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Modeling And Class-Room Study Of Demographic Projections

P. Arun[1] and Jasneet Kaur Wadhwa[2]
[1]*Department of Electronics, SGTB Khalsa College, University of Delhi, Delhi 110007 (INDIA)*
[2]*Department of Economics, SGTB Khalsa College, University of Delhi, Delhi 110007 (INDIA)*

Abstract
The study discusses the advantages of introducing software simulations for population demography studies at the undergraduate level, for students with some knowledge in programming. It highlights India's potential for economic growth through investments in human resources and the need to bridge the gap between economic issues and policy decisions based on population dynamics. The reference to the previous work that demonstrates the ease of simulating population projections using basic inputs like birth and death rates is used and we propose to advance this idea by incorporating fertility rates and additional factors such as immigration, emigration, and natural calamities in the simulation. Based on this, the population of India to the year 2111 has been projected using the birth rate, death rate and Age Specific Fertility Rate data from Census data. The study concludes by emphasizing the benefits of such simulations in training students to project beyond the limitations of census exercises and make informed policy decisions.
Key words*: Population demography, Population Projection, Fertility rate*

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I. INTRODUCTION

India is at a point where it can live up to its potential, roping the benefits of its investments made on human resources over the last three-four decades. From the initial years where, large population was seen as a bane (Malthus, 1888), to the situation where it is now considered a resource (Bloom et al 2000), the development hence makes for an interesting subject for study. However, what is more exciting is the possibility of hands-on class-room evaluation of various scenarios made possible with computer simulations. In fact, in his recent work, Barreto (2018), discusses the importance of introducing the study of population and demography in undergraduate curriculum. Indeed, there is a disconnect at the under-graduate level between economic issues and policy decision making based on a dynamically varying parameter of population and its demography. Rapid education and technological interventions have resulted in the slowing varying population and its demography to become a rapid and dynamical variable. In fact, in some developing countries, changes in population and its demography are now so rapid that contrast is visible *with*in a couple of decades (sometimes earlier). This, thus throws off-gear some of the best policies planned. Hence, it becomes imperative to base decisions on simulated projections of changes in populations based on minimum input parameters and test/model changes based on critical parameters of interest. While most of the developed world's many ignore population as a variable due to the more or less stabilized population size by minimization of birth-rate and maximizing average age, developing countries such as India still need to monitor population and its demography and plan and frame policies accordingly.

Barreto (2018) showed that such simulations can be done easily in classrooms even with common spreadsheet softwares like Excel. He used just two inputs, the birth-rate and the death-rate to project population demography in future. His work suggested how easy it was to "improve demographic literacy" in class.

The present study advances Barreto's (Barreto, 2018) idea of introducing population demography in under-graduate class-room of University of Delhi, where students have prerequisite idea of programming with tools like python, C, MATLAB/ Scilab and Mathematica. This affords the possibility of not just investigating effect of birth-rate and the death-rate but also add fertility rate. Decrease in death-rate and infant mortality has been seen to affect the fertility-rate (Bloom et al 2003). Considering this is about human-beings, who are free to decide and make decision on their family size etc., establishing a universal co-relation between death-rates and fertility rates is impossible. However, the programmer is at liberty to make reasonable assumptions and see the consequences based on simulated numbers. Simulation further allows for inserting effects of immigration, emigration, natural calamities and pandemics. The following passage discusses simulations done in context with Indian population using Scilab.

