Stable and non-stable momentum of population growth: Examining the dominating effect of younger age-structure over fast fertility decline in Indian states

Introduction

The concept of population momentum refers to the fact that a population typically does not stop growing (or declining) the instant its fertility reaches replacement. Instead, in a closed population, growth or decline gradually slows until a stationary population is attained. The relative amount of momentum is usually measured by the ratio of the size of the long-run stationary population to that of the population when replacement fertility is first achieved (Nathan Keyfitz, 1971). For most of the country which have not yet completed their demographic transition, population momentum is still expected to contribute significantly to the future growth as relatively large cohort of children enter to their reproductive age and bear children. Population momentum contributes importantly to future population growth in developing countries. Bongaarts (1994) has estimated that momentum accounts for nearly one-half of projected future growth in the developing world over the next century. For the period 2000 to 2100, momentum is the most important factor in projected future growth for the world and all major regions except Europe and sub-Saharan Africa. For every region in the developing world except sub-Saharan Africa, momentum is a more important contributor to future population growth than all other factors combined. During the next half-century, momentum is projected to account for 58% of future population growth in the developing world (Bongaarts & Bulatao, 1999). In addition, one should not overlook the contribution of negative momentum to population decline in the developed world. Even with an immediate fertility rebound back to replacement, Europe’s population (ignoring migration) is projected to fall by 7% from current numbers before levelling off. And, in addition to Bulgaria, 11 other countries (all of which, except Japan, are in Europe) are projected to decline by more than 10% owing to negative momentum, even if fertility were to rise instantaneously and permanently to replacement.

Objectives of the study

The purpose of this study is to convey the deeper understanding of how age composition contributes to the long term population size in terms of ‘population momentum’ under various assumptions regarding the fertility level. The specific objectives of the present study is to decompose the total population momentum under immediate fertility decline to replacement level into two constituents and multiplicative parts i.e. “non-stable” momentum and “stable” momentum for India and its major states.

Data and methodology

The present study fulfils its objectives based on the some classic parameters like intrinsic growth rate, net reproduction rate, mean age of childbearing and reproductive value etc. for Indian states. Additionally, it will require the age wise population composition which is taken from Census-2011 data and the fertility and mortality schedules are taken from Sample Registration System, Registrar General of India. Methodological descriptions are discussed in detail in the following sections. Statistical software STATA 13 is used to project the observed as well as stable equivalent population using population projection matrix based on current and replacement rates.

Keyfitz’s general expression for population momentum: Given the above mentioned limitations, the original Keyfitz’s formula for population momentum cannot be applied to a general population if that population is not initially stable. But, Keyfitz himself provided the basis for more general expression (N. Keyfitz, 1985). Using Lotka’s integral equation for the birth trajectory in a population subject to constant vital rates, he showed that when replacement fertility rates, $m^*(a) = m(a)/\text{NRR}$, are imposed on a closed population whose age distribution is $N(a)$ and survival function $p(a)$, the annual number of births in the eventual stationary population will be

$$B_S = \frac{\int_0^\beta N(x) \int_x^\beta \frac{p(y)}{p(y)} m^*(y)dydx}{A^*} \qquad (4.2)$$

where A^* is the mean age at birth in the stationary population.

