A multistate lifetable analysis for the effects of the 1st marriage and marital reproduction on fertility in Singapore

Keita Suga
National institute of population and social security research
Tokyo, Japan

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This study examines the patterns and demographic factors underlying the fertility changes by major ethnic group in Singapore for 1980-2010, with focusing on the differential role of the 1st marriage by ethnic group. In order to derive the 1st marriage effects on annual changes in a period fertility measure during 1980-2010 in Singapore, we need to overcome the fact that the necessary data are not available in most of years during the period. We develop a numerical model to construct multistate lifetables each year for 1980-2010. Results show ethnic differentials and similarities in the 1st marriage and marital fertility effects.

Singapore has drawn demographers' attentions for intensive population control policies and their effects on fertility (Saw 2005; Wong and Yeoh 2003; Yap 2009; Straughan et al. 2009). Around ten years after the fertility rates attained the replacement level in 1975, Singapore government started relaxing and abolishing anti-natalist policies, and then introducing restrictive pro-natalist policies. To these policy interventions, TFRs responded differently by the ethnic group.

Figure 1 shows period TFR by ethnic group in Singapore for 1975-2010. On the one hand, Malays' TFR turned to increase at 1979, when anti-natal policies continued, and stayed above the replacement level throughout the 1990s, but is rapidly declining after 2000. On the other hand, Chinese's TFR stopped to decline in 1983 when pro-natal policies selectively targeting highly educated females were introduced. It increased from 1986 to 1988, but declined steadily since the 1990s. It also has fluctuations for tiger years(1986, 1998, 2010) and dragon years(1988, 2000). In short, TFRs recovered about the replacement reproduction in the late 1980s. However, fertility rates resumed to decline from the early 1990s. As a reaction to the prolonged fertility declines, the government strengthened and enhanced the pro-natalist policies under three rounds of "Marriage and Parenthood Package" since the 2000.

One of the most frequently mentioned policy interventions in Singapore is a promotion of marriage and its distinct effects by education attainment levels. Ethnic differentials of fertility are also argued from this perspective as an extent that Chinese females are relatively better educated. Nevertheless, there are few studies directly analyzing either an effect of nuptiality on fertility changes or its ethnic differentials in Singapore, partly because of limited data availability.

With utilizing only statistical tables publicized by Singapore government, this paper estimates multistate lifetables regarding the 1st marriage and parity specific childbirths by ethnic group each year for 1980-2010. Then, we derive the 1st marriage effect on annual fertility changes by a decomposition method for a difference in a period measures. In Singapore, population at risk for the multistate lifetable (i.e. female population by marriage and birth state) is available only in the decennial census years. Still, we are able to construct multistate lifetables each single year, if the size of the total population and the number of demographic events during the period are known; the situation that we often encounter in many other countries. The reason is that the number of demographic events has strong correlation to hazard rates and information from vital statistics scaled by total population is enough to recover the transition probability matrix. Furthermore, more information gives better estimates; we are able to improve the lifetable estimates, if we observe the populations at risk in more than two times and the number of demographic events during interim years. Finally, the decomposition results reveal ethnic differentials and similarities: for overall changes of fertility changes from 1980 to 2010, nuptiality accounted completely for Malay's fertility changes, while both nuptiality and marital fertility affected Chinese fertility; negative nuptiality effects have increasingly impacts both on Malay's and Chinese fertilities in recent years.

Data and Methodology

Multistate lifetable analysis of fertility with limited data

In general, a multistate lifetable requires, for construction, transition probabilities for all state transitions, each of which is calculated by (1) the number of demographic events by states (i.e. the number of demographic events that risk population experiences) for numerator and (2) population by states (i.e. population at risk) for denominator. The latter is obtained by the state distribution multiplied by total population of all states. For the case of Singapore, the number of marriages and live births by the order (numerators for the state transition probabilities) can be obtained from vital statistics each year[i]. The state distributions (distributions of the nevermarried and parity specific evermarried females) by ethnic group are computable from the results of population census[ii] only in the decennial census years after 1980 but not available in other interim periods. Thus, we need to estimate states distributions for interim periods to construct multistate lifetables for each year 1980-2010. Once, with the intervening state distributions between census years at hand, we are able to calculate the state transition probabilities with the number of marriages and childbirths divided by the state distributions scaled to mid-year population estimates, then the multistate lifetable is constructed via a standard procedure (e.g. Pollani 2001).

Figure 2 shows overview of the multistate lifetable construction that employs an estimation for the state distribution between census years. First, notice that state transition rates in a particular year t correspond with probabilities for age x~x+4 population moving from state i to other states j until age x+1~x+5 for the year t. For instance, the 1st marriage hazard of age x~x+4 in year t may be treated as a probability of female population being evermarried by age x+1~x+5 conditional on the cohort being nevermarried at age x~x+4 in year t. We take advantage of this nature of state transition rates to estimate the state distribution of age x~x+4 in year t+1 with the state distribution of age x~x+4 in year t multiplied by the transition probability for the age and a transformation of age x+1~x+5 to x~x+4 of newly calculated state distribution for year t+1. Furthermore, with a state distribution from year-t census taken as an initial value and forward recursive estimations of state distributions, we have an estimate for the next census in year T, when another state distribution is observed. We improve state distribution estimates from year t+1 to T-1 with an additive adjustment term by age and state, which is identified by means of minimizing mean squared errors of the state distribution estimate for year T from the census distribution. Figure 3 depicts the detail of the adjustment strategy for the 1st marriage of a birth cohort whose age was 20-24 in year t as an example. See appendix 1 for the mathematical details of solving the adjustment problem.

The adjustment for the state distribution estimates between census years has four advantages. First, the state distributions obtained from the *Singapore Census of Population* could be erroneous, because the results for the state distribution calculations are obtained based on 10-20% sample surveys. We need to smooth the connections between the state transition rates before and after census years, and the smooth connections are automatically accomplished by the adjustment. Second, in estimation of the state distribution in year t+1 from the distribution in year t, we need to apply the half of the hazard rates for year t and the half of year t+1(from midyear of t to midyear of t+1) but not the hazard rates for year t as in the present procedure. Third, data are available only by the five-year age category. When estimating state distributions for age x~x+4 in year t+1, we need to retrieve state distributions for age x~x+4 from those of age x+1~x+5 by an age transformation. Here we assume uniformities of the rates among age x~x+4 and age x+1~x+5 and obtain rates for age x~x+4 by 1/5 of junior cohorts plus 4/5 of senior cohorts. This uniformity assumption gives only rough estimates. Finally, these discrepancies are cumulated forward.

Decomposition method

As a measure of completed period fertilities which summaries the multistate lifetables, we calculate the total period average parity (TPAP), which is a weighted sum of a lifetable function, $l_x(parity)$ for parity 1 and over, at the end of the reproduction age with their parities as the weight. It is evident from the construction of the multistate lifetables that TPAP is a function of hazard rates for the 1st marriage and order-specific births given by married women. To achieve a decomposition of the components, this study extends an analysis in Suga(2012) by employing a generalized Kitagawa's decomposition method to a difference of the function (Das Gupta 1993). It can be shown that a difference of TPAP in year T from a year of reference (t=0) is decomposed into two components as in Eq. [1], from which Eq.[2] follows.

$$TPAP_t - TPAP_{t-1} = \mathrm{A}_t + \mathrm{B}_t \qquad \text{Eq.[1]}$$

$$\frac{1}{T}\left(TPAP_T - TPAP_0\right) = \frac{1}{T}\left(TPAP_T^{\alpha} - TPAP_0\right) + \frac{1}{T}\left(TPAP_T^{\beta} - TPAP_0\right). \qquad \text{Eq.[2]}$$

Where $TPAP_T = TPAP_0 + \sum_{\tau=1}^{T}\mathrm{A}_\tau + \sum_{\tau=1}^{T}\mathrm{B}_\tau$ Eq.[3]

$$TPAP_T^{\alpha} = TPAP_0 + \sum_{\tau=1}^{T}\mathrm{A}_\tau \qquad \text{Eq.[4]}$$

$$TPAP_T^{\beta} = TPAP_0 + \sum_{\tau=1}^{T}\mathrm{B}_\tau \qquad \text{Eq.[5].}$$

In Eq. [1], A_t measures an effect of a change in the 1st marriage hazard on the difference of TPAP, and B_t quantifies a contribution of a change in marital childbirth hazards, and TPAP calculated by the multistate lifetable for year T is decomposed into the sum of TPAP in the year of reference ($TPAP_0$), total first marriage effects over the period from year 0~1 to year T-1~T ($\sum_{\tau=1}^{T}\mathrm{A}_\tau$) and total effects of childbirth hazards over the period from year 0~1 to year T-1~T ($\sum_{\tau=1}^{T} \mathrm{B}_{\tau}$). We call $TPAP_T^{\alpha}$ in Eq.[4] as "cumulated first marriage effect". It is a period measure which increases/decreases only in response to the change in the 1st marriage hazard. It corresponds with time series of the total average number of births that women in hypothetical cohorts would have, if no change in childbirth hazards and shapes of the age schedule from year 0 to year T. Similarly, $TPAP_T^{\beta}$ in Eq.[5], "cumulated marital fertility effects", reveals time series of period total average parities with a fixed naptiality. It reflects a cumulative effect of changes in childbirth hazards of the ever-married from year 0 to year T, interpreted as the number of births of women in hypothetical cohorts under a constant 1st- marriage hazard at the level of year 0 with an invariant shape of age pattern. Eq.[2] decomposes an annual average change of TPAP from year 0 to T into contributions of the cumulated nuptiality and marital childbirths.

Defining $TPAP_T^{\alpha}$ in Eq.[4] and $TPAP_T^{\beta}$ in Eq.[5] is attractive, because the decomposition result can be graphically summarized and demonstrated in one single figure. Notice from the equations [3], [4] and [5] that the difference between the cumulated marital fertility (first marriage) effect and the TPAP calculated by the multistate lifetable for year t equals to the total first marriage (marital fertility) effects cumulated from year 0~1 up to year t-1~t. Figure 4 depicts Eq. [3], [4] and [5] for Chinese in Singapore, and illustrates that the area between the dotted line and the solid line corresponds to the total decline of TPAP due to the decrease in the marital fertility from 1980 upto each year ($-\sum_{\tau=1}^{t} \mathrm{B}_{\tau}$).

Summary of the results

Figure 5 depicts the decomposition results for Chinese and figure 6 corresponds with the result for Malay's TPAP. Table 1 summarized the calculation of percent distribution of both effects for overall change in 1980-2010.

By the comparison between figure 5 and 6, it is evident that the changes in marital fertility affected TPAP severer for the Chinese than for the Malay. Among the Chinese, table 1 shows that both the 1st marriage- and marital fertility- effects account halves of the decline in TPAP for 1980-2010. Moreover, figure 5 shows that TPAP decreased mainly due to marital fertility effects for 1980-1984 and 1988-1999, while decreases of the 1st marriage increasingly affected TPAP after 2000. Among the Malays, table 1 confirms that marital childbirth hazards had the positive net effects on TPAP for

1980-2010 overall. Also, figure 6 shows positive marital fertility effects increased from the mid-1980s to around 1990 and decreased from around 2000 to the mid-2000s; marital fertility effects stayed almost unchanged in other periods and the 1st marriage effects were attributable to TPAP falls after the early 2000s. Prolonged decline in Malay's TPAP since the 1990s with the stability of the cumulated marital fertility effect imply a role of nuptiality as a primary determinant of Malay's fertility decline, especially after the early 2000s.

Table 2 summarizes the ethnic differentials and similarities in the 1st marriage and marital fertility effect on fertility changes by specific periods. Contrary to impressions from the figures for 1980-2010 overall, ethnic differentials are found only in one period for each of effects. First, in 1990s Malay's marital fertility was almost constant, while Chinese marital fertility decreased by 12%. Second, after 2000 Chinese 1st marriage effect decreased by 13%, while Malay's 1st marriage effect fallen by 30%. For other periods, although the magnitude of the fertility varies by ethnic group, patterns of the fertility coincide among two factors.

Concluding remarks

In this paper, we have discussed about how to construct multistate lifetable when state distributions could not be obtained in parts of years, and proposed a numerical model. Even when statistical tables for population at risk for a specific event are not available, we could still construct multistate lifetables, if the size of the total population and the number of demographic events until the year were known. The reason is that the number of demographic events has strong correlation to hazard rates, and information from vital statistics scaled by total population is enough to construct transition probability matrix.

Moreover, if state distributions are observed in more than years and we have the number of demographic events during interim years, we could improve state distribution estimates. The reason is simply using information both from the beginning and the end of the period is better than using only one of them.

Finally, we found ethnic differentials and similarities in the 1st marriage and marital fertility effects. We should be cautious to derive policy implication from the results, because fertility changes as a consequence of many factors that may be endogenous and it is arduous to isolate the effects of policy without an access to more detailed data. However, the fact that Malay's rapid fertility decline after 2000 was a consequence of the 1st marriage effect may call for new research directions to further discuss policy implications, because the government introduced intensive pro-natal policy after 2000. Although Malay's fertility is higher than Chinese in 2010, this fact would suggest that Malay's marriage and fertility behavior be getting resembling Chinese behavior.

Appendix 1. The method for solving the adjustment problem

Let $S=\{1,2,3,4,5,6\}$ denotes the state space. States from 1 to 6 correspond with the marriage and childbirths states as in the following order: nevermarried, evermarried and no child; evermarried and parity 1; evermarried and parity 2; evermarried and parity 3; evermarried and parity 4 and over. Let ${}_5L^{c,S_i,t}_{x\sim x+4}$ be a rate of female population of age x~x+4 who stays in the i^th^ state at the time of census in year t. Let ${}^{i\to j}M^{t\to t+1}_{x=x+4\to x+1\sim x+5}$ be the state transition of female of age x~x+4 in year t moving from state i to other states j until age x+1~x+5 by the year t+1. Let ${}_5K^{S_i,t+1}_{x+1\sim x+5}$ be a estimate for the rate of female population of age x+1~x+5 who stays the i^th^ state in year t+1. Let ${}_5L^{p,S_i,t+1}_{x+1\sim x+5}$ denote a estimate for the rate of female population of age x+1~x+5 who stays the i^th^ state in year t+1. Then $\left\{{}_5K^{S_i,\tau}_a, {}_5L^{p,S_i,\tau}_a\right\}$ for $\tau=t+1,\cdots,t+5$ and $a=x+1\sim x+5,\cdots,x+5\sim x+9$ may be solved recursively starting from year-t census distribution until the year t+5 when the next census distribution is available as in Eq.[A1]~[A2].

$$
\begin{aligned}
{}_5K^{S_i,t+1}_{x+1\sim x+5} &= {}_5L^{c,S_i,t}_{x\sim x+4}\cdot\left(1-{}^{i\to i+1}M^{t\to t+1}_{x=x+4\to x+1\sim x+5}\right) \quad \textit{if t is census year}\\
&= {}_5L^{p,S_i,t}_{x\sim x+4}\cdot\left(1-{}^{i\to i+1}M^{t\to t+1}_{x=x+4\to x+1\sim x+5}\right) \quad \textit{otherwise}
\end{aligned}
\qquad \text{Eq.[A1]}
$$

$$
\begin{aligned}
{}_5L^{p,S_i,t+1}_{x+5\sim x+9} &= \delta^{S_i,t\to t+5}_{x\sim x+4\to x+5\sim x+9} + \left({}_5L^{c,S_i,t+1}_{x-4\sim x} + 4\cdot{}_5L^{c,S_i,t+1}_{x+1\sim x+5}\right)/5 \quad \textit{if t is census year}\\
&= \delta^{S_i,t\to t+5}_{x\sim x+4\to x+5\sim x+9} + \left({}_5K^{S_i,t+1}_{x-4\sim x} + 4\cdot{}_5K^{S_i,t+1}_{x+1\sim x+5}\right)/5 \quad \textit{otherwise}
\end{aligned}
\qquad \text{Eq.[A2]}
$$

where $\left\{{}_5K^{S_1,t+1}_{16\sim 20}, {}_5K^{S_2,t+1}_{16\sim 20},\cdots,{}_5K^{S_6,t+1}_{16\sim 20}\right\}=\{1,0,\cdots,0\}$ is given by a radix for the model lifetable, Eq.[A2] defines $\left\{{}_5L^{p,S_i,t+1}_{x+5\sim x+9}\right\}$, and we call $\delta^{S_i,t\to t+5}_{x\sim x+4\to x+5\sim x+9}$ as the average error in the estimation for the rate of female population of age x+5~x+9, who stays in i^th^ state in year t+5, based on the state distribution in year-t census for the same cohort whose age was x~x+4 in year t. The average error spreads the total error, $\left({}_5L^{p,S_i,t+5}_{x+5\sim x+9} - {}_5L^{c,S_i,t+5}_{x+5\sim x+9}\right)$,

over each predicted values of $\left\{{}_5L^{p,S_i,t}_{x+5\sim x+9}\right\}$ for interim years between two censuses.

We solve the average errors $\left\{\delta^{S_i,t\to t+5}_{x\sim x+4\to x+5\sim x+9}\right\}$ for each state $\{S_i\}$ *for* $i = 2,\cdots,6$ and age $\{x \sim x+4\}$ *for* $x = 20,25,\cdots,45$ by interim period between censuses $\{t \to t+10\}$ *for* $t = 1980,1990,2000$ and $\{t \to t+5\}$ *for* $t = 2005,2010$ by means of minimizing sum of squared errors $\sum_{i=1}^{6}\left(\varepsilon^{i,t\to t+5}_{x\sim x+4\to x+5\sim x+9}\right)^2$, where each of squared errors is calculated by a system of 6 highly nonlinear equations as in Eq.[A3]~[A4]. For the optimization, we rely on the modified newton's method with initial values of $\mathbf{0} = \left\{\delta^{S_i,t\to t+5}_{x\sim x+4\to x+5\sim x+9}\right\}_{i=2,\cdots,6}$. Then, state distributions of all year during the interim period, ${}_5L^{p,S_i,\tau}_{x\sim x+4}$, will be recovered by Eq.[A2].

$$\varepsilon^{i,t\to t+5}_{x\sim x+4\to x+5\sim x+9} = \log\left({}_5L^{p,i,t+5}_{x\sim x+4} \Big/ \left(1 - {}_5L^{p,i,t+5}_{x\sim x+4}\right)\right) - \log\left({}_5L^{c,i,t+5}_{x\sim x+4} \Big/ \left(1 - {}_5L^{c,i,t+5}_{x\sim x+4}\right)\right) \text{ for } i = 2,\cdots,6 \qquad \text{Eq.[A3]}$$

$$\varepsilon^{1,t\to t+5}_{x\sim x+4\to x+5\sim x+9} = \log\left(\left(1 - \sum_{i=2}^{6} {}_5L^{p,i,t+5}_{x\sim x+4}\right) \Big/ \left(\sum_{i=2}^{6} {}_5L^{p,i,t+5}_{x\sim x+4}\right)\right) - \log\left({}_5L^{c,1,t+5}_{x\sim x+4} \Big/ \left(1 - {}_5L^{c,1,t+5}_{x\sim x+4}\right)\right) \qquad \text{Eq.[A4]}$$

$${}_5L^{p,S_i,t}_{x\sim x+4} \in [0,1] \quad \forall i,t,x \qquad \text{Eq.[A5]}$$

$$\sum_{i=1}^{6} {}_5L^{p,S_i,t}_{x\sim x+4} = 1 \quad \forall t,x \qquad \text{Eq.[A6]}$$

Note that state distributions are probability distributions so that they must satisfy two conditions specified in Eq.[A4]~[A5]. We apply log-odds transformation as in Eq.[A3] for the first restriction Eq.[A4] and impose the second restriction Eq.[A6] on state 1 as shown in Eq.[A4].

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[ii] For 1980-2010, the number of live births by the order, mother's age and ethnic group can be taken from *Report on the Registration of Births and Deaths* (Registry of Births and Deaths, Immigration and Checkpoints). No data are available for the 1st marriages by women's age and ethnic group, but the 1st marriages by women's age and registration system are available in *Statistics on Marriages and Divorces* (Department of Statistics, Singapore). In 2010, 83% of total marriages was registered under the Women's Charter in which 76% of wives was Chinese. Muslim marriages accounted 13% of total marriages and 73% of muslim wives was Malay. Thus, we expect that the fraction of the 1st marriage among all marriages under Women's Charter given an age should be strongly correlated with Chinese fraction of the 1st marriage among marriages given an age. Then, we indirectly estimate Chinese age-specific first marriages by sum of two parts; Chinese marriage under Women's Charter multiplied by the fraction of 1st marriage under Women's Charter, and the inter-ethnic Muslim marriage of Chinese multiplied by an age distribution of Muslim marriages of other than Malays or Indians and the fraction of 1st marriage under Muslim Law Act.

[ii] Khoo, Chian Kim(1981) *Singapore: Census of Population 1980, Release No.2*

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Figures and table

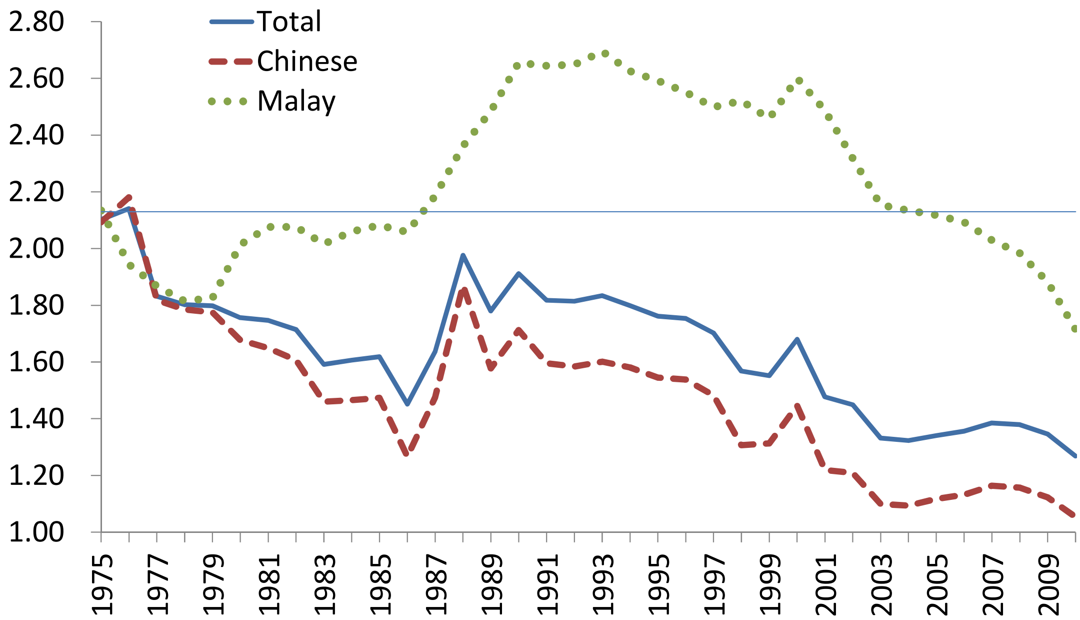
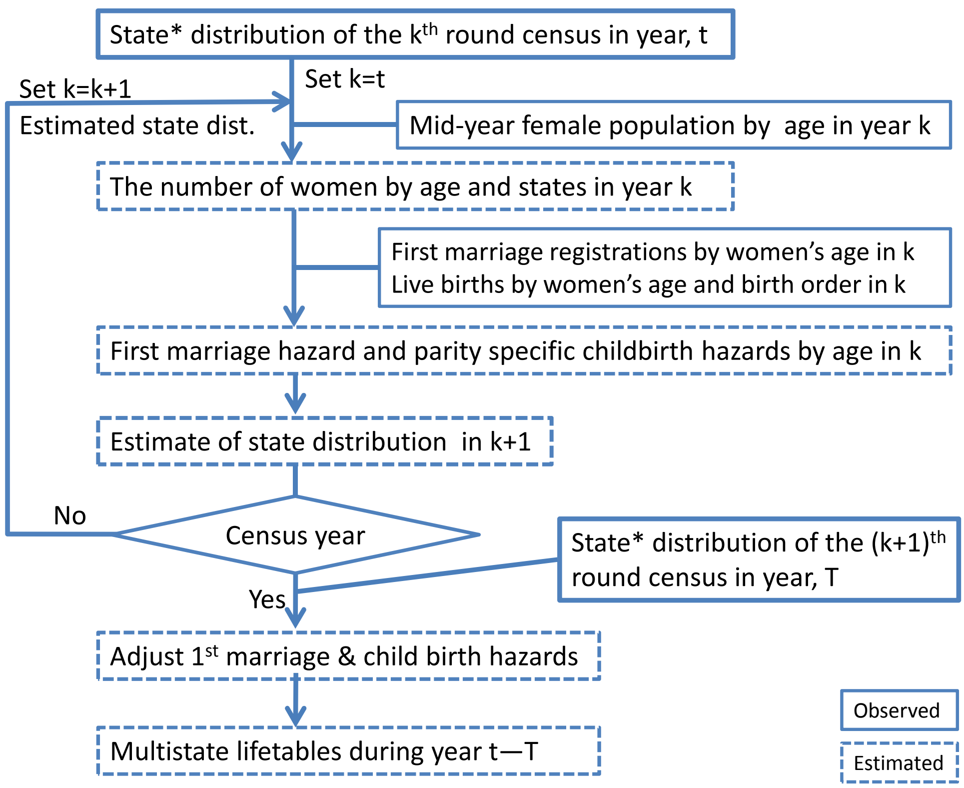


Figure 1. Period TFR by ethnic group in Singapore: 1975-2010.



*States={Nevermarried, Married&[No child, parity 1, parity2 , parity 3, parity 4+]}

Figure 2. Multistate lifetable construction with limited data.

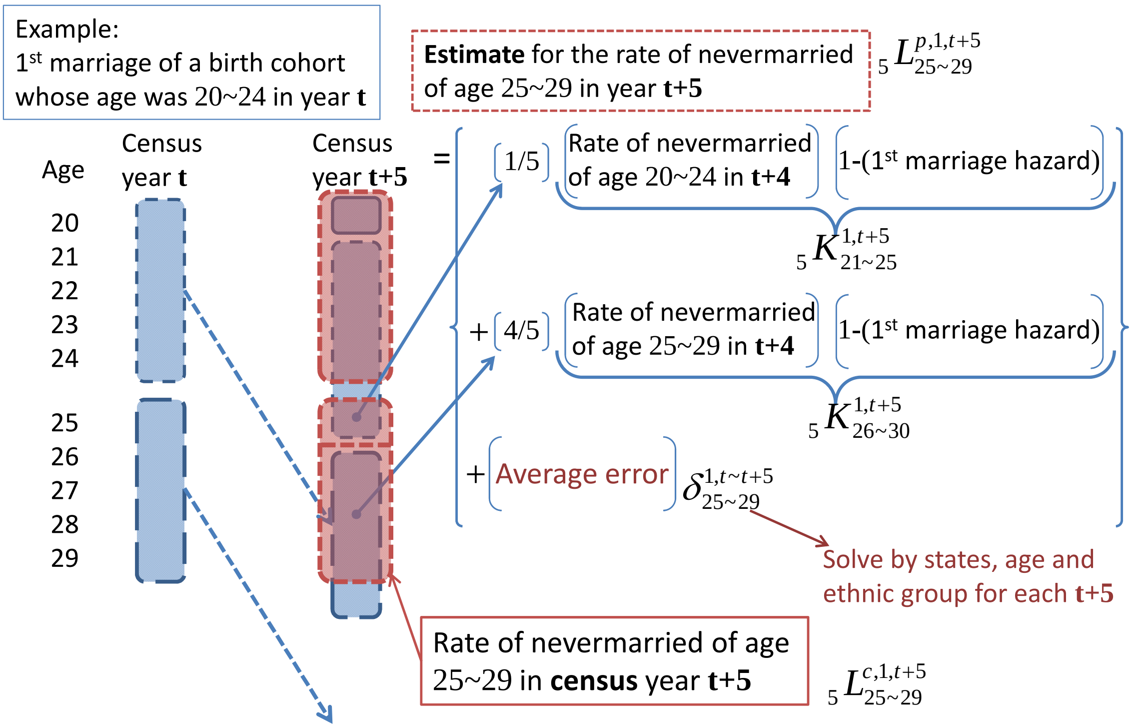


Figure 3. Adjustment strategy for the fist marriage and marital childbirth hazards.

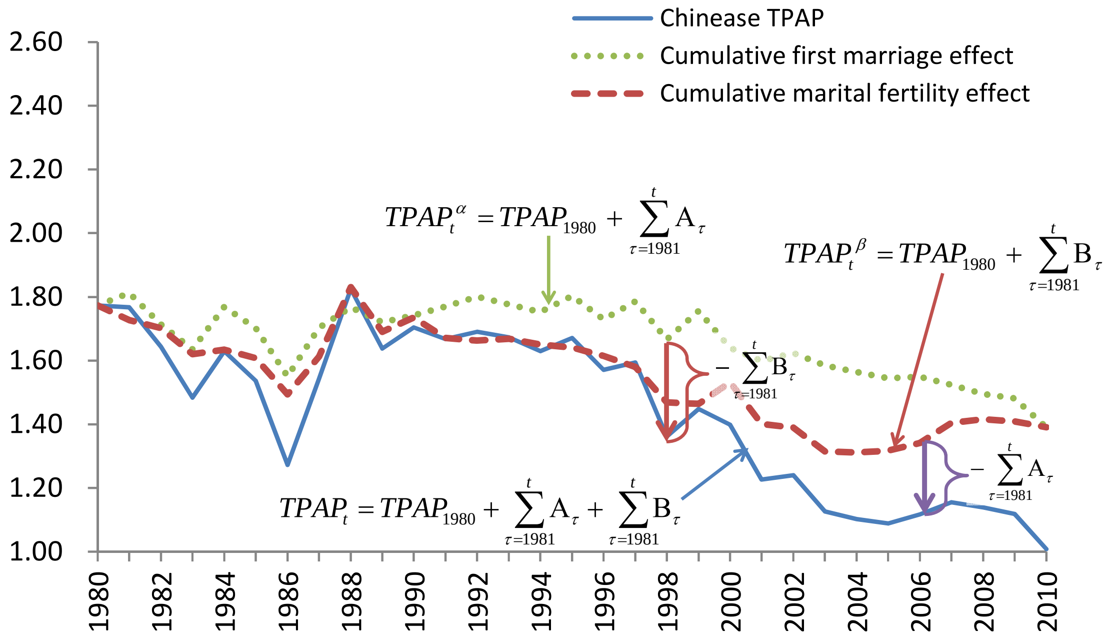


Figure 4. Decomposition of period TPAP into the first marriage component and the marital fertility component.

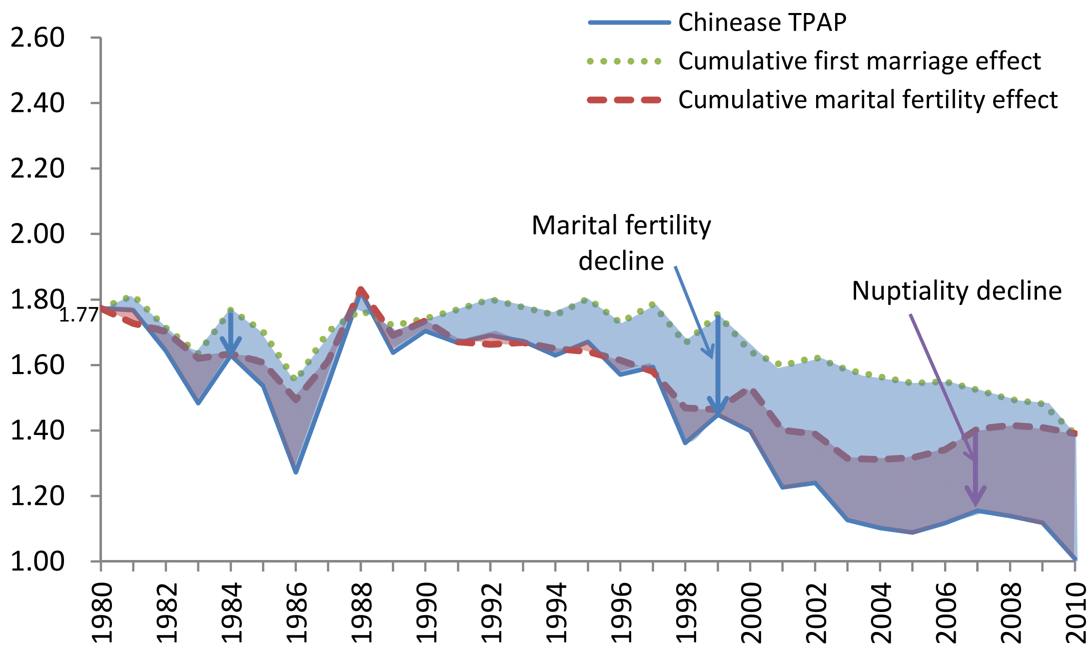


Figure 5. Decomposition result of TPAP into effects of the first marriage and marