependency ratio (the population below working age divided by the population of working age) contributed to the economic growth miracle in East Asia (see also, among others, [18]). As a consequence, falling youth dependency ratios in developing countries can create an opportunity for economic growth in the developing world. [4], [6], [7],[10], [12] show empirical support for this claim by finding a positive and significant effect of declining youth dependency on economic growth in cross-country regressions applied to developing and developed countries.

Except in the work by Bloom and Williamson [6] and Lindh [19] the implication of the evidence for age structure effects for future predictive power of age structure changes has not yet been discussed. Lindh [19] presents evidence that statistical models of inflation and GDP growth explained mainly by the share of 5-year age groups perform well in out-of-sample forecasting on a horizon of 3-5 years ahead during the 1990s. A different methodology is used in Bloom and Williamson [6]. The authors use the estimated coefficients on population growth rates and growth rates of the economically active population (15-64 old age group) — as estimated by a cross-county regression of economic growth applied to 78 developing and developed countries — to assess the past (1965-1990) and forecast the future (1990-2025) contribution of demographic change on economic growth. Their results indicate "that population dynamics can explain between 1.37 and 1.87 percentage points of growth in GDP per capita in East Asia or as much as one-third of the miracle ..." (p.441, where miracle refers to growth rate of GDP per capita of 6% observed over the same time period in East Asia). For their forecasts the authors combine the estimated coefficients on the population variable with the medium variant of UN population projections. Their results indicate that "in East Asia, the growth in GDP per capita attributable to demographic influences is projected to be negative between 1990 and 2025, ... a loss of 0.14 to 0.44 percentage point up to 2025". On the other hand countries in South Asia are projected to gain from their demographic changes in the

[1]The theoretical framework behind the reduced form models applied in econometric studies are the life cycle model of savings and investment as well as the labor productivity that is varying by age of employees.

future.

Similar to Bloom and Williamson, our paper aims to forecast economic growth in developing countries by combining the estimated coefficients of a regression of economic growth with population projections. However, by simply applying the medium variant of the UN population projection Bloom and Williamson cannot indicate the likelihood with which the predicted demographic contributions will take place. In contrast, we combine our result of a pooled time-series and cross-country regression of economic growth with probabilistic population projections of a developing country.

The aim of the paper is to indicate the likelihood of the contribution of future demographic changes for economic growth in India. India is a country for which probabilistic population projections are available. In addition, India is an ideal country for our purpose since it has not yet had the dramatic fall in youth dependency (which we observe for many of the Asian countries) and which has not yet had a very dramatic increase in the elderly dependency ratio. Recently a survey of India in The Economist [25], p.13 argues similarly: 'The most fundamental long-term reason for optimism is demographic.' We therefore combine estimates on the demographic effects from growth regressions with probabilistic forecasts of demographic developments.

The set up of the paper is as follows. In the next section we show our results of a a pooled time-series and cross-country regression of economic growth applied to developing and developed countries. Section 3 reviews recent applications of probabilistic demographic projections in economics. A short review of the past and future trends in demographic indicators (based on UN projections) for India is presented in section 4. Section 5 combines the demographic forecasts for India with the estimations obtained by the growth regression. The final section concludes.

2 The role of demographic variables in explaining economic growth

According to the neoclassical growth model population growth reduces economic growth due to capital dilution. However, various studies using cross-country data found an insignificant effect of population growth on economic growth. Recently, Bloom and Williamson [6] challenged this result (see also [4]). They confirmed that population growth has no effect on economic growth in growth equations with the growth rate of the total population as the only demographic variable. However, they showed that demography matters for economic growth, once one considers changes in the age structure of the population, that is, once one drops the implicit assumption of a constant age composition of the population. More specifically, the authors regressed the growth rate of GDP per capita on the growth rate of the working age population and the growth rate of the total population (and various other control variables). These estimations showed a positive and significant effect on growth of GDP per capita due to growth of the working age population, and an opposite, negative and significant effect from the growth of the total population.

Since World War II developing countries have been undergoing a demographic transition at varying rates and times. During a demographic transition infant mortality declines and fertility falls only after a time lag. As a consequence, a demographic transition leads first to a demographic "burden" due to a rising youth dependency ratio (the population below working age divided by the population of working age). Later, as fertility declines, the demographic transition leads to a demographic "dividend" due to a declining youth dependency ratio (cf. [5]). Bloom and Williamson [6] used the quantitative results of their cross-country regressions to calculate the contribution of age structure changes to East Asian economic growth (see the discussion in the introduction).

According to their view the demographic "dividend" leads to opportunities for growth of output per capita for two reasons. First, there is an *accounting effect* because a rising ratio of the working age population to the total population increases the ratio of "producers" to "consumers". Obviously this contributes positively to growth of output per capita. Second, there might also exist *behavioral effects* on growth of output per capita. As [6] stress, a rising growth rate of the working age population leads, on the one hand, to capital dilution, that is, a reduction of the ratio of capital to the working age population. On the other hand, a rising ratio of the working age population to the total population implies a falling dependency ratio (the population below and above working age divided by the population of working age). [3] show empirically for aggregate data of developing and developed countries that a falling dependency ratio boosts the ratio of savings over output (see, among others, also [11]).

Mathematically the accounting effect and the behavioral effect can be decomposed from the following identity that results from taking the natural logarithm of output per capita and differentiating the resulting expression with respect to time, which yields

$$\hat{y} = \hat{\tilde{y}} + \hat{l} \tag{1}$$

where $y = Y/N, \tilde{y} = Y/L, l = L/N$ and Y denotes total output, N denotes the population and L denotes the working population and a "hat" on top of a variable indicates the growth rate. (A comprehensive review of the recent economic-demographic modelling and the role of accounting effects can be found in [13]). The growth rate of output per worker, $\hat{\tilde{y}}$, contains the behavioral effects, while the term $\hat{l}$, which equals the difference between the growth rate of the working population and the growth rate of the total population, is the accounting effect.