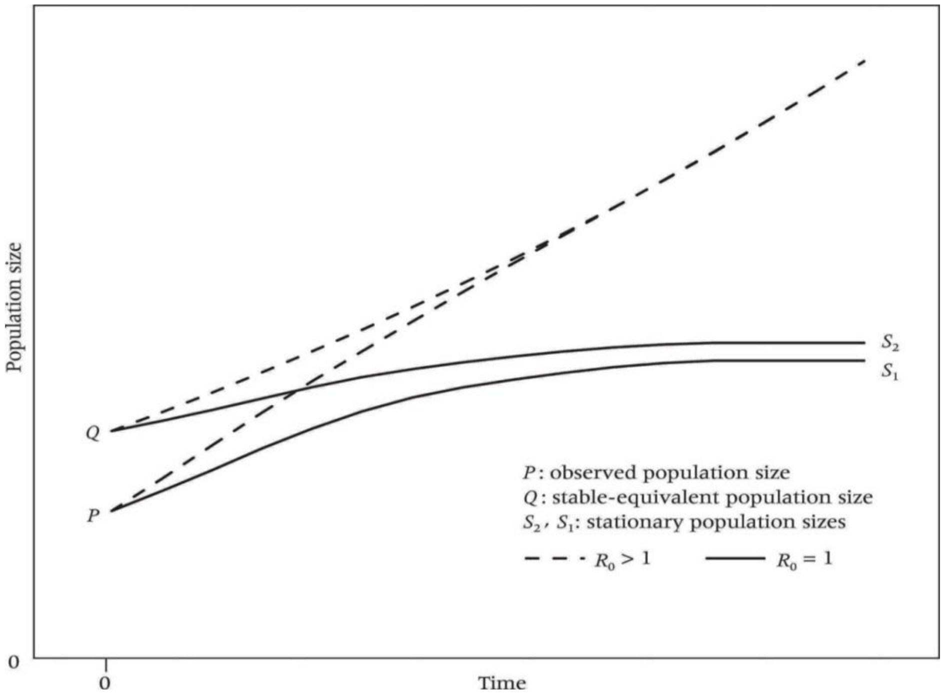
Decomposition of total momentum into non-stable momentum and stable momentum

For a given population, total population momentum is the size of the hypothetical stationary population achieved by projecting today's starting population with replacement fertility, zero net migration, and today's constant death rates, divided by the starting population today (Blue & Espenshade, 2011). Therefore the total population momentum is the cumulative contribution of age composition to the change in future population size. Espenshade, Olgiati, and Levin (2011) disaggregated the familiar momentum (i.e. total momentum) measure into two multiplicative parts: non-stable momentum and stable momentum. Total momentum captures the effects of deviations between population's current age distribution and the stationary age distribution produced by replacement fertility.

Theoretical framework for decomposition of population momentum

The stylized ingredients of a unified framework are shown in Figure 4.1 which is originally developed by Espenshade, Olgiati and Levin (2011). Let *P* be the size of an arbitrary initial population-arbitrary with respect to size, age structure, fertility and mortality. The main assumption is that the population consists entirely of female population and is closed to the migration. For the sake of illustration, fertility in Fig. 4.1 is above replacement level. Suppose that birth rates are lowered instantaneously to replacement at time t = 0 by dividing the observed fertility schedule by the net reproduction rate (R_0) and that fertility and mortality are then held constant. As shown by the lower solid line, the population eventually converges to a stationary population with size S_1. The ratio $\boldsymbol{S_1/P}$ is the usual measure of total population momentum.

Figure 4.1 Framework for understanding total momentum, non-stable momentum and stable momentum for a population



Source: Espenshade, Olgiati, and Levin (2011)

Suppose instead that the observed population P is projected holding current fertility and mortality constant. It will ultimately converge to a stable population as indicated by the trajectory of the lower dashed line in Fig. 4.1. Once a stable state has been attained, imagine using the stable growth rate (Lotka's r) to reverse project the size of the stable population back to $t = 0$. The reverse projection follows an exponential curve represented by the upper dashed line. The new population is the stable equivalent population. It has size Q, and its age distribution is the stable age distribution implied by the indefinite continuation of current fertility and mortality. It is asymptotically equivalent to the observed population in the sense that if both are projected forward from $t = 0$ holding current fertility and mortality constant, they will eventually become indistinguishable with respect to population size and age composition. We measure non-stable momentum with the ratio $\boldsymbol{Q/P}$.

Finally, consider a projection of the stable equivalent population using the same constant replacement-level fertility and mortality used to produce the lower solid line in Fig. 4.1. The size of the population begins at Q and follows the upper solid curve before levelling off at a stationary population of size S_2. Stable momentum is measured by the ratio $\boldsymbol{S_2/Q}$. The stationary populations represented by the endpoints of the two solid lines have the same proportionate age distributions, but they do not necessarily have the same size.

We may write the total momentum as the identity

$$Total\ Momentum\ = \frac{S_1}{P} \equiv \frac{Q}{P} \times \frac{S_2}{Q} \times \frac{S_1}{S_2}$$

In other words, total momentum is the product of non-stable momentum, stable momentum, and an offset factor represented by the ratio S_1 / S_2. If, however, $S_1 = S_2$, then

$$\frac{S_1}{P} \equiv \frac{Q}{P} \times \frac{S_2}{Q}$$

and, we would have accomplished an exact factorization of total population momentum, into the product of non-stable and stable momentum. Though, empirically it has been shown that deviations between S_1 and S_2 are negligible.

