Population Projection for India – A System Dynamics Approach

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Abstract

Population projections are central to all forecasting that involves public resource use. Leading international agencies such as the World Bank, the United Nations' population division, academics and India's own Census bureau provide extensive data and inputs on demographic modelling. But a literature survey indicates an absence of easy to understand plug and play models that can use all the essential aspects of available inputs. To address this, a System Dynamics design has been used in this paper to construct population models for India. System Dynamics allows a modular stock and flow approach that is able to incorporate all critical data points. Along with a simple four stage model, a detailed twelve stage model for India's population dynamics has been presented. At the aggregate level, population projections appear to be insensitive to intra-group changes in fertility and mortality rates. However, population projections are found to be quite sensitive to changes in fertility over time. A 10% change in the current fertility rate can change India's exponentially rising population to a declining population. This highlights the importance of fertility rates in dictating India's destiny. In contrast to fertility rate changes, the population projection change for mortality rate changes is relatively insignificant.

Keywords: India, Population Projection, Demographic estimates, India Census Data

1. Introduction

Population growth has been an important concern for policy makers. Yet the constant strife and significant crowding out from some of the basic services is disturbingly revealing. Crammed trains, impossibly difficult university admissions, food and water scarcity have been amongst the glaring problems. In some cases these problems have led to popular unrest. A mismatch between the supply of services and the number of people using these services (population growth led demand) continues to present challenges for planners in both the developing and the underdeveloped worlds.

In terms of size and pace, amongst the most populous countries, India's population has reportedly grown (World Bank, 2015) the fastest - cumulatively by 221% from 376 million in 1950 to 1206 million by 2010 (as shown in Figure 1). In comparison, the world population has been estimated to increase at rate of 174% - from 2526 million in 1950 to 6916 million in 2010. China, with a 1386 million strong population, is the most populous country in the world. In comparison to India, China's population growth from 1950 has been a sobering 150%. By 2028 however, United Nation estimates suggest that India would be overtaking China in terms of population.

Rapidly changing population dynamics has created a mix of opportunities and challenges. India is expected to have the world's youngest (India Planning Commission, 2015) workforce accounting for a fifth (The Economist, 2013) of the total global working age population. But for an estimated 857 (UN, 2014) million rural people – the highest in the world – there will be need to comprehensively plan for sustainable development. With regard to poverty, while the number of poor people (400 million, 2011) in India has been declining (World Bank, 2011), India still houses the largest world share of extremely poor people. According to World Bank estimates, India accounts for 33% of the world's poorest of the poor, second to sub-Saharan Africa at 34%. On the

resource side, natural resource exhaustion is an imminent danger. India's rapid population growth is expected to affect the country's water availability the most. India has been estimated (UN, Vital Water Graphics, 2015) to be one of five countries globally that are likely to face water shortages in the next twenty five years. Half of India's total annual rainfall has been estimated to being received in a twenty hour (Keller et al, 2000) window in a year. Data such as this underlines the extreme diversity and uncertainty associated with India's rainfall dependence.
Freer and faster markets and inevitable economic growth can bring with them additional planning problems. Economic growth without consideration of environment costs has a debilitating effect.
The Intergovernmental panel for climate change for example has been highlighting the widespread impact of greenhouse gases (which are at the highest in history) on natural systems (IPCC, Climate Change Report, 2014). But so far the worst of IPCC's forecasts on climate change are consistently becoming a reality (Jorgen Randers, 2052: A Global Forecast for the next 40 years, 2012). Government policies keep lacking coordinated action. Agencies claim that valuable time is being squandered away and that the world may have to expect newer forms of irreversible environmental damage.

Criticism against unsustainable growth is not new. Thomas Malthus's An Essay on the Principle of Population (1798) was published in the backdrop of the French revolution. In the 1900s, considered effort on sustainable growth started with the publication of Silent Spring a book that details the detrimental effects of pesticides (Carson, Silent Spring, 1962). "Limits to growth" a 1972 book, highlights the problems that exponentially growing populations with limited resources can face. The formulation of the human development index brought newer standards for defining development itself (Amartya Sen, 1990). But a cohesive global acceptance of sustainable growth is still a distant goal. The sustainability and planning questions become more complicated for nations such as India where economic growth is seen to be required to lift people out of poverty. A fine balance has to be understood and planned for countries like India where the population size is significant, dense and growing.

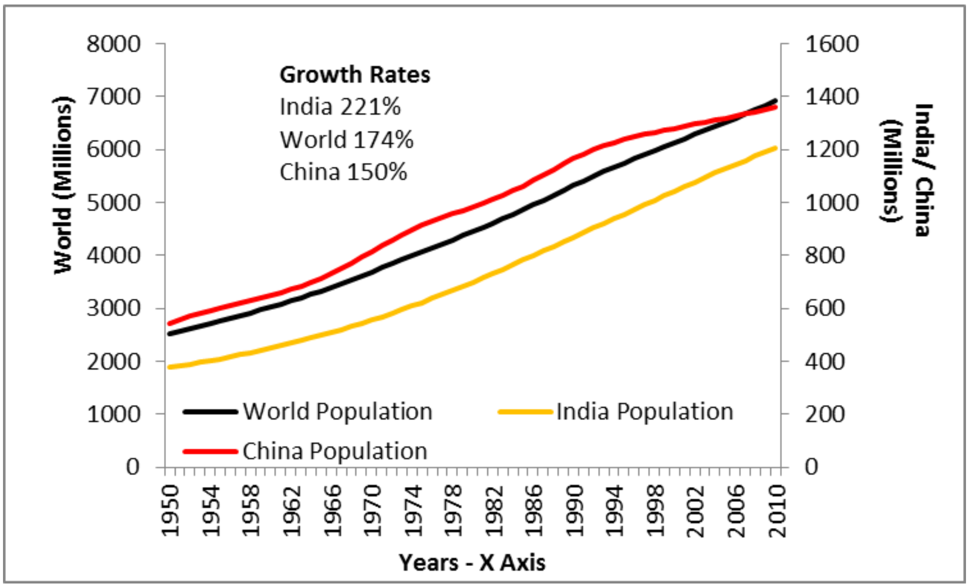

Figure 1: World Population Changes (Source: United Nations Data)

Globally, over the last two decades the population problem has acquired additional dimensions. Declining population growth countries such as Japan (Anderson et al, 2014) and or Germany (Sutrisno et al, 2011) are facing the "Ageing Population" challenge. On the other hand, high growth rate population countries such as India have been forced to contain the challenge of providing (Agarwal, 2014) necessities and services in as sustained (Laksmana, 2013) a manner as possible.