II. METHODOLOGY-SIMULATION

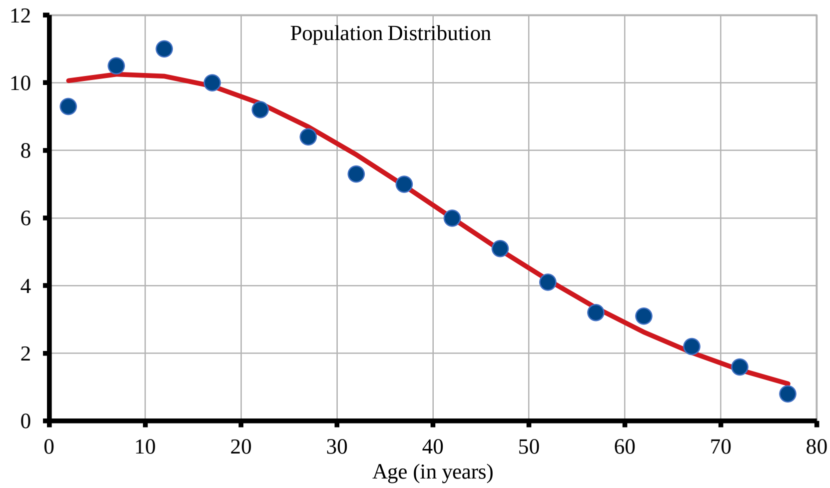
In this paper, we have simulated the population demography of India from the year 2011 to 2111 (basically a period of hundred years) using the birth-rate, infant mortality rate, fertility rate and death-rate as reported by Government of India (GOI) reported census of 2011 (The 2020-21 Census has been delayed due to the COVID-19 pandemic). The detailed census reports clearly show that these quantities strongly vary from state to state in India, for keeping the introductory/ educational simulations simple have considered the country as a whole. Though, as stated above, these quantities are dynamically evolving with time, we have for the present study, considered constant. We have used Scilab, considering it to be a free-ware and easily downloadable and installable in popular operating systems like Windows and Ubuntu and is being taught at under-graduate levels in University of Delhi.

Table1. Age-wise distribution of Population(Percentage)

Age (in years)	Percentage of population
0-4	9.3
5-9	10.5
10-14	11
15-19	10
20-24	9.2
25-29	8.4
30-34	7.3
35-39	7
40-44	6
45-49	5.1
50-54	4.1
55-59	3.2
60-64	3.1
65-69	2.2
70-74	1.6
75-79	0.8
80+	0.9
Age not stated	0.4

Source: Government of India's Ministry of Statistics and Programme Implementation Report [GOI]

Figure 1: The normal distribution of the population profile shows a "young" population in India (2011)



Source: Based on data in Table 1

The simulation involves defining an initial population profile. The population distribution with age given by the Government of India's Ministry of Statistics and Programme Implementation Report [GOI] (Table 1) based on Census 2011 (Figure 1) shows a normal (Gaussian) distribution. The red line shows the curve fit of the equation

$$N(x) = N_o e^{-\frac{(x-b)^2}{2c^2}} \qquad \text{Eqn. (1)}$$

to the data points. A good fit was obtained for N_o=10.20%, b =8.35 years and c=32.53 years. This reflects the young population of India in the year 2011, with largest percentage of the population having age around 10 years old (median age).

The total population is given as

$N_{Total} = \sum N(x)$ Eqn. (2)

The second parameter required for the simulation is the Death Rate. On an average, the population perishing due to deaths increases with increasing age (Comfort 1964; Strehler 1977). This is explained due to the "accumulation of damages" over the years to the physical body organs over the year more popularly called degeneracy with time. The variation in death rate with age was given as (Olshansky et al, 1997)

$\gamma(x) = pe^{qx}$ Eqn. (3)

where `p' and `q' are fitting parameters and have values greater than zero. More recently, modeling has shown that this empirical relation of death rate with age holds irrespective of how damages accumulate (Ledberg, 2020). The statistical data published by the Government of India's *Ministry of Statistics and Programme Implementation Report* 2016 (Table 2) follows the exponential trend for ages above sixty (see fig 2), with fitting parameters p and q equal to 0.00934 and 0.116, respectively.

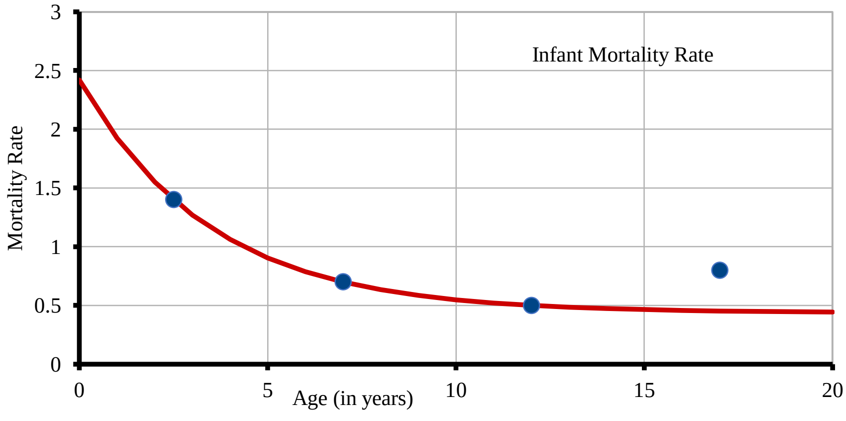
Table2. Age-specific death rate (per 1000) of population in India, 2013

Age-group	Total Deaths
60-64	18.4
65-69	29.7
70-74	48.8
75-79	70.7
80-84	115.1
85+	212.7

Source: Government of India's Ministry of Statistics and Programme Implementation Report [GOI]

Figure 2*:* The exponential increase in death-rate with increasing age post age of sixty is clear from the Government of India's Ministry of Statistics and Program Implementation Report (2016) data.

Figure 3: The Infant Mortality Rate (IMR) as per the data from National Institute of Public Cooperation and Child Development Handbook (2018) for the year 2011.



The third parameter required for our simulation is the infant mortality rate. While most of the developed countries have been able to arrest infant mortality, for a country as large as India, the process is still on and unfortunately death during birth and during infancy is still prevalent due to large population without access to proper health care and nutrition. Based on the *National Institute of Public Cooperation and Child Development Handbook* (2018) data, it is clear that infant mortality/death-rate also shows an exponential relation with increasing age, ibid a decreasing trend (Fig. 3)

$$\eta(x) = 2.0e^{-0.29x} + 0.44 \qquad \text{Eqn. (4)}$$

These two terms (Equation 3 and 4) together are technically called the Age Specific Death Rate (ASDR). Combining the two equations, the remaining population (at age `x', N_l) after a year is evaluated (Each iteration of the program is an elapse of one year and it records changes in population demography), in the simulation, using the equation

$$N_l = \left[1 - \left(\frac{\gamma+\eta}{1000}\right)\right] N(x) \qquad \text{Eqn. (5)}$$

The new population added to existing population, by birth (immigration has not been factored in the present work), is given as

$$N_{Birth} = \frac{1}{2}\sum N(x) \times ASFR(x) \qquad \text{Eqn. (6)}$$

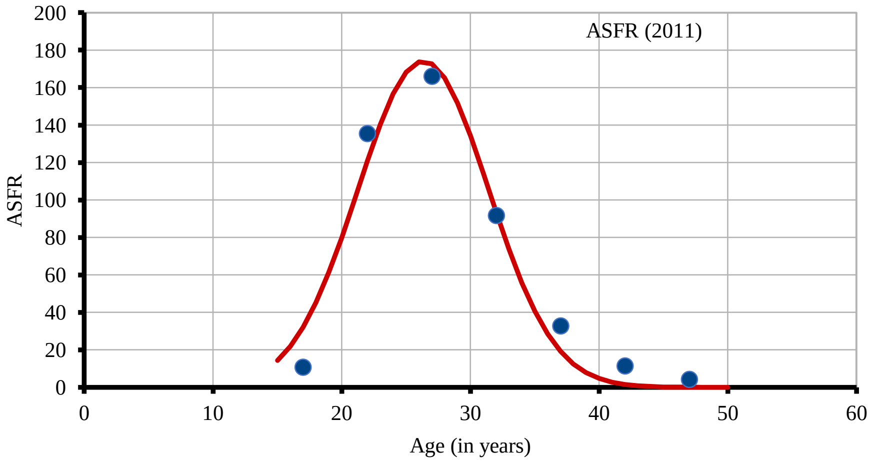
where ASFR(x) is the Age Specific Fertility Rate. The multiple factor of half in Equation (6) is an idealization based on assumption of a sex-ratio of 1:1. In general, the expression should be written as

$$N_{Birth} = \left(\frac{1}{SexRatio+1}\right)\sum N(x) \times ASFR(x) \qquad \text{Eqn. (7)}$$