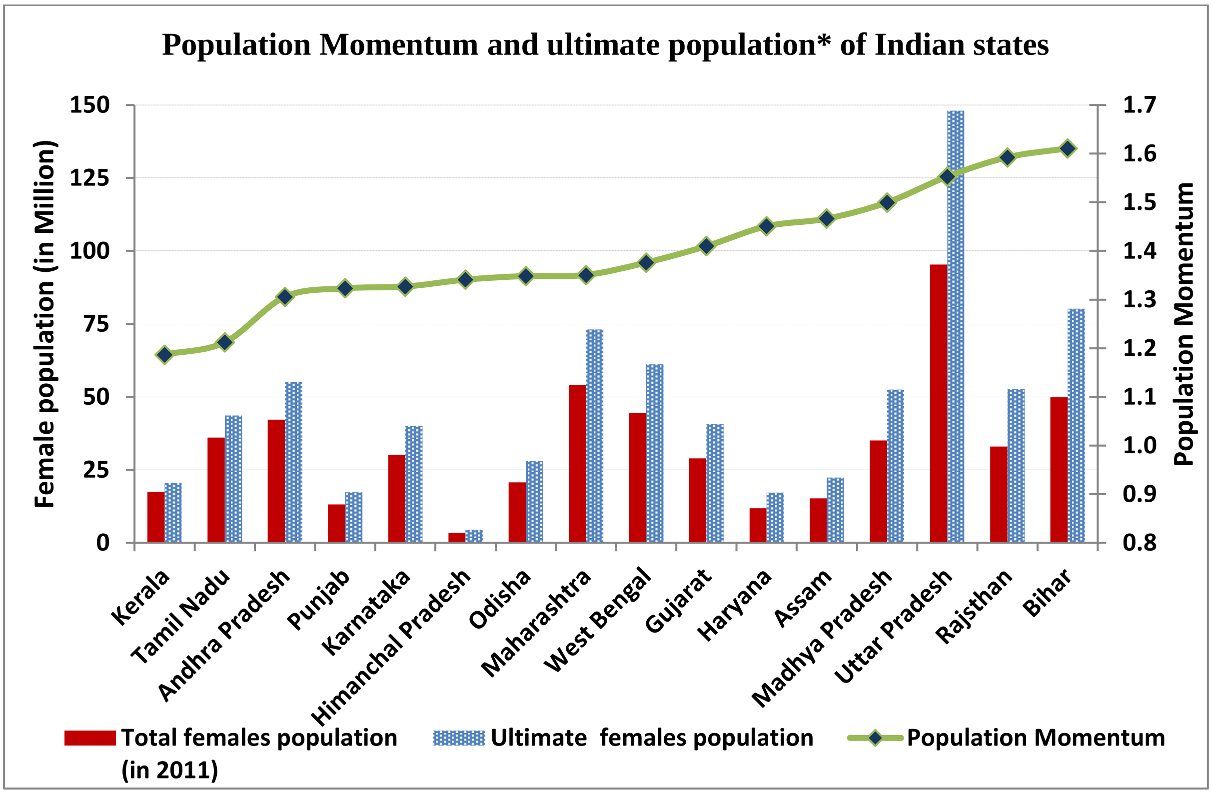
Results and discussion

This study discuss about size of the ultimate population attained if the vital rates are brought down to replacement level and kept constant further. It is well known fact that any population does not become stationary the moment it attains replacement fertility, rather it grow for some years before it settles to a fixed level. Here in the following section, the population momentum of India and its major states under assumption of immediate fertility decline to replacement level for 2011 population and then existing vital rates.

Population momentum under immediate drop to replacement fertility for Indian states

The population momentum for Indian states based on their 2011 population, if these states would attained the replacement fertility (NRR=1) immediately then, are estimated using the general expression of population momentum given by Nathan Keyfitz which is discussed in earlier section. Henceforth, in the whole discussion, population refers to female's population only as all calculations are done for one-sex population. It may be mentioned that for the calculation of population momentum, each state is assumed to be closed to migration. At national level, the observed female population of India in 2011 was around 587 million. If India could have attained replacement fertility in 2011 immediately, then the ultimate population would be 1.44 times higher than the observed level and will reach at 847 million.