How soon will India's rapidly expanding population base stabilise? Will India transition to an “Ageing Society”? Understanding the answers to these and other related questions can provide planners with policy making insights.

Notable international agencies, including the World Bank and the United Nations, have been publishing population estimates for most countries in the world including India. UN country population estimates (UN, 2012) are available till 2100. Estimates provided by the World Bank (HealthStats, 2015) reach out till the year 2050. System dynamics techniques have been used to present very detailed population/ state of world estimates till 2052 (Randers, 2012). India's 2011 Census provides both data points and estimates by individual states for India's population. India's 2011 Census also provides population estimates (India Census, 2011) till 2025-26.

The methodology and data from all sources – India's Census (India Census, Projections & Methodology, 2011), the World Bank, the UN – equips researchers to better understand India's population problem. These bodies of work use a mix of the structural and statistical models to forecast population. But the representative workings of the models have not been covered in the published reports. A discussion of the interlinkages between the population distributions (components) and the corresponding movement of these distributions over time has not been covered as well. Furthermore, India specific sensitivity analysis for some of the key assumptions is an undercovered topic as well.

Objectives

The objectives of this work are as follows:

- Understanding and refining existing population projection methodologies and data sources
- Modelling India's population distribution using a Systems Dynamics approach
- Projecting and understanding India's population distribution and growth for the next hundred years
- Comparing model output given a change in assumptions and a change in modelling approach

Scope

The key motivation for this work is to develop an understanding and build a framework for modelling population projections. As such the following has not been covered in the model:

a. Impact and dynamics between population growth and resource usage
b. Factors and interventions that affect population growth. Some of the variables that have an impact but are treated as beyond scope include - economic prosperity, literacy, climate change, energy, food, and water availability.

The rest of the paper is organised as follows. Section 2 introduces popular modelling techniques for projecting populations and gives an overview of the data categories in the India Census 2011 data. Section 3 describes a simple 4 Stage Model. Section 4 discusses an elaborate 12 Stage Model. Section 5 summarises the findings in this paper.

1. The Background

Mathematical Models

A simple single stock population model is expressed as population change being a function of the population's birth rate (B) and the mortality rate (M). Both the birth rate (B) and mortality rate (M) are taken as functions of population N and time t. This model is denoted as:

dN/dt = B*N – M*N

The Malthusian model (Smith, Mathematics magazine, 1976) is built on the assumption that the population grows at a constant rate P (B – M). This relationship transforms equation above into:

$N(t) = N_0 * e^{Pt}$ (where N_0 is the initial population)

The Verhulst model (1840), named after Belgian mathematician P. F. Verhulst, modified the Malthusian model by treating the mortality rate to be a linear function of population. The model assumes the birth rate B to be constant. The Verhulst model came to be known as the logistic model and was used in 1940 to successfully predict the United States population. Raymond Pearl a John Hopkins University Professor, saw in the basic logistic model a universal law of biological growth.

dN/dt = (B – mN)*N

The equations discussed above provide the gist of basic population modelling. In addition to these techniques, mathematical models and advanced artificial neural networks (Lee & Tuljapurkar, 2008) or generalized delta learning models have been used to predict population. These models identify patterns in historical data sets for projecting future estimates.

Structural Models

In contrast, the population component of the World3 (a system dynamics based model), became popular for accurately predicting world population. The model derives its projections based on interactions between population growth, economic growth and environmental change (Meadows et al, 1974).

The United Nations population projections are said to be using a mix of component and mathematical modelling (UN, World Population Prospects, 2014). Component modelling is based on applying fertility, mortality and migration estimates to groups or age buckets of population. The Indian Census too, uses a form of component modelling for projecting population (National Commission on Population, 2006). The cohort component model projections depend on the structure of the data and baseline data. The key variables in cohort component modelling are expected to be constant over time. Instead a stock flow models allow for modular control and for changes to be made to control variables.

Data Sources

India's 2011 Census documentation provides the following data points:

* Single Year Age data by Sex and state in which resident
* Number of women and currently married women by age, number of births last year
* Crude death rates by sex and state in which resident
* Percentage distribution of total deaths by broad age groups – in other words, percentage deaths for the following categories:
    - <1 (14.5%)
    - 1-4 (3.9%)
    - 5-14 (2.7%)
    - 15-59 (30.9%)
    - 60+ (48%)

2. India’s Population – A 4 Stage Model

This section introduces modelling by building a 4 stage population model. This model divides the population into four distinct components – a) from infancy to teen-age as the first stage (“Youth – Child”); adult hood is divided into two stages – b) Teen-age to reproductive age (“Adult”), c) post reproductive age to retirement (“Senior Adult”) and the last stage as Old age (“Old”). In terms of population growth impact, the four stages outlined above correspond to the following distinctive characteristics:

* In the Youth – Child stage, mortality rates tend to be higher (given higher mortality for a new born child), fertility rates on the other hand are near zero
* The Adult stage is characterized by low mortality rates but have the highest fertility rate
* Senior Adult stage circles back to a low mortality rate and a very low fertility rate
* In the last stage “Old”, fertility rates remain very low but the mortality rates rise sharply

Crude birth rates affect the inflow at the first stage and crude death rates determine the outflows at each stage. The crude birth and death rates arise from the population distribution across the stages. The crude birth and death rates, in addition to the internal structure, are also influenced by fertility and mortality rates. The fertility and mortality rates in turn sum up all the external influences on the model.

A description of the 4 stage model, shown in Figure 2, follows:

* Youth-Child, Adult, Senior Adult and Old represent the four different stocks in the model. The populations that these stocks carry add up to India's total population.