As per the data of 2011, the multiple factor for India would be 0.47, however, since our study is more based to show importance of introducing population demography in an under-graduate class, we carried out our simulation with Equation (6). The ASFR is again age dependent and usually decreases with increasing age. However, this is a more complex parameter to determine since it depends on local culture and customs (fluctuations in infant mortality rate, recession etc. effects ASFR). Figure 4 shows the plot of ASFR data given by the *National Institute of Public Cooperation and Child Development Handbook* (2018) for the year 2011. The best curve fit done to the data shows a Gaussian trend with coefficients as

$$ASFR(x) = 174e^{-\left(\frac{(x-26)^2}{50}\right)} \qquad \text{Eqn. (8)}$$

Figure 4: The ASFR of Indian women as per the data from National Institute of Public Cooperation and Child Development Handbook (2018) for the year 2011.

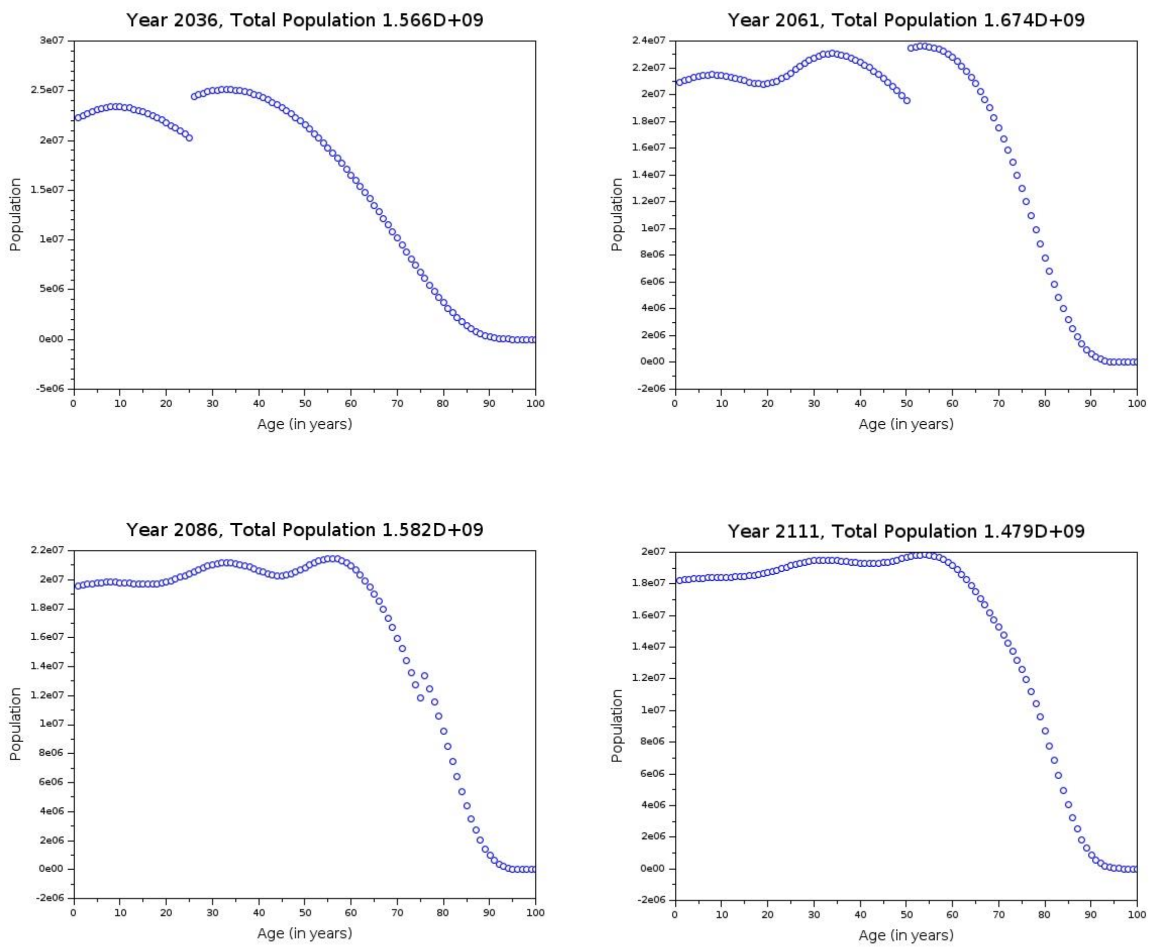


The society's trend in India to get female offspring married off before the age of thirty is evident from the peak in ASFR at 25-26 years of age which is followed by a rapid fall. The narrowing of the ASFR peak in the late 1990's, implying a fall in fertility rate, will manifest as a decelerator in India's population growth as will be seen in the simulation results below.

III. RESULTS & DISCUSSIONS

Figure 5 plots the results of our simulation and shows the population distribution with age at the end of the year 2036, 2061, 2086 and 2111. These years were selected for their visual distinct differences. The clink in plots is an artifact of simulation caused due to the mismatch of initial data obtained from histogram (binned data) and those generated by simulation. The clink propagates as more and years are simulated. We have not smoothened the data for making appearance of graphs agreeable.

Figure 5: The population distribution with age of India as simulated for the years 2036, 2061, 2086 and 2111



The population distribution with age of India at 2036 argues well for India. The young population of 2011 (peak between age 8-14, fig 1) have matured and are in their productive age (30-40) in 2036.The bulge in population distribution between the age 30-40, shows that the dependent age group population is not dominant as in 2011 and that there is a very small fraction of the population in age group above 60 years. Hence, the social welfare cost on the government would be low, giving it leg room to make investment in the sector of education and infrastructure to encourage industrial investments and growth. If in the intermediate period (2020-2030), the government invests on education, research and development with emphasis on start-ups, due to a sizable population in the working age group, 2030-40 promises a period when the country can have an “economic lift-off”. Our previous work (Singh, A. et al 2020) discussed the necessity of increased life expectancy for Technological development. The study showed that even in USA, it was only after the average life span of the population increased did it achieve technological advances. If a cursory examination of Japan’s population distribution with age is made (Ministry of Health Labour and Welfare website), you will notice that the population for age group 15-64 peaked around 1970’s. It was during this period that Japan led the world in electronic innovations.

Our simulation results also suggests that the net population of India though will show a downward trend post 2070, will not bulge or peak in the productive age where this population would be earning and contributing to the GDP. In fact the flattening out is due to multiple peaks hidden. These peaks repeat themselves after every twenty five years and is intimately related to the peaking age of ASFR (fig 4). Also, the life expectancy of Indian population is expected to increase by about ten years by 2061. Unlike Japan, in 2070 while India's social welfare requirements will increase due to the increasing population over the age of sixty, there will be no let-off for investments on the dependent age group (5-20). This would imply urgent measures to be taken post 2040 to encourage saving or pension schemes for those in service and also to adjust the ASFR by encouraging delay in marriageable age, elongating the education period of children (especially girl child) and encouraging employment of females in non-labor/ organized sector (Canning, 2015). We are working on projecting how the Indian population would fare with different ASFR and would be present the results shortly. The simulation suggests that post 2070, the size of the Indian population would continue shrinking with no major change in its profile. This again is because the simulation is quite basic and assumes demographic parameters like birth-rate, death-rate, infant mortality and ASFR remains constant as determined in 2011.

The rich information that can be generated and analyzed in an under-graduate class with simple programming is surprising and the flexibility to expand and include more realistic variables is astonishing. The approach allows for project-based learning that is presently totally absent in our curriculum.

IV. CONCLUSIONS

The manuscript advances an argument on the merits of introducing software simulation for population demography studies at under-graduate level. As an example, it shows how India is following in the footsteps of developed countries like USA and Japan in terms of population distribution with age and suggests proper investments on human resource development would result in similar economic growth. Thus, the availability of data affords the students to develop the concept of projection and evolve policy decisions. With the projected statistics, students may project the investment government will have to make in education, number of teachers required in years to come, investment in job creation etc. Such simulations of course are used by professional of the field and bureaucrats, but would allow students to train and project beyond ten years, and not be limited by frequency of census exercise. Students could clearly infer the path that India's population demography is following and project that if proper investments are made, India in 2030-40 would be in a position to make large strides in economic development.

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