While [6] focus on output per capita as the dependent variable, a recent literature argues that an understanding of international differences in output per worker is needed, since only workers contribute to production. Most importantly, as can be seen from (1), the growth rate of output per capita contains behavioral effects, as well as, an accounting effect from age structure changes. Hence, from regressions with the growth rate of output per capita it is rather complicate to assess behavioral effects (see [4] for an assessment of behavioral effects from such regressions). In contrast, the growth rate of output per worker is free of an accounting effect. Hence, all age structure effects in regressions with the growth rate of output per worker are behavioral effects. In turn, the accounting effect can be calculated directly from calculating the difference between the growth rates of the working population and the growth rate of the total population, with no need to apply regressions for this task. Hence, we estimate behavioral effects from regressing growth of output per worker on its determinants and calculate the accounting effect directly with no use of regression exercises (see some regressions in [13] for a similar estimation strategy to assess behavioral effects and [14] for estimating behavioral effects from regressions with growth of output per working age person on its determinants).

We apply the findings in [14] who uses pooled time-series and cross-section data of five year averages, from 1965 to 1990, of seventy countries of the world, to explain the growth rate of output per worker between 1965 and 1990 (see Appendix A for the definitions and data sources of the variables of the following regression, and Appendix B for the list of countries included in the data set of the regression). As an independent variable Kögel [14] includes a measure for social infrastructure abbreviated *socinf* (*socinf* is based on an index of government antidiversion policy and an index that measures the fraction of years between 1950 and 1994 that a country has been open to trade, see [14], p.9). Further, the author includes the natural logarithm of output per worker in the base year as an independent variable. If negative and significant, then the coefficient of this variable indicates the tendency of convergence of output per worker to a value that is in the steady state the same for all countries, provided all countries have the same value for their control variables. Last but not least, the author includes the level of the youth dependency ratio as measured by the population aged $0 - 15$ divided by the population aged $15-64$. In addition, [9] argue that the variable *socinf* contains measurement errors. For this reason [14] instruments the variable that measures *socinf* with the same instruments as [9] to obtain an indicator *socinf* that is uncorrelated with measurement errors (see [14], p.10 for further details). Table 1 shows the results of 2SLS regression of the aforementioned variables (with White-Huber heteroscedasticity-consistent standard errors).

Apart from focusing on growth of output per worker instead of growth of output per capita, the regression differs from the regressions in Bloom and Williamson [6] and Bloom, Canning and Malaney [4] with respect to three important aspects. First, the aforementioned authors test for effects of growth rates of demographic variables, while Table 1 tests for an effect of the level of age structure ([13] and [14] independently suggested to include only the level of age structure for the same reasons). The motivation for doing so is the fact that, at least in the transition to a steady state, growth of output per worker is affected by the level of savings. In turn, [3] have empirically confirmed that the level of savings is affected by the level of age structure variables and not their growth rates. Second, the authors do not give attention to the possibility that there might be a difference between the effect from an increase in the youth dependency ratio and the effect from an increase in the elderly dependency ratio (the population above working age divided by the population of working age). However, when we included only developing countries in the sample, then the elderly dependency ratio was insignificant for economic growth (results not shown). Future research might aim to examine possible reasons for the lack of significance of the elderly dependency ratio in developing countries (although probably variation of the elderly dependency ratio is qualitatively rather unimportant for developing countries). However, as we aim to apply the estimates of the regression to developing countries only, the regression equations should only contain the youth dependency ratio and the elderly dependency ratio should clearly be dropped. Third, the aforementioned authors included various mainly geographic variables as additional control variables. It turned out that these geographic variables are insignificant (at least for developing countries), once some geographic variables are used as instruments for social infrastructure as in Hall and Jones [9] and this paper when we instrument the variable that measures social infrastructure.[2] Therefore, these control variables were dropped from the regression equations of Table 1.

The first column of numbers in Table 1 shows that the youth dependency ratio is negative and significant. In addition, output per worker is negative and significant, while social infrastructure is positive and significant. The second column of numbers shows standardized coefficients of the regression of the first column. The youth dependency ratio turns out to be about as important for growth of output per worker as social infrastructure and the tendency of convergence of income per worker (as measured by output per worker in the base year).[3]

3 Applications of probabilistic demographic projections

The common approach to quantify the uncertainty in future outcomes of economic and demographic variables is the scenario based approach. It starts to build up alternative trajectories (commonly referred to as low, medium and high variant) for the various input variables of the forecasting model. The next step is then to 'bundle combinations of these trajectories together to calculate high, medium and low projection "scenarios". The way the bundling is done depends on the purpose of the projections, and has an important influence on the results.' ([16], p.6).

For instance consider the population projections by UN [27] (also used

[2]This is consistent with a recent literature, which finds insignificant effects of various geographic variables on the *level* of GDP per capita, once some geographic variables are used as instruments for various measures of quality of institutions (see, e.g., [1], [8], and [23]).

[3]Note that random effects estimation - results not shown - gave again almost exactly identical results. Further, with fixed country effects estimation - not shown - the coefficient of the youth dependency ratio remains again negative and significant.

Table 1: Explaining growth of output per worker 1965-90, panel data of five-year averages

Dependent variable: Annual average growth rate of output per worker (x100)		
Independent variables	2SLS with fixed time effects	standardized coefficients
Constant	8.63	
	(3.93)	
Ln of output per worker in base year	-0.95	-0.27
	(-3.53)	
Socinf	4.18	0.24
	(3.20)	
Ln of youth dependency ratio	-1.97	-0.25
	(-2.79)	
R^2	0.25	0.25
Number of observations	350	350

[a](White-Huber) heteroscedasticity–consistent t-statistics are reported in parentheses below the coefficient estimates.