* Each of the stocks above impact the “Birth Rate” (an inflow rate for the “Youth-Child” stock), through corresponding fertility rates. In reality, given low fertility rates for other stock variables, the Adult fertility rate is likely to have the most impact.

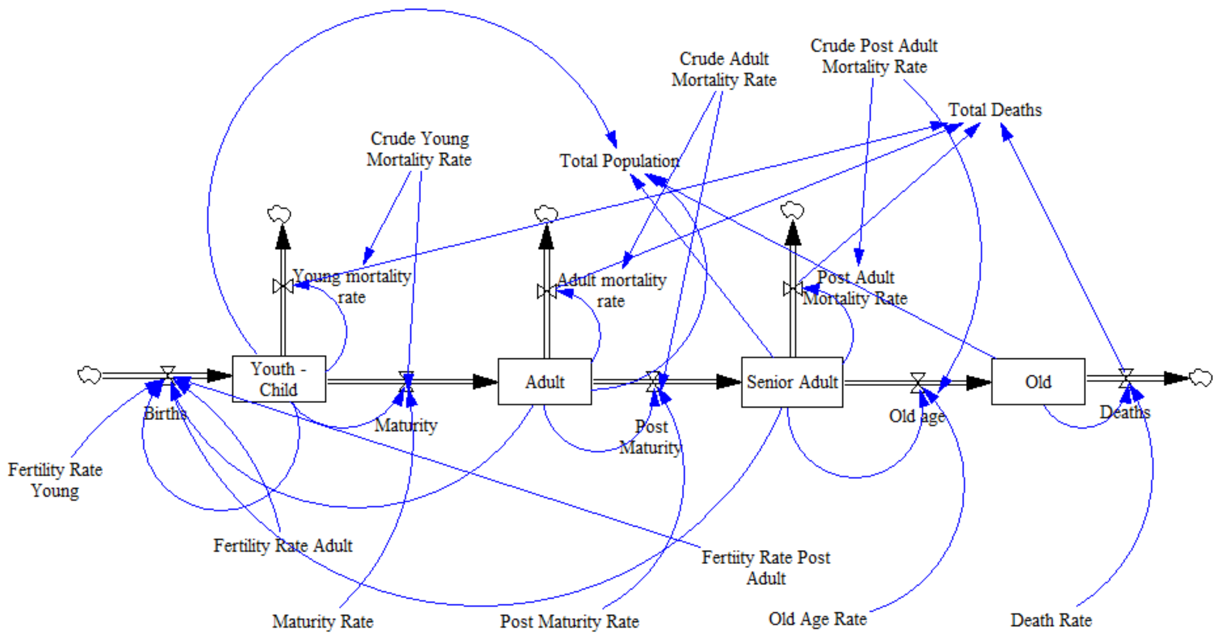

Figure 2: 4 Stage Model

* The pass-through rates denote the rate at which members in one stock flow over to the successive stock.
* The mortality variable in between each of the stages determines the percentage members who never make it to the next stage.
* The death rate variable after the “Old” stock sets the rate at which members in the “Old” stock perish.
* Variables “Total Population” and “Total Deaths” add up corresponding stock and flow variables respectively.

Assumptions in the 4 Stage Model

The assumptions used in applying the available data to the basic 4 stage model include:

* The initial or starting values for each stock are as of Census 2011 data.

* While the Census data shows that the sex distribution is quite skewed in several Indian states, in this work, we assume a sex ratio of 1:1 in all age groups. To compensate for the fact that there are fewer women than men in India, we calculate fertility per person in an age group and not fertility per woman. That is:

Age group fertility = (Total number of children born last year for this age group)/(Number of people in the age group)

* Both the UN model, and the World3 model estimate mortality based on an elaborate Life Expectancy model. Since we have the Census data on mortality available, we calculate Mortality rates as described next.

The India Census data gives the crude death rate at an All India level (7.2 persons per thousand). The Census data also gives a mortality weighting factor for each age bucket. Using the weighting factor and the total number of deaths, the model determines the mortality factor for each age bucket.

The age groups in the simplified 4 stage model tend to “hide” some of the data points. For instance, the high infant mortality rate gets evenly spread out to the entire “Youth – Child” (0-14) bucket.
* We assume same mortality rates for men and women.

* The fertility and mortality rates stay unchanged throughout the simulation (at their 2011 value).

* The population distribution components pass through (i.e. age) at average rates. For instance the “Youth – Child” age group covers ages between 0 and 14 years. It is assumed that the number of people (in this case children) maturing to “Adults” each year is on average 1/15th of the total population. In reality, this is not true as the number of children in each age bucket depend on the number of people born in that age group and the survival rate till the boundary that marks the “Youth – Child” stage.

Inputs to the 4 Stage Model

Based on the assumptions listed above and available input data, the age buckets, fertility, and mortality inputs have been computed in the tables below:

4 Stage	
Age Cohorts	
Age Group	Population Mn
0-14	372.4
15-44	579.5
45-59	150.5
60-100+	103.8
Table 1	

4 Stage	
Fertility	
Babies Mn	Fertility
0.058844	0.000158
19.693613	0.033982
1.145771	0.007611
0	0.000000
Table 2	

4 Stage		
Mortality		
% Weight	Deaths Mn	Mortality
0.211	1.8	0.004921
0.0618	0.5	0.000926
0.2472	2.1	0.014264
0.48	4.2	0.040147
Table 3		

Output of the 4 Stage Model

Model outputs have been shown in Figures 3 and 4 below. The first figure show the Total Population as predicted by the model for the next hundred years. The Y axis for the graph is in number of people in millions.

Starting with a population of 1207 million, this model estimates that over 10 years, the population could grow by a cumulative 10% to 1331 million. In the 50th year the 4 stage model predicts a population of 1656 million (cumulative 37% growth) and in the 100th year the population estimate has been calculated to be 1874 million (cumulative 55% from 2011)

The births and deaths charts below suggest an interesting dynamics. A growing and changing population distribution, over time, is closing out the gap between the number of deaths every year (about 9 million people at Time=Now) and number of births every year (about 21 mn at Time=Now) to about 25 million births and deaths in 100 years.