Figure 4.2 Population momentums under assumption of immediate fertility decline to replacement level based on 2011 rates in Indian states



Source: Author's calculation;
** refers to female population only as all calculations is based on one-sex population*

Figure 4.2 presents the population momentum for Indian states under the assumption of immediate fertility decline to replacement level along with observed and ultimate population sizes. The highest population momentum is observed for Bihar (1.61 times) followed by Rajasthan (1.59 times), Uttar Pradesh (1.55 times), Madhya Pradesh (1.49 times) whereas the lowest momentum is observed for Kerala (1.19 times) followed by Tamil Nadu (1.21 times), Andhra Pradesh (1.30 times), Punjab (1.32 times), and Karnataka (1.33 times). Population momentum for other states lies in the range of 1.34 to 1.47. Southern states, Punjab, HP are experiencing the lowest fertility since long before so have the lowest momentum.

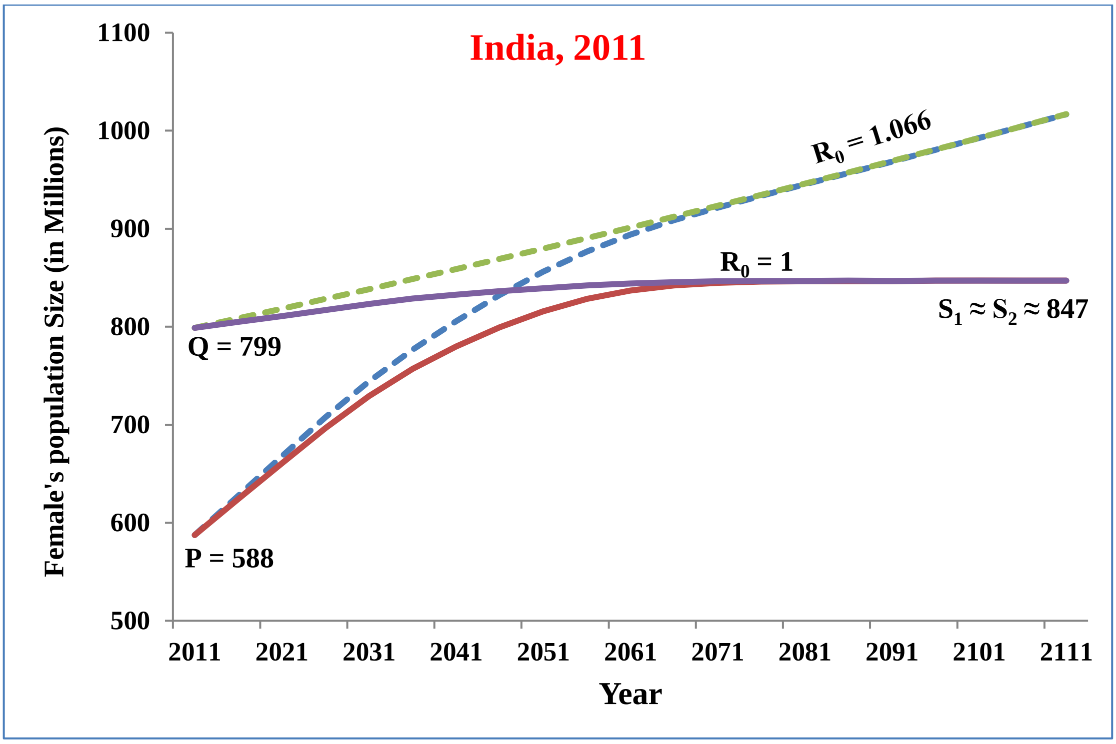
In 2011, most of the Indian states have achieved below replacement fertility i.e. net reproduction rate (NRR) below one, except Bihar (NRR=1.57), Uttar Pradesh (NRR=1.39), Madhya Pradesh (NRR=1.30), Rajasthan (NRR=1.27), Gujarat (NRR=1.05), and Assam (NRR=1.03). One should not get confused that population momentum can be estimated only for above replacement fertility states rather it can also be estimated for below replacement fertility states. Actually, after fertility transition there is a time lag during which population growth is continued as long as its age-distribution is favourable to higher birth rate. On the other hand, the high fertility states are comprises of relatively younger population, therefore, even if their fertility is dropped to replacement level abruptly, these states would grow further about more than 50 percent before being stationary.

In actual size, Uttar Pradesh has the highest observed female's population around 95 million which would increase to 148 million. The second highest observed population is for Maharashtra (54 million) followed by Bihar (50 million) but ultimate population size is higher for Bihar (80 million) compared to Maharashtra (73 million). This is because Bihar has higher fertility resulting into comparatively younger population than Maharashtra. Likewise, the high fertility states like Bihar, Uttar Pradesh, Madhya Pradesh and Rajasthan shares the maximum population of India and have the highest momentum too, therefore, the ultimate population of India will be more dependent on the growth of these high fertility states. In the states like Haryana, Gujarat, Assam and Odisha having NRR near to one, the momentum will be the main contributor to future population growth.

Decomposition of population momentum for Indian states

This study attempts to understand how total population momentum under immediate fertility decline to replacement level for Indian states can be disaggregated into non-stable momentum and stable momentum. Figure 4.3 presents the projection of the female population for India to empirically illustrate the decomposition of population momentum. In 2011, observed population was around 588 million and the size of the stable equivalent population was around 799 million. When both populations are projected forward for 100 years assuming replacement fertility, they converge to a stationary level of around 847 million. Hence, the total momentum = S_1/P=847/799=1.4419 can be decomposed into its two constituents called non-stable momentum=Q/P=799/588=1.3598, and stable momentum=S_2/Q=847/799=1.0601. Similar projections is done for the observed and stable-equivalent population of 16 major states of India for next hundred years based on observed and replacement fertility both.

Figure 4.3 Projection of female populations of India based on current fertility as well as assumed replacement fertility during 2011



Source: Author's estimation

In most of the Indian states, fertility has already fallen below replacement level, thus, having negative intrinsic growth rates during 2011. Only few states like Bihar, Uttar Pradesh, Madhya Pradesh, Rajasthan, Gujarat and Assam have above replacement fertility. Interestingly, it appears that the observed and their stable equivalent are asymptotically equivalent with respect to both current and replacement fertility (Figure 4.4 to Figure 4.7).

The values of total, non-stable and stable momentum for India and its major states are calculated and the results are presented in Table 4.1. There is an excellent agreement between column 1 and column 4 of Table 4.1 suggests that the products of non-stable and stable momentum are good approximations of the total momentum for Indian states. The estimate indicates that India's population would grow by an additional 44 percent, as total momentum was around 1.44, if the fertility rate had moved instantaneously to replacement in 2011. The non-stable momentum for India in 2011 was around 1.36 whereas stable momentum was around 1.06. The natural logarithm of the total, non-stable and stable momentum, presented in Table 4.2, shows that non-stable momentum accounts for about 84% of total momentum of India, and stable momentum contributes about 16%.

While looking at the state wise estimates of different component of population momentum in Table 4.1, it may be clearly observed that high fertility states like Bihar, Uttar Pradesh, Madhya Pradesh, Rajasthan have the largest values of total momentum and stable momentum and have lowest value for non-stable momentum. On the contrary, Kerala and Tamil Nadu have lowest values for total and stable momentum and have moderately high value for non-stable momentum. Since total momentum is the function of ratio between proportions in observed and stationary populations at young ages, therefore it will surely be influenced by the recent history of crude birth rates. High birth rates induced larger value whereas low birth rate predicts smaller value of total momentum. For example, Kerala and Tamil Nadu are enjoying below replacement fertility since many decades, thus, their age distribution have comparatively less younger population, thus have lowest total momentum. Recently, many states like Punjab, Tamil Nadu, West Bengal, Himanchal Pradesh Andhra Pradesh, and West Bengal have achieved the lowest fertility; therefore, these states have lowest value of stable momentum.

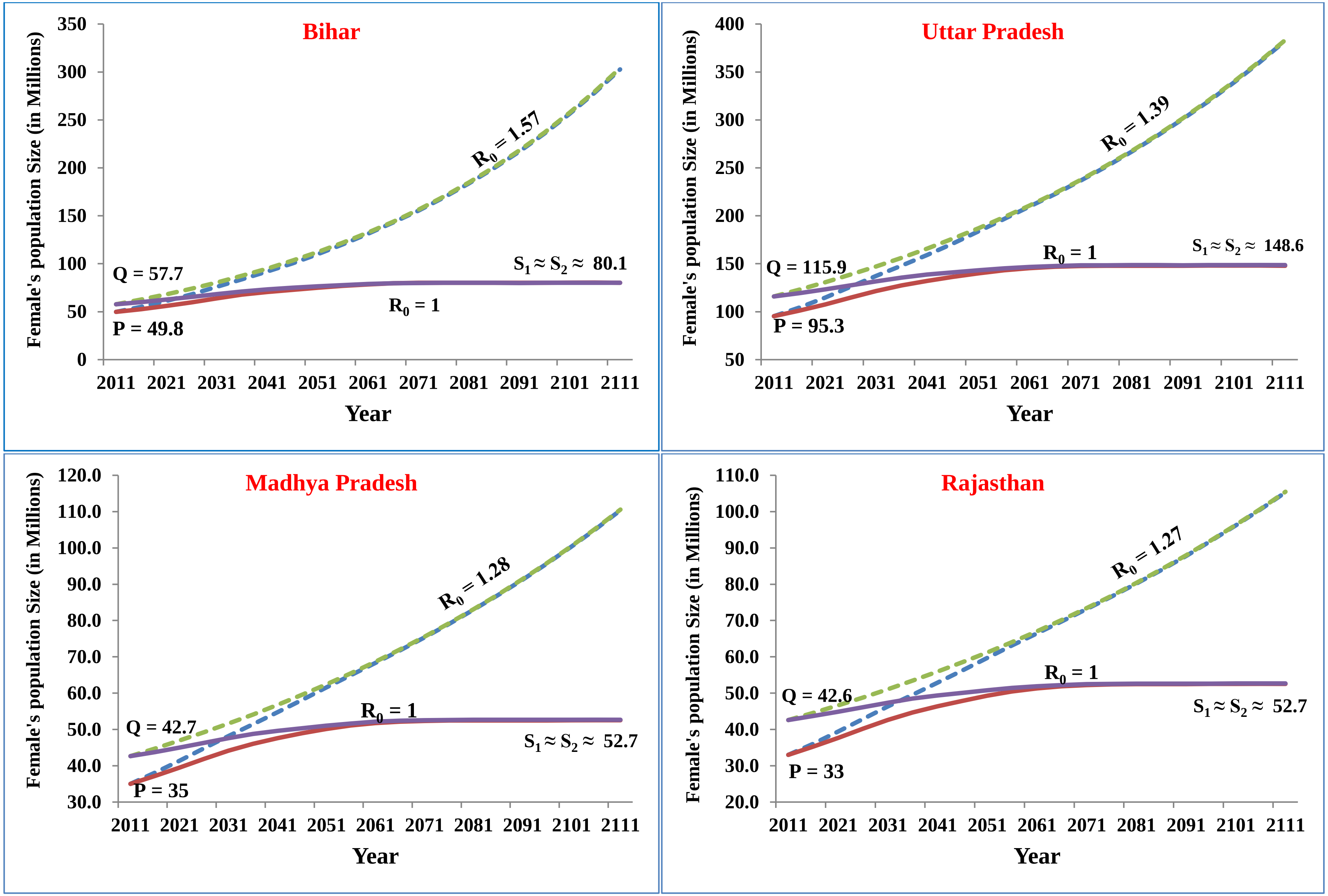
Non-stable momentum depends largely on relative proportions in the observed and stable equivalent age distributions before the onset of child bearing. Populations whose fertility is substantially below replacement level and whose age distributions had not fully adjusted to new fertility regime will have the high values of non-stable momentum. For example, the highest value of non-stable momentum in Indian states is for West Bengal (1.7729) followed by Punjab (1.7688), Himanchal Pradesh (1.7265), Maharashtra (1.6685), and Andhra Pradesh (1.6630). Although, these states have the lowest fertility as their NRR range from 0.76 to 0.81, but the fertility decline in these states is very recent phenomena. Hence, their age distributions are yet very far from the stable structures resulting into high values of non-stable momentum. On the other hand, the lowest value of non-stable momentum is for Bihar (1.1503), Uttar Pradesh (1.2112), Madhya Pradesh (1.2153), and Rajasthan (1.2881) which could be attributed to the high and relatively constant fertility resulting into age distributions which are approximately stable.

Stable momentum value involves a comparison between a population’s stable and stationary age distributions in the initial ages. When fertility is substantially above replacement level, stable age distribution will be young relative to stationary age distribution, which produces large value of stable momentum. If the fertility is much below replacement, the opposite circumstance will arise and values for stable momentum will be negative i.e. less than unity. For example, the highest value of stable momentum is for Bihar (1.3895) followed by Uttar Pradesh (1.2907), Madhya Pradesh (1.2428), and Rajasthan (1.2355); and the lowest value of

Table 4.1 Decomposition of Total Population Momentum into Non-stable and Stable Momentum for India and its major states based on 2011 female population and vital rates

States/India	Total Momentum S1/P	Non-stable Momentum Q/P	Stable Momentum S2/Q	Non-stable Momentum × stable Momentum	S1/S2
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Kerala	1.1681	1.3664	0.8550	1.1682	1.000
Tamil Nadu	1.2043	1.5794	0.7622	1.2037	1.000
Andhra Pradesh	1.3038	1.6630	0.7833	1.3025	1.001
Punjab	1.3119	1.7688	0.7417	1.3120	1.000
Karnataka	1.3223	1.5251	0.8667	1.3218	1.000
Himanchal Pradesh	1.3283	1.7265	0.7699	1.3292	0.999
Maharashtra	1.3405	1.6685	0.8042	1.3417	0.999
Odisha	1.3568	1.4025	0.9676	1.3571	1.000
West Bengal	1.3710	1.7729	0.7744	1.3730	0.999
Gujarat	1.4060	1.3503	1.0414	1.4062	1.000
Haryana	1.4442	1.5030	0.9608	1.4441	1.000
Assam	1.4793	1.4290	1.0352	1.4792	1.000
Madhya Pradesh	1.5098	1.2153	1.2428	1.5104	1.000
Uttar Pradesh	1.5630	1.2112	1.2907	1.5633	1.000
Rajasthan	1.5923	1.2881	1.2355	1.5915	1.001
Bihar	1.6135	1.1503	1.3895	1.5983	1.010
India	**1.4419**	**1.3598**	**1.0601**	**1.4415**	**1.000**

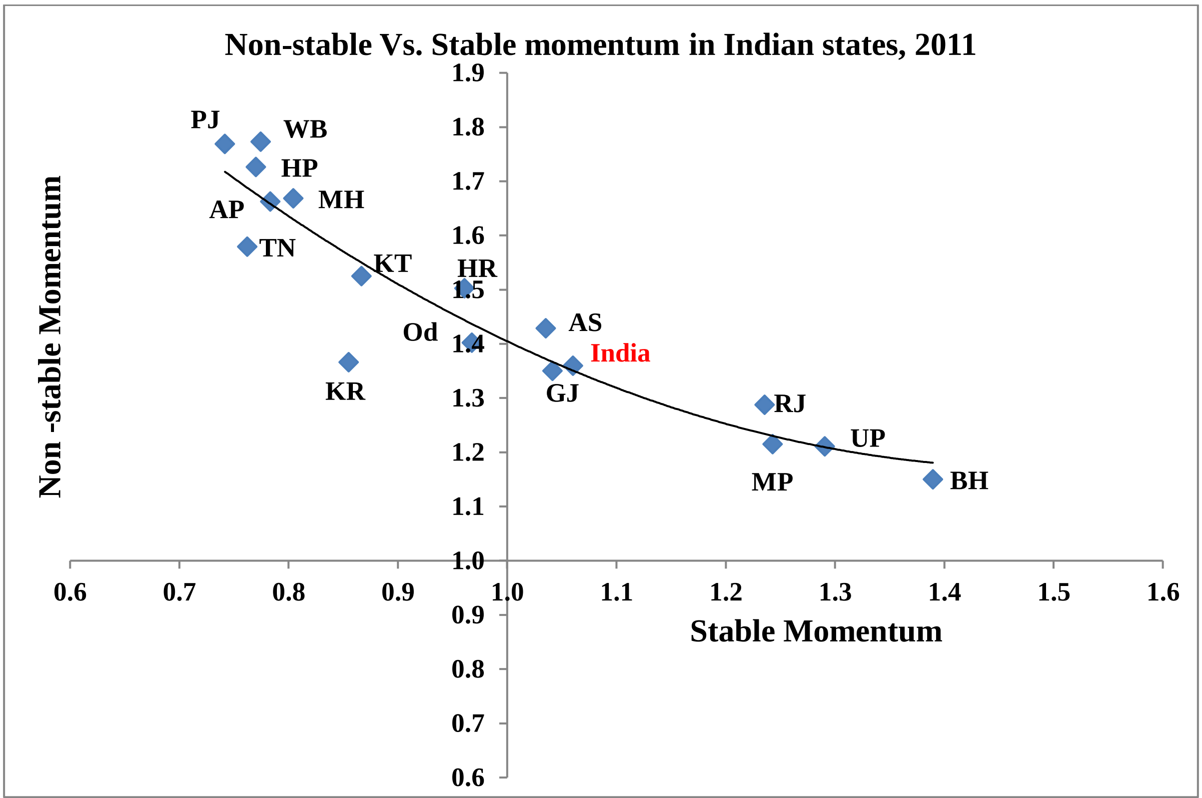
Figure 4.7 Projection of female populations of Indian states (high fertility states) for 2011-2111



stable momentum is for Punjab (0.7417) followed by Tamil Nadu (0.7622), Himanchal Pradesh (0.7699), and West Bengal (0.7744).

Figure 4.8 contains the scatter plot of points whose coordinates correspond to stable and non-stable momentum of major Indian states in 2011. The pattern depict that lower stable momentum is accompanied by the larger non-stable momentum and larger stable momentum is accompanied by smaller non-stable momentum. States like Punjab, West Bengal, Andhra Pradesh with recent history of substantially fertility decline below replacement have lowest negative stable momentum but have highest positive non-stable momentum. On the contrary, states like Bihar, Uttar Pradesh, Madhya Pradesh and Rajasthan have high and constant fertility, thus these states have the lowest non-stable momentum. Kerala has smallest total momentum as well as non-stable momentum among other low fertility states because it has maintained the low fertility since last two decades and its age distribution are near to stable.

Figure 4.8 Relation between non-stable momentum and stable momentum



Source: *Author's calculations based on 2011 population and vital rates.*

Summary and conclusion

The present study envisages the long term scenario of population sizes under different assumptions of fertility transition. It is quite evident from the findings that the future population growth of the Indian states are mostly attributable to the population momentum. There are some bigger states like Uttar Pradesh, Bhar, Madhya Pradesh, Rajasthan etc. which have still very high fertility rates, which ultimate population will be much higher because of their high fertility as well as the consequent momentum after the transition. Decompostion of total momentum of these states into stable momentum and non-stable momentum highlihts the posssible contribution of existing schedule of vital rates and current age distributions respectively. Low fertility states which have negative intrinsic growth rates e.g. South Indian states, Punjab, Himanchal Pradesh which have achieved sub replacement fertility many years before will have its propective growth due to their age distributions. On the other hand, high fertility states of North and central region will initially grow due to their high fertility and once they are succesful in reducing their fertility, the further growth would be prominantly attributable to their young age distributions. Although the fertility decline to replacemnt level is a gradual phenomenon but the speed of decline would matter most in deciding the ultimate size of these states.

The effect of nonstable momentum in compare to stable momentum is prominent and dominating while deciding the ultiate population size of Indian states. Though this effects can be normalized with increasing the mean age at marriage and mean age at first birth significantly and also by avoiding the second order births (Bongaarts, 1994). Hence, in India, the population policy at national and state level should be reframe so that it could motivate people to adopt the ‘Later, Longer and Lesser’ approach while deciding their fertility demand. Although India should not adopt the coercive approach like one child policy or makingg legislation to increase the age at marriage or forceful implementation of permanent methods of familiy plannings, but it must go for indirect non-coercive approach with proper implementation. One of the important option for the state government could be rapid human capital formation through education with greater investment and promotion for girls education, especially for secondary and higher level. Bongaarts (1994) suggests that longer the girls stay in school and colleges, later they will be married and greater will be the delay in child bearings. Another approach could be improved adolscent health and reproductive behaviour and lenthening the interval between births by promoting the use of contraceptions through efffective family planning proggramme. A comprehensive approach to implement all policy options is required on urgent basis, especially in backward states of northern and central regions but in general for whole India to avoide adverse consequences of rapid population growth.

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