[b]Fixed time effects are not shown.

[c]Social infrastructure was instrumented by using the predicted values from the first stage regression including five explanatory variables: (i) The fraction of the population in a country that speaks English as first language.(ii) The fraction of the population in a country that speaks French, German, Portuguese or Spanish as first language (eurfrac). (iii) The predicted trade share of an economy. (iv) An index of the distance from the equator (latitude) (v) An indicator of state antiquity.

by [6]). They assume six different scenarios where the first three of them are defined as low, medium and high while the latter three scenarios are the constant-fertility, constant-mortality and zero migration scenario. Since we shall compare the first three scenarios with our probabilistic scenarios in the next section, we shortly summarize the assumptions behind those scenarios. The low, medium and high scenario only differ with respect to the fertility assumptions while the mortality and migration assumptions are similar across all three scenarios (see [27] for further details). The assumptions of the low, medium and high variant are therefore set in order to highlight the effects that different fertility paths have on other demographic parameters. As summarized in [16], p.6 not only does the scenario based approach not assign any probability to its alternative variants of future demographic developments but the approach is seriously flawed with respect to several of its assumptions, e.g. assuming the cross correlations of all errors to be $+1.0$ or -1.0, etc. Most importantly for our purpose, one can not directly move from the uncertainty assessed to the low, medium and high variant of the fertility to the uncertainty of the resulting youth dependency ratio since the latter is a nonlinear function of two population numbers.

During the last decade several authors have developed stochastic population forecasts (see [17] for a review of probabilistic approaches to population forecasting). While alternative approaches differ with respect to the methodology that generates the input vectors for the projection model (e.g. time series modelling versus expert opinions are used to yield future time paths of fertility and mortality), the ultimate aim of those methods is the same: to derive prediction intervals for future realizations of population numbers or more general population functionals such as the dependency ratios.

In recent years several authors ([16],[26]) have also started to apply stochastic population forecasts in economics and environmental studies ([22]). E.g. Lee and Edwards [16] apply stochastic population forecasts to predict the fiscal impact of population ageing in the US and to assess its uncertainty. Specific applications include stochastic projections for social security, stochastic projections for medicare costs and stochastic projections of the balance in the Social Security Trust fund (all applied for the USA). Stochastic simulations are applied to generate the stochastic forecasts for the quantity of interest. For example to forecast the balance of the Social Security Trust Fund one combines the stochastic population forecasts with forecasts of economic variables (like productivity changes and changes in the interest rate) and applies those to the mathematical expression which yields the social security balance each time period. Each realization of a demographic forecast and an economic forecast will yield one stochastic simulation trajectory. After generating at least one thousand of those stochastic trajectories we can apply a frequency distribution to the outcome variable of interest (the social security balance) to estimate the probability distribution of the forecast. We shall proceed in a similar fashion in section 5 where we combine the econometric results from the previous section with stochastic forecasts of the population.

An alternative methodology that aims to combine the scenario based approach with stochastic population forecasts, termed *conditional probabilistic population forecast*, has been first introduced by [2]. Sanderson et al. [24] provide a recent overview of the methodology.[4] An application to climate models is presented in [22]. The basic idea it to keep the scenario approach but use subjective probabilities to quantify the uncertainty in the consequences of those development patterns for output variables such as emissions. In a first step probabilistic population projections conditional on storylines are developed. Next these projections are combined with the per capita emissions rates derived from the scenarios of the environmental module. The outcome of such a procedure is manifold ([22], p. 5), e.g. the likelihood of a single existing scenario can be judged as well as the relative likelihood of outcomes across storylines.

Clearly, the application of stochastic population forecasts to other research fields is yet in its infancy but as these applications in economics and environmental studies have shown there is a substantial gain in applying stochastic forecasts. Most importantly as stressed in [26], p. 389: '.. attention must be paid to translating uncertainty estimates into measures meaningful to the user.' Tuljapurkar then continues to present an example of choosing where to invest one's money. Knowing the variance of the return of an investment would greatly improve the decision problem since the variance is a measure of risk and risk itself enters the utility function. Let us try to translate the meaning of the probabilistic forecasts in terms of our research question, the long run economic growth forecasts. We may rephrase the research question. Instead of showing that "there is a probability of e.g. $x\%$ that the growth rate of India will be $y\%$ in 2025" we may rather find an answer to the following question which is more accessible to the user: "What is

[4] This differs from the term conditional forecasts as used in [16], p. 8., where conditional forecasts refer to the fact that age specific benefit and tax schedules are kept constant for projection of the future balance of the Social Security Trust Fund.

the probability that India in 2025 will surpass the growth rate in output per worker that has been achieved in 2000". We may then even further continue and pose the question of how the probability of reaching a specific growth rate at some future date may depend on the variability of the input factors, e.g. what if India would take over the value of the social infrastructure parameter as observed in a developed country like the UK? Another question of interest to the user might be "What is the probability that more than half of the growth rate of output per worker in the next decades will be explained by demographic changes such as the decline in the youth dependency ratio". Knowing the answers to those questions, i.e. knowing the probability with which alternative future development paths will realize, might definitely help governments in their planning processes of social infrastructure, trade policies, labor markets, etc.

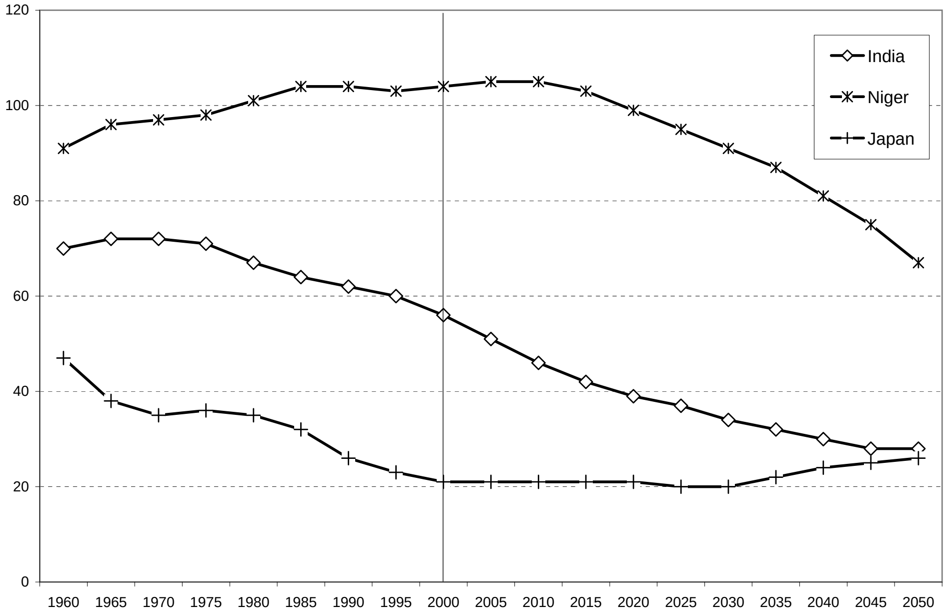
4 The demographic past and future of India

To show the peculiarity of the development of the demographic structure in India we compare the past and projected (according to the UN medium variant) age structure of India with the age structure observed in Japan and Niger, two countries at different stages of their development as compared to India. Figure 1 shows the youth dependency ratios (the population of age 0-15 divided by the economically active population of age 15-64) for India, Niger and Japan.[5] Since 1970 India's youth dependency ratio has been falling and will fall until 2045. In contrast, Niger (one of the poorest countries of the world) has not yet been experiencing a fall of the youth dependency ratio. This fall is expected to occur not earlier than in 2010. Most importantly, in the entire period 2000-2050, India's youth dependency ratio will be much lower than Niger's youth dependency ratio. Hence, India will experience a much larger 'demographic dividend' than Niger. In contrast, Japan had its demographic transition much earlier than India. Throughout the entire period 1960-2000 Japan's youth dependency ratio has been falling and the youth dependency ratio is projected to stay constant in the period 2000-2050.

Since Figure 1 shows that in the entire period 2000-2050 Japan's youth dependency ratio will be lower than India's youth dependency ratio, one might be tempted to conclude that Japan will experience a larger 'demo-

[5]We add a vertical line at the year 2000 since this will constitute the starting period for our probabilistic projections.

Figure 1: Youth dependency ratios; selected countries



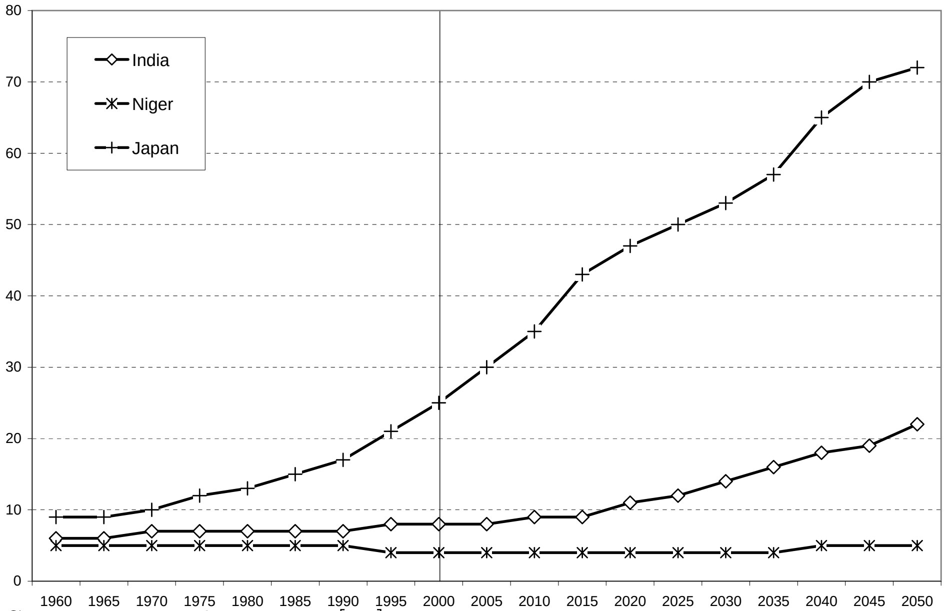
Source: United Nations [27]

graphic dividend' than India. However, as Figure 2 indicates, for Japan the elderly dependency ratio is projected to increase markedly during the next decade while the increase in the elderly dependency ratio is only moderate for India and almost constant for Niger during the projected time period 2000-2050.

To summarize: Figure 1 and Figure 2 show that in 2000-2050 a decline of the youth dependency ratio to a very low level will be the dominant demographic feature in India. In contrast, an enormous increase of the elderly dependency ratio to a very high level will be the dominant demographic feature in Japan. Hence, India will experience a 'demographic dividend' in 2000-2050 (while Japan will actually experience a 'demographic burden').

In the following section we consider the likelihood that the youth dependency ratio and the accounting effect will follow the path projected by the UN medium variant projections. We then investigate the contribution of the demographic uncertainty for uncertainty in long run economic growth rates in India.

Figure 2: Elderly dependency ratios; selected countries



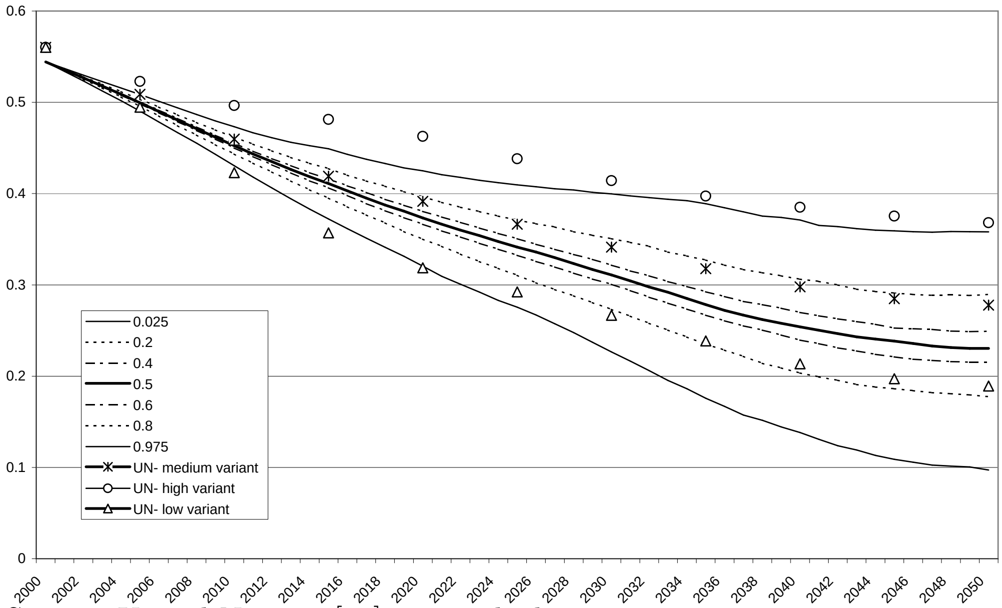
Source: United Nations [27]

5 Probabilistic demographic and long run economic growth projections for India

We start by putting together probabilistic projections of the youth dependency ratio and the accounting effect.

In Figure 3 we plot percentiles of the probability distribution of the youth dependency ratio together with the low, medium and high variant of the UN projections. There should be a 20% chance that the true value of the youth dependency ratio falls between the 0.4% and 0.6% bounds. During the first two decades mainly the uncertainty in the number of births and the uncertainty in the number of surviving people in the working age population determines the probability distribution. As the uncertain births start to enter the denominator (working age population) the uncertainty in the youth dependency ratio further increases from 2020 onwards. A further broadening of the probability distribution results from the uncertain fertility applied to uncertain numbers of young women in fertile ages. The uncertainty seems to be symmetric in the upward and downward direction. In 2050 there is a

Figure 3: Probabilistic and UN forecasts for the youth dependency ratio in India

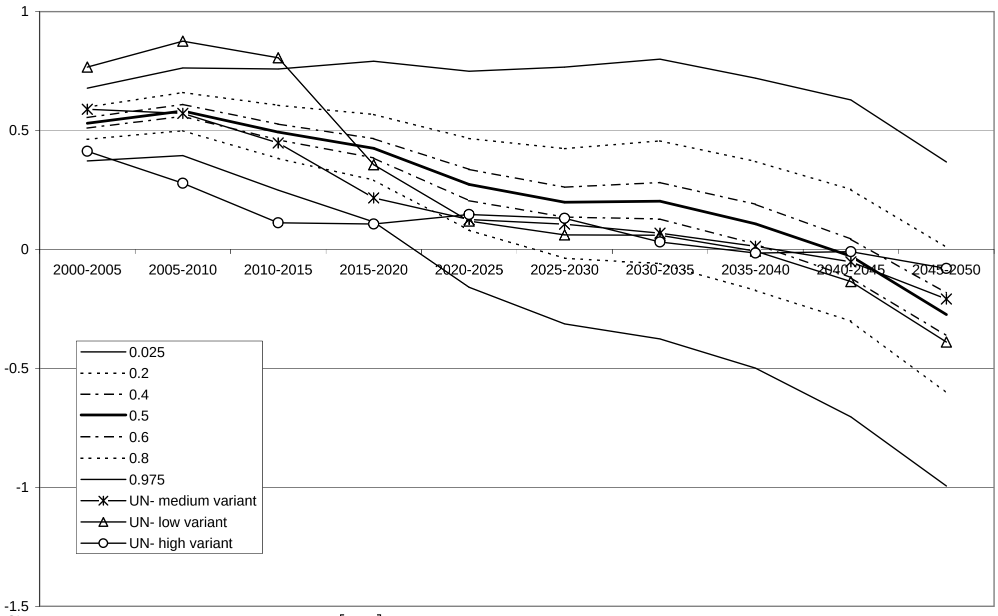


Source: United Nations [27], own calculations.

2.5% chance that the youth dependency ratio has fallen by 82% while there is an equal chance that it has fallen by 34% only.

Comparing our results with the UN projections indicates that the low and medium variant are close to our 20% and respectively 80% prediction interval. This implies that the true value of the youth dependency ratio would be expected to fall below the low and medium bound for these projections about 20% and respectively 80% of the time given our stochastic population forecasts. The high variant of the UN projections lies outside the 97.5% prediction interval implying that the true value would be expected to fall below the high bound of the UN projections about 97.5% of the time. Alternatively we may say that there is a 80% chance that the true value of the youth dependency ratio will fall between the low and high variant of the UN projections. Given that our probabilistic projections are a good representation of the uncertainty in the projected youth dependency ratio, and given the fact that the decline in the youth dependency ratio will be a driving factor for economic growth in India, the UN projections are very conservative and

Figure 4: Probabilistic and UN forecasts for the accounting effect



Source: United Nations [27], own calculations.

would underestimate the contribution of demographic changes for long run economic growth performance.

In Figure 4 we plot the probabilistic projections for the accounting effect (the difference between the growth rate of the working population and the total population) together with the deterministic projections by the UN. (Since forecasts of labor force participation rates are difficult and lie outside the scope of the paper, we approximate in the projections for accounting effects the working population with the working *age* population). Most interestingly the high and low variant of the UN would imply that the accounting effect is almost the same across scenarios starting in 2020. However, as our probabilistic projections indicate, the uncertainty about the future development of the accounting effect is not negligible. In fact, there is an equal chance of 2.5% that the accounting effect will be positive and exceed .4 or be negative and fall below -1. Hence, for the accounting effect it therefore becomes most obvious that a deterministic forecast like the UN projections will underestimate long run uncertainty.

As a next step we combine the probabilistic demographic projections of

India with the panel regression results from Table 1. More specifically each time period we draw one realization of the stochastic population projections. Iterating the regression equation forward in time yields a stochastic time path for output per worker. We assemble $1,000$ stochastic simulations of the growth rate of output per worker and plot the resulting probability distribution in Figure 5. Note, that we assume uncertainty only in the demographic variables and ignore any uncertainty that is caused by the estimation procedure.[6]

Compared to the past experience of economic growth rates our results indicate that there is about the same likelihood that the growth rate of per worker output will be either below or above the growth rate of output per worker reached in 2000. Recalling that our structural equation used to forecast economic growth only includes two time varying regressors — the lagged dependent variable and the youth dependency ratio — the results in Figure 5 lend themselves to another interesting interpretation. For the median the behavioral effect (represented by the youth dependency ratio) will exactly counterbalance the negative convergence term and the growth rate of output per worker will remain close to 4%, the value attained at the beginning of our forecasting time period. On the other hand, projected growth rates that are lower and respectively higher as compared to the value of 4% imply that the convergence term dominates respectively the behavioral effect dominates.

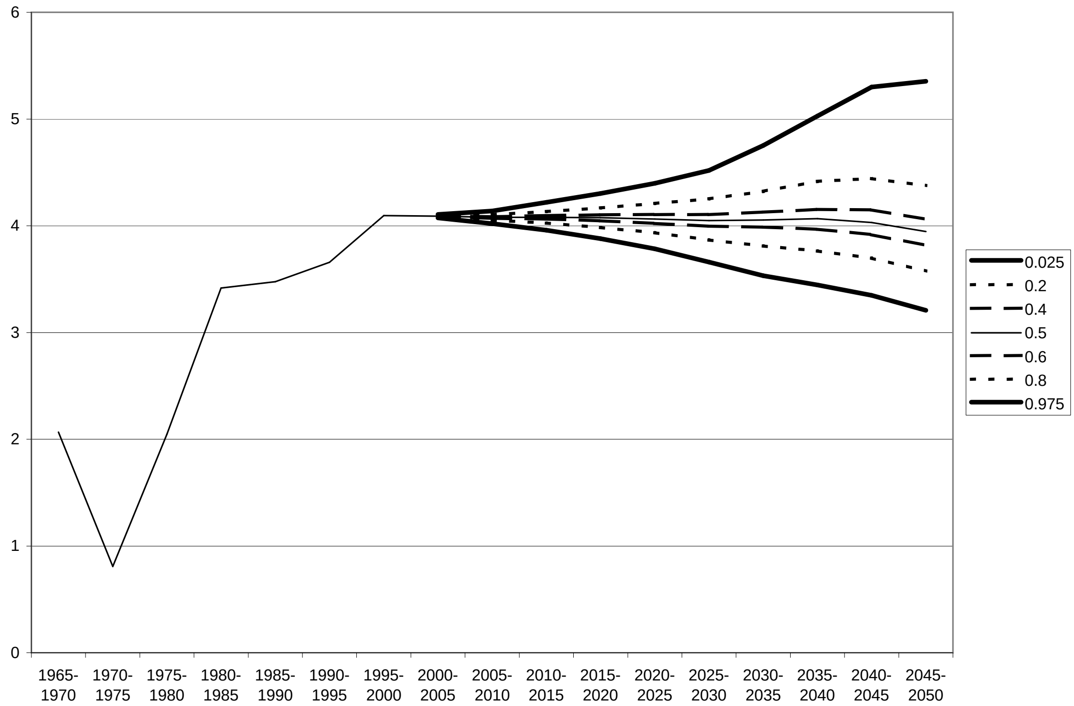
Alternatively we may compare the results in Figure 5 to the partial effect of a change in the variable socinf. If India's social infrastructure increased from its current level to the current level of the UK (the country with the highest predicted social infrastructure in our world sample) the growth gain would be about 2.15 per cent. This growth gain would be about 1.7 times the growth gain predicted under demographic uncertainty for the 97.5 percentile which is about 1.3 per cent. More generally from Figure 5 we may argue that by considering demographic uncertainty only there is a 95 per cent chance that the predicted growth rate of output per worker in 2045-2050 will be between 3.2 and 5.4 per cent.

The effect of demographic uncertainty on the growth rate of output per capita is given in Figure 6.[7] Though the prediction intervals are initially

[6] See Appendix C for the result of including regression uncertainty in addition to demographic uncertainty.

[7] To obtain a stochastic time path for output per capita we add up a stochastic time path of output per worker with its corresponding stochastic time path of the difference

Figure 5: Probabilistic forecasts for the growth rate of output per worker (considering demographic uncertainty only)



Source: United Nations [27], own calculations.

broader for the projections of per capita output (since the accounting effect is favorable during the first two decades of the 21st century) the results for 2045-50 are similar as those for per worker output. There is a 95 per cent chance that the predicted growth rate of output per capita in 2045-2050 will be between 2.6 and 5.4 per cent.

6 Conclusion

We draw on recent literature that has shown that age structure may have an important effect on economic growth. These effects work through a pure accounting effect (a change in the ratio of producing to consuming people in an economy) and a behavioral effect which relates to the change in output per worker.

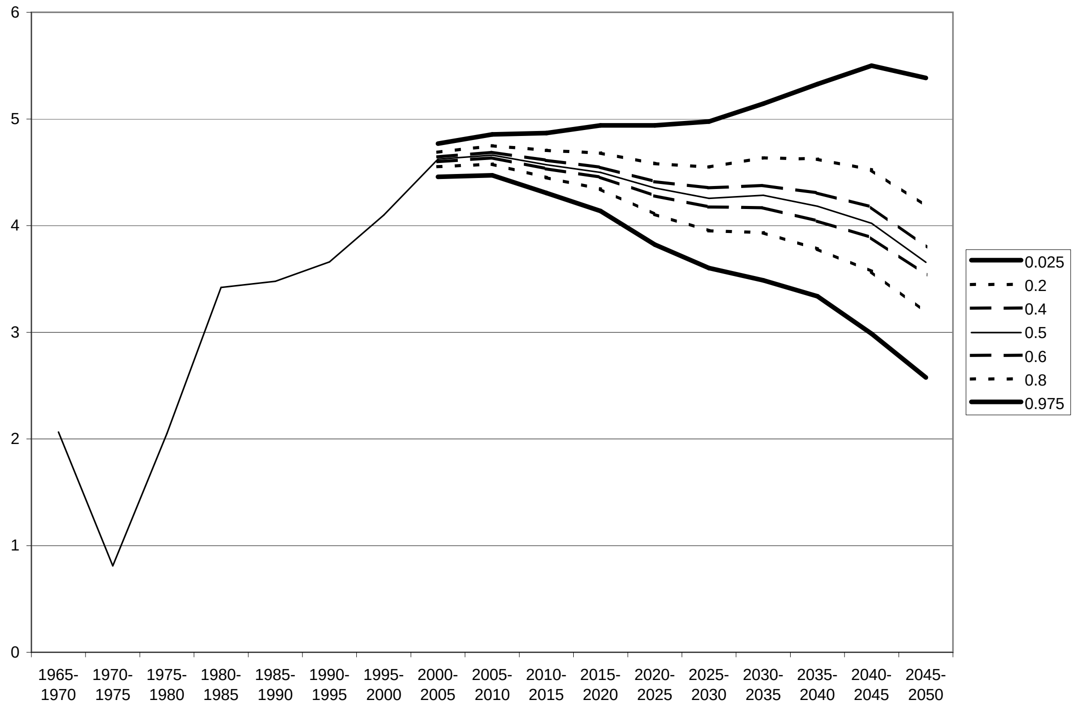
To assess the role of demographic change for the behavioral effect we applied in a first step a pooled time series cross-section estimate to data of five year averages from 1965 to 1990 of seventy countries of the world. Our results indicate a negative and significant effect of the youth dependency ratio and the output per worker in the base year and a positive and significant effect of social infrastructure.

In a second step we combine the estimated coefficients of the regression of economic growth with probabilistic population projections of India to qualify the growth potential embodied in India's changing age structure. If one considers only demographic uncertainty we find that there is a 95 per cent chance that the predicted growth rate of output per worker in 2045-2050 will be between 3.2 and 5.4 percent compared to a value of 4.1 per cent in 1995-2000. The width of the prediction interval increases if we add to the uncertainty of the youth dependency ratio the uncertainty of the accounting effect to arrive at predictions of output per worker. We find that there is a 95 per cent chance that the predicted growth rate of output per capita in 2045-2050 will be between 2.6 and 5.4 per cent.

Although changes in age structure may turn out favorable to economic growth, during the next decades the symmetry of the prediction interval (in case of predicting per worker output) indicates that there is an equal chance that economic growth may decline as well. When we consider per worker output, the asymmetric prediction interval indicates that the chances that

between the growth rate of the working and the total population (i.e. the accounting effect).

Figure 6: Probabilistic forecasts for the growth rate of output per capita (considering demographic uncertainty only)



Source: United Nations [27], own calculations.

economic growth declines during the next 50 years exceeds the chances of continued economic growth. The latter result is driven by the accounting effect (the difference between the growth rate of the working population and the total population) that is predicted to decline over time.

As our partial effect of a change from India's social infrastructure variable to the level currently observed in the UK has shown, the gain in economic growth would be about 1.7 times the growth gain predicted under demographic uncertainty for the 97.5 percentile of the prediction interval. La Porta et al. [15] argue that government performance improves with per capita income. Since in this case there would be bi-directional causality, it seems not feasible to quantify a feedback effect from economic growth to better social infrastructure. Nevertheless, keeping in mind the possibility of improving social infrastructure, India's future economic growth might be more delightful than our predictions that consider only the change in the age structure.

Last but not least, it needs to be mentioned that our predictions of economic growth are sensitive to the model structure we have chosen. In future work we aim to study the implications of predicted age structure changes on economic growth under alternative model specifications.

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Appendix A: The data of the regression in section 2

Output per worker (in constant international dollars of 1985)
Source: Global Development Network Growth Database, Easterly and Yu, World Bank (2001) (available at http://www.worldbank.org/research/growth/GDNdata.htm).

Youth dependency ratio
Definition: Population of age 0-14 divided by population of age 15-64.
Source: World Development Indicators 2000 (cd-rom).

Openness
Definition: Fraction of years between 1950-94 in which a country is open to trade. For each year a country is classified as open if it satisfies all of the following five criteria: (i) Nontariff barriers cover less than fourty percent of trade. (ii) Average tariff rates of less than fourty percent. (iii) A black market premium that depreciated by less than twenty percent relative to the official exchange rate, during the 1970s or 1980s. (iv) Country is not a socialist economic system according to the classification of Kornai (1992). (v) Not a state monopolist on major exports.
Source: Index of Sachs and Warner (1995) (available at Chad Jones' data archive at http://elsa.berkeley.edu/~chad/datasets.html).

GADP
Definition: Government antidiversion policies.
Source: International Country Risk Guide, which rated developing and developed countries according to 24 categories of risk for international investors. Knack and Keefer (1995) constructed the GADP index as the average of five of these categories (available at Chad Jones' data archive).

(i) ENGFRAC and (ii) EURFRAC
Definition: Fraction of population in a country that speaks as first language (i) English or (ii) English, French, German, Portuguese or Spanish.
Source: Chad Jones' data archive.

Lnfrankrom
Definition: Predicted trade share of an economy.
Source: Frankel and Romer (1999) (available at Chad Jones' data archive)

Latitude
Definition: Distance from the equator measured as the value of latitude in degrees divided by 90. Location data correspond to the center of the country or the province within a country with the largest number of people.
Source: Global Demography Project at the University of California, Santa Barbara, obtained by Hall and Jones (1999)
(data available at Chad Jones' data archive)

Statehist5
Definition: An indicator of state antiquity.
Source: Bockstette et al. (1995).

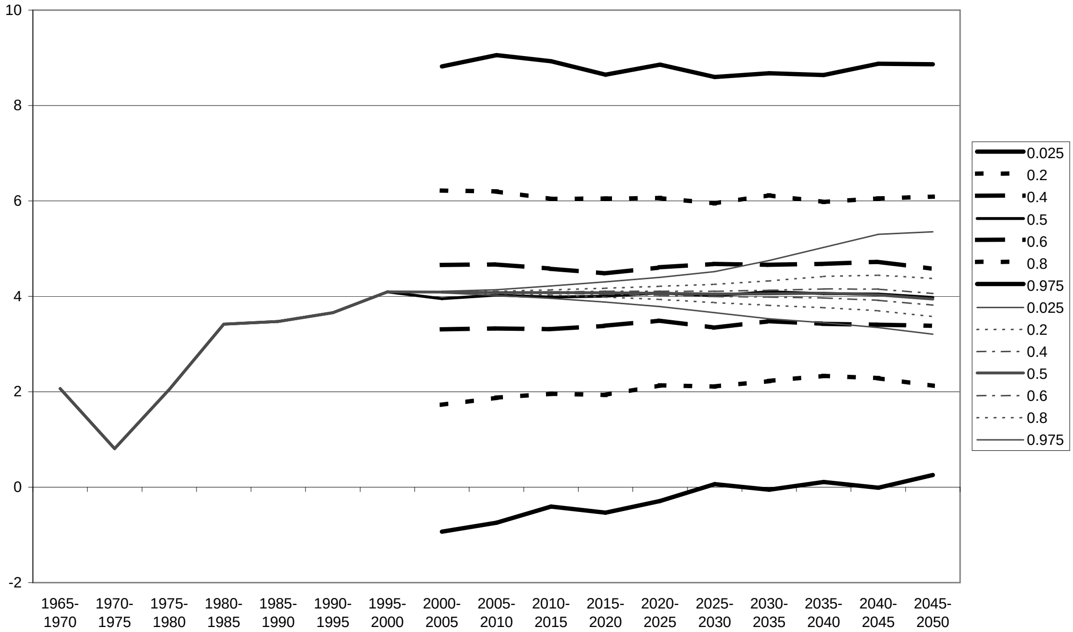
Appendix B: List of countries included in data set of the regression in section 2

Argentina	Guyana	Peru
Algeria	Honduras	Philippines
Australia	Hong Kong	Portugal
Austria	India	Singapore,
Bangladesh,	Indonesia	South Africa
Belgium	Ireland	Spain
Bolivia	Israel	Sri Lanka
Brazil	Italy	Sweden
Cameroon	Jamaica	Switzerland
Canada	Japan	Syrian Arab Rep.
Central African Rep.	Jordan	Thailand
Chile	Kenya	Togo
Colombia	Korea, Rep.	Trinidad and Tobago
Costa Rica	Malawi,	Tunisia
Cyprus	Malaysia	Turkey
Denmark.	Mali	Uganda
Dominican Rep.	Mauritius	United Kingdom
Ecuador	Mexico	United States
El Salvador	Netherlands	Uruguay
Finland	New Zealand	Venezuela, RB
France	Nicaragua	Zambia
Ghana	Norway	Zimbabwe
Greece	Pakistan	
Guatemala	Paraguay	

Appendix C: Probabilistic forecasts of the growth rate of output per worker considering regression uncertainty in addition to demographic uncertainty.

Uncertainty in the projected growth rates of output per worker is not only caused by uncertainty in future developments of demographic indicators, but also by regression uncertainty. In Figure 7 we plot the percentiles of the probability distribution of the growth rate of output per worker when we consider only demographic uncertainty and alternatively if we consider demographic and regression uncertainty. As the width of the prediction intervals indicates, model uncertainty dominates uncertainty in demographic variables. Since we regard uncertainty in the model as 'ignorance' about the true model rather than uncertainty due to predictions of independent variables, we have restricted our discussions to demographic uncertainty only.

Figure 7: Probabilistic forecasts for the growth rate of output per worker considering regression uncertainty in addition to demographic uncertainty



Source: United Nations [27], own calculations.