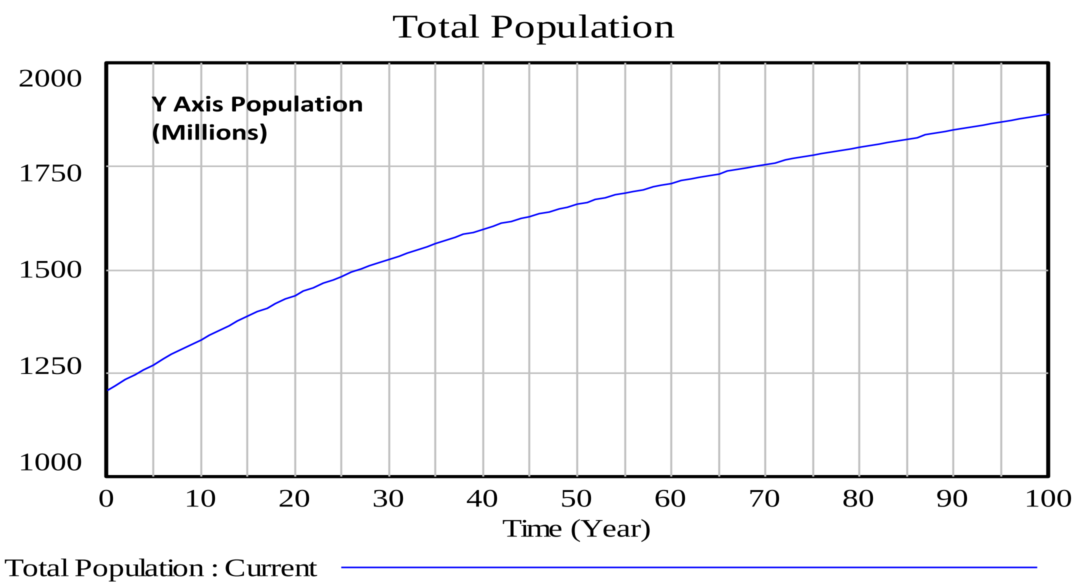

Figure 3: Total Population projection (in Millions on the Y Axis) – 4 Stage Model

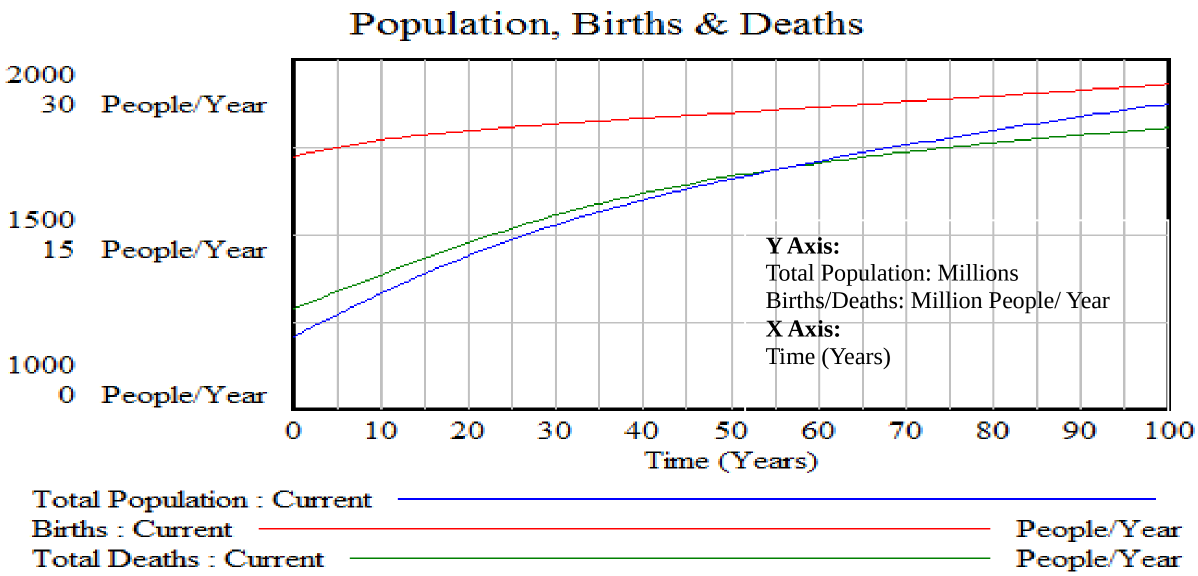

Figure 4: Total Population, Changes in Birth and Death Rates – 4 Stage Model

3. The 12 Stage Model

The four stage model described above provides an understanding of the basic changes in the population distribution under the impact of different fertility and mortality rates for the different constituent age groups. This principle has resulted in a 12 stage model based on the Census 2011 data. These twelve groups are described below according to their fertility and mortality characteristics:

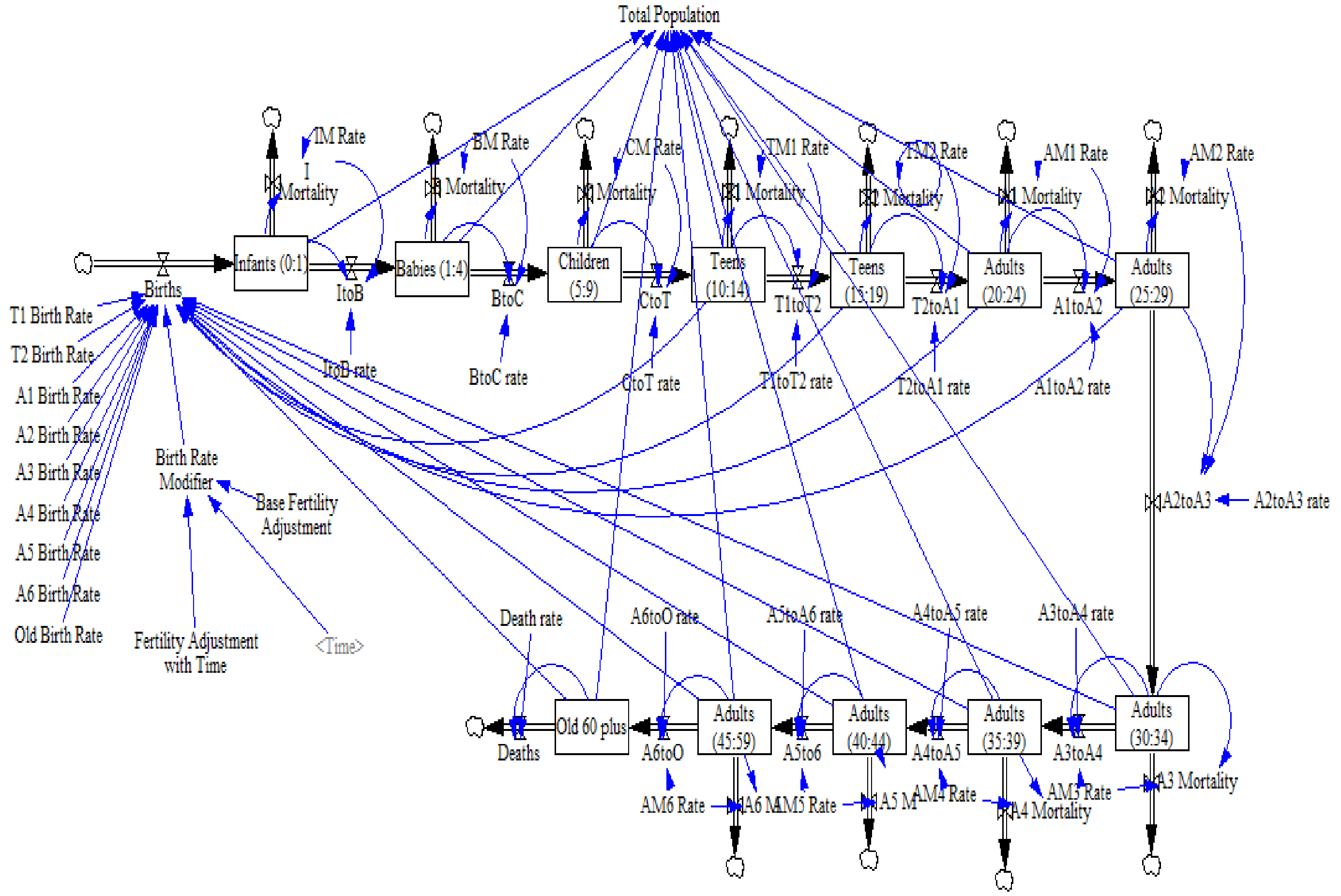

Figure 5: 12 Stage Model

- Infants (0:1) – Infant mortality data has been made available in the Census data set. This input has justified a separate age bucket for the 0-1 year age group. Apart from the "Old (60 plus)" age group, the Infants age group has the highest mortality rate.
- Babies (1:4) – This age group is a four year bucket. This age group has significantly lower mortality than then Infants age group.
- Children (5:9) – This age group is a four year bucket. This age group has lower mortality than then the Babies age group.
- Teens (10:14) – This age group shares a similar mortality profile with the "Children" group but unlike the "Children" group, scarily enough, this group has a non-zero fertility count as well.
- Teens (15:19) – The fertility levels for this age group have increased but the mortality levels too are higher than the Teens (10:14) group.
- Adults (20:24) – As expected, this group has the highest fertility amongst all groups.
- Adults (25:24) - Fertility levels in this group are the second highest.
- Adults (30:34) - Fertility levels in this group are the third highest.
- Adults (35:39) - Fertility levels in this group are the fourth highest.
- Adults (40:44) - Fertility levels in this group are the fifth highest.
- Adults (45:49) –This group is a post menopause group (for the females), so expectedly, fertility levels in this group bottom out and stay lower than the Teens (15:19) age group.
- Old (60 plus) – Mortality rates in this age group are the highest.

The 12 stage model shown in Figure 5 is described next:

- Each of the age bracket described above, is modeled as a separate “Stock”.
- Like the 4 stage model, the flow between the two age brackets is governed by the pass through rate.
- Since most buckets in the 12 stage model have a 5 year span, the pass through rates for these buckets is around 20% (after correcting for mortality).
- The birth rates for each of the reproductive buckets have been computed and are shown in Tables 4 through 6.
- “Birth Rate Modifier”, “Base Fertility Rate Adjustment” and “Fertility Adjustment with Time” have been introduced as additional variables to gauge the effect of changing (or declining fertility over time). In particular, “Fertility Adjustment with Time” has been created as a Lookup variable. The variable is capable of assuming different values over time. For the base case scenario we have assumed that the variable remains constant over the next 100 years.

Additional assumptions for the 12 stage model

In addition to the assumptions highlighted for the four stage basic model, we make few more assumptions for the 12 stage model.

As per the Census, the Teens (10:14) age bucket has registered some “new born” infants as their children. The absolute number is low (59 thousand babies compared to 20.7 million births per year) but nevertheless we distribute this value evenly among the Teens (10:14) stage group and assign a fertility value for this age group.

The “Births Last Year” data has two buckets for post menopause adults. The first bucket is for age groups between 45 and 49 years. The second bucket is for age groups above fifty years. Given relatively small absolute values (new born children assigned to this bucket) in this, the model combines the births in both the buckets to form a unified birth rate.

In order to take into account the under reporting of babies born (but who have died) we adjust the fertility estimate upward by calculating an adjustment factor. To calculate this factor, we first calculate Estimated Births as follows:

Estimated Births = Infants (0:1) + (Estimated Births*Infant Mortality Rate/2)

It assumes that 0-1 year deaths are evenly spread over that age group. Hence, only half the infant births in a year can be attributed to infants born that year. The other half of the 0-1 year children dying in any given year must be born the year before.

Even this adjustment is likely to underestimate the actual fertility, as it assumes that 0-1 year deaths are evenly spread. However, latest World Bank (World Bank, 2013) statistics suggest that 28 out of 41 infant deaths in India are at the neo-natal stage (up to 28 days old). We, however, restrict ourselves to Census of India data in this work.

From the previous equation, we can calculate Estimated Births and Base Fertility Adjustment as:

Estimated Births = Infants (0:1) + (Estimated Births*Infant Mortality Rate/2)

Base Fertility Adjustment = (Infants (0:1) + (Estimated Births*Infant Mortality Rate/2))
/Reported Births

Inputs to the 12 Stage Model

Based on the assumptions discussed so far and the available input data, the age buckets, fertility, and mortality inputs for the model are shown in the tables below.

12 Stage	
Age Group	Population Mn
Infants	20.3
Babies (1-4)	92.5
Children (5:9)	126.9
Teens (10:14)	132.7
Teens (15:19)	120.5
Adults (20-24)	111.4
Adults (25-29)	101.4
Adults (30-34)	88.6
Adults (35-39)	85.1
Adults (40-44)	72.4
Adults (45-59)	150.5
Old (60 plus)	103.8
Table 4	

12 Stage		
	Fertility	
	Babies Mn	Fertility
Teens (10:14)	0.1	0.0004434
Teens (15:19)	1.3	0.010676
Adults (20-24)	7.1	0.063432
Adults (25-29)	6.1	0.059671
Adults (30-34)	3.0	0.033854
Adults (35-39)	1.4	0.016625
Adults (40-44)	0.9	0.012050
Adults (45-59)	0.9	0.004504
Old (60 plus)	0.2	0.004504
	Table 5	

12 Stage			
	Mortality		
Age Group	% Weight	Deaths Mn	Mortality
Infants	14.5%	1.3	0.062007
Babies (1-4)	3.9%	0.3	0.003662
Children (5:9)	1.4%	0.1	0.000924
Teens (10:14)	1.4%	0.1	0.000884
Teens (15:19)	4.4%	0.4	0.003181
Adults (20-24)	4.4%	0.4	0.003441
Adults (25-29)	4.4%	0.4	0.003781
Adults (30-34)	4.4%	0.4	0.004328
Adults (35-39)	4.4%	0.4	0.004503
Adults (40-44)	4.4%	0.4	0.005293
Adults (45-59)	4.4%	0.4	0.002547
Old (60 plus)	48.0%	4.2	0.040147
	Table 6		

Output of the 12 Stage Model

The first prominent feature for the output from the 12 stage model is that the population projections from the 12 stage model closely overlap with the projections from the 4 stage model. At the aggregate level, the inputs for both the models are identical. The outputs from the 4 stage and 12 stage models suggest that the aggregate population projection is not very sensitive to intra-age bucket changes in fertility/ mortality assumptions.

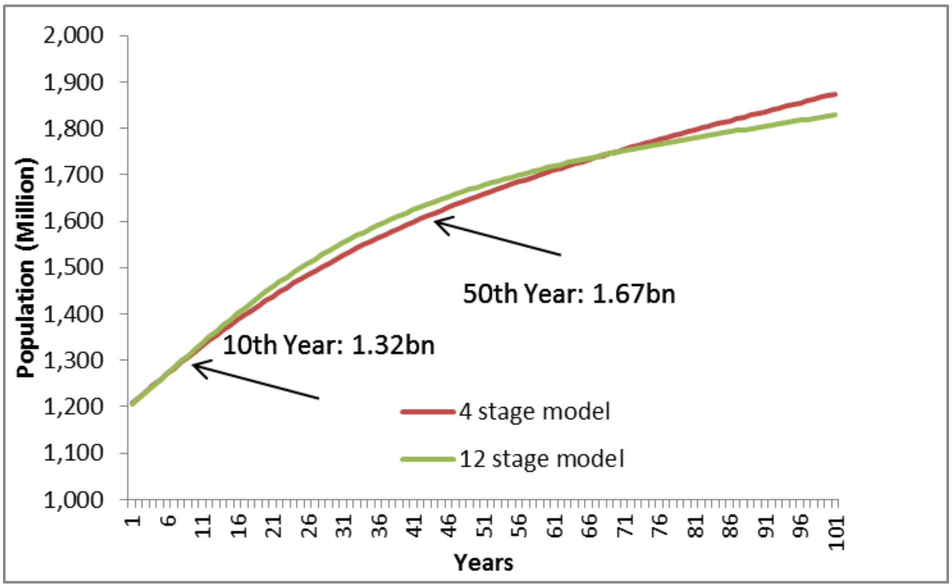

Figure 6: Comparing the projections of 4 stage and 12 stage models (Y Axis in Millions)

The overlap in the results between the 4 stage and 12 stage model gives lesser reasons to build a 100 stage population model (1 stock for each year in 0-100 age group as Census data for population in each age group is available).

The 12 stage model however, gives an important direction as to the movement of population distributions over time.

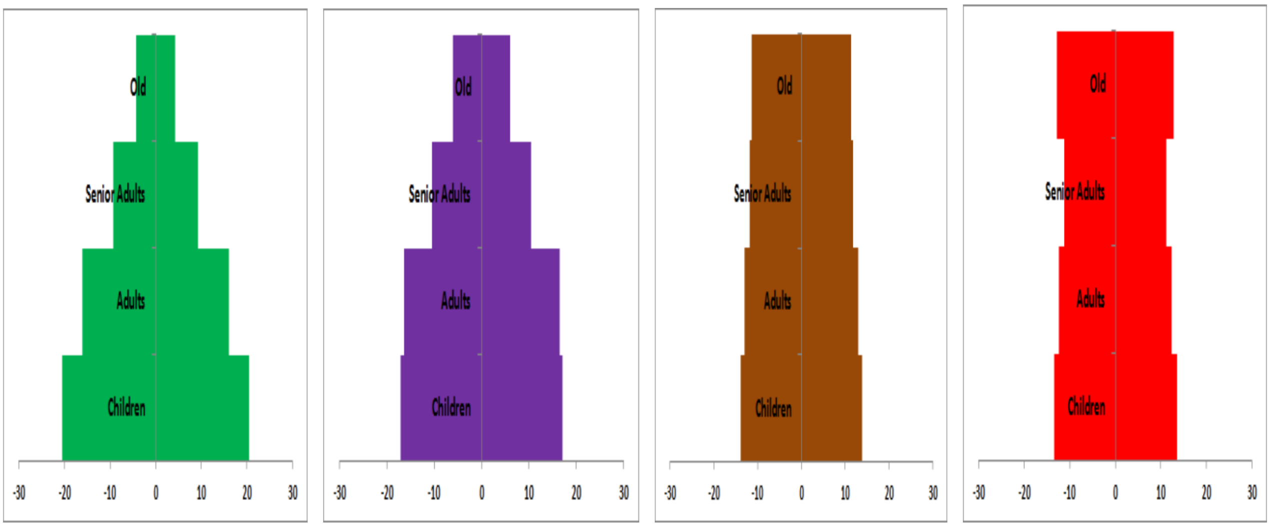

Figure 7: India's Population Distributions. X Axis: % distribution (left females, right males, assumed to be equal); Y Axis: Categories; green distribution (current); purple (in 10 years), brown (in 50years), red (in 100 years)

As referred to earlier in this paper, India's population distribution is currently enjoying a rich demographic dividend – a young workforce with a lesser burden of older dependants. Figure 7 (left most panel) depicts India's current population distribution.

Figure 7 also shows the manner in which India's current population distribution is transitioning to an ageing society. In the next decade India's percentage share for Adults is expected to catch-up with the percentage share for Children. In 50 years, Senior Adults are being estimated to equalise in terms of percentage share with Adults and Children. Finally in 100 years from now, India would transition to a rapidly ageing society. That is, in the next 100 years, India's "Old" would carry an almost equal share in terms of present of total population as that of the children.

Impact of Change in Fertility Rate

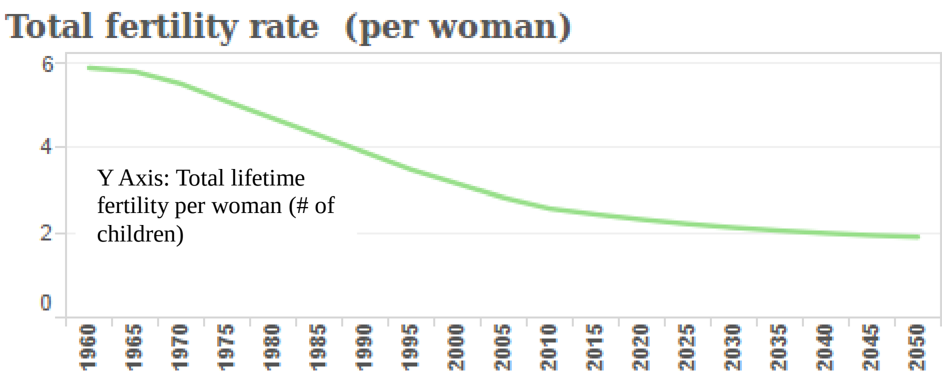

Figure 8: Declining Fertility Rates. X Axis Years; Y Axis: Fertility Rate for India. Source: World Bank data

Over time, fertility rate in India climbed down from a high of 6 in 1960 to 2.2 now (World Bank projections) and is expected to go down further (Figure 8). In order to take this into account, as discussed in the paper earlier, the 12 stage model has been subjected to two levels of declining fertility – a) fertility declining by 5% over next ten years and then stagnating, b) fertility declining by 10% over next ten years and then stagnating.

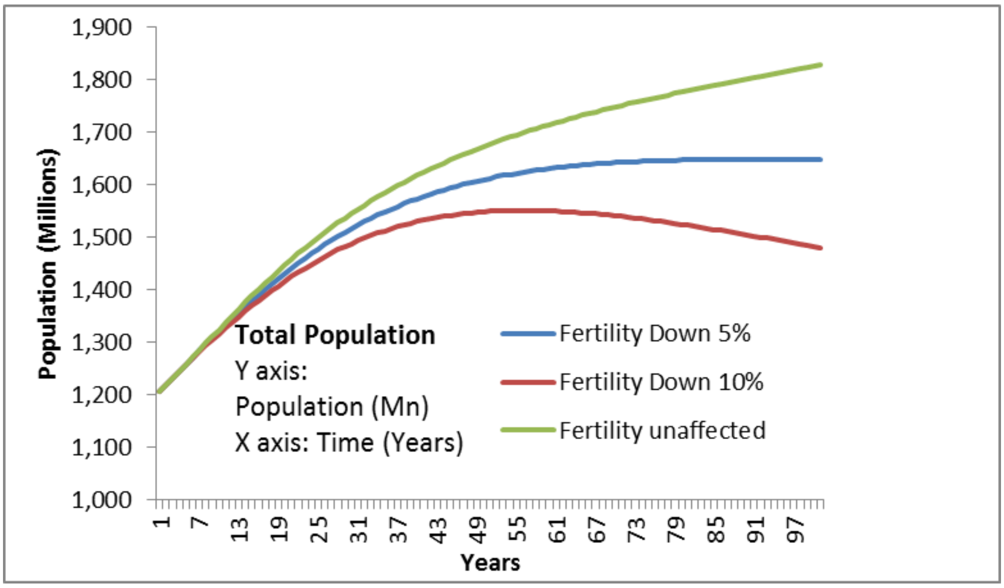

Figure 9 – Declining Fertility Rates affect population trajectories

Figure 9 shows the effect of declining fertility on population projections. If fertility declines by 5% over the next ten years, India's population is could stabilise at the1.62 bn level over the next 50 years. In the extreme case, if fertility goes down by 10%, India's population could actually peak at 1.5 bn around year 40 and then start declining. This means that a 10% change in fertility can result in a 25% change in the year 2111 population. These substantial changes in population trajectories highlight the importance of fertility management in population growth.

Figure 10 shows the changes to population projections for changes in the death rate input.

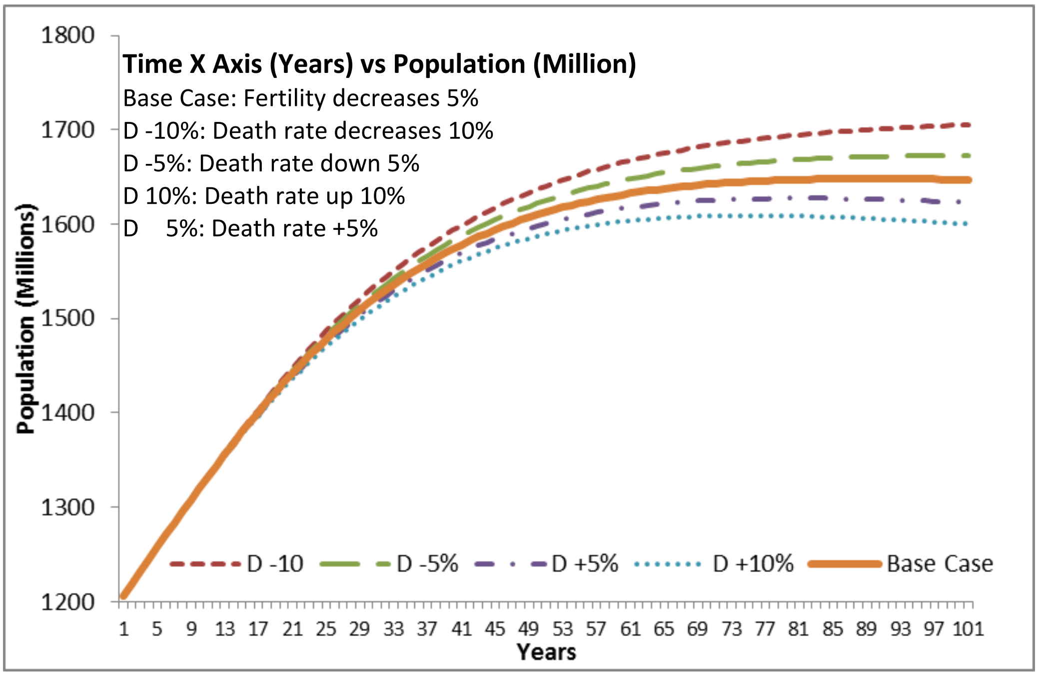

Figure 10 – Changes in Death Rates and the effect on population trajectories

Impact of Change in Mortality Rate

There has been an argument in literature that the crude death rate could also increase over time (Randers, 2012) at the rate of 0-2% per year. For finding the population projection sensitivity, the 12 stage model was subjected to changes in fertility over time. The model suggests that changes in population projection are relatively insensitive to changes in the death rate. Over a 50 year period, the change in population estimate for a -10% change in death rate to +10% change in death rate is limited to 3.2%.

Comparison with Other Projections

The Table 7 below shows the estimated population projections for the different model outputs – a) the 12 stage model, b) the 12 stage model with 5% fertility decline over 10 years c) the 12 stage model with 10% fertility decline over 10 years, and the projections available from d) India's Census e) World Bank and f) United Nations

Note that our projections differ significantly from the 2026 projections made in the 2011 Indian Census Report. WB projection goes upto year 2051 and does not predict a declining population scenario further down the line. The UN Medium Fertility projection indeed predicts a declining trend and is closest to our projection. The UN projection uses a component based model similar to ours, but the complete details of the model are not reported. The Indian Census and WB projections do not report the specific models that were used.

Sensitivity Analysis & Estimates						
Population Estimates (Million)						
	Simple 12	D-5-12	D-10-12	Census	WB	UN Med
Year 2026	1401	1390	1379	1340	1343	1431
Year 2051	1624	1578	1533	-	1620	1624
Year 2100	1802	1648	1505	-	-	1547
	Simple 12 - Simple 12 Stage					
	D-5-12	12 Stage 5% fertilitiy decline				
	D-10-12	12 Stage 10% fertilitiy decline				
	WB	World Bank				
	UN Med	UN Medium fertility forecasts				
	Table 7					

4. Conclusions & Future Work

India's Census report also provides mortality and fertility estimates for each of India's constituent states. Using these estimates to calculate population projections could lead to higher total population values (Dyson et al, 2005). Furthermore the population projections for individual states could indicate "flare" points – states where populations could keep growing at a significant pace.
The 12 stage model has been designed to account for all available critical input variables including fertility rates and death rates for different age groups. Continuous cohorting (Eberlain et al, 2012) technique can be explored to understand impact of issues arising out of fixed ageing buckets.

Also, at the aggregate level, population projections appear to be insensitive to intra-group changes in fertility and mortality rates as long as aggregate values for these variables remain same. However, population projections are quite sensitive to changes in fertility with time. India's population trajectory could significantly alter if fertility levels keep coming down. A 10% change in the fertility rate can change an exponentially rising population to a declining population. This highlights the importance of fertility rate in dictating a nation’s destiny.

Based on current fertility reduction trend, this 10% decline appears to be highly probable. It is possible that part of this decline may be counterbalanced by a concomitant decline in mortality rates. It seems intuitive that economic progress could bring down the mortality rates further. On the other hand, World3 model predicts that the mortality rates would go up after 2015 (A Global Forecast for the Next Forty Years, Jorgen Randers), due to increasing pollution and overcrowding. However, the change in mortality rate has an additive impact on population since it largely effects population of older, non-reproductive section of the society. On the other hand, a change in the fertility rate has a compounding effect because new-born children will form the future reproductive group. Given the conflicting projections, we have assumed a constant mortality rate (at 2011 levels) in this work, and have left more detailed exploration for future. Factors affecting mortality and fertility rates can be studied and framed into a System Dynamics structure. However such factors have not been modelled in this paper.

As discussed before, Census of India data is probably slightly underestimating fertility rate. Our assumption of equal sex ratio also means we are very slightly underestimating fertility rates in the model. Also, since the government will keep trying its best to reduce mortality rates, the consequences of not achieving a 10% reduction in real fertility rates will be drastic, and it is important for the Government of India to continue promoting family planning measures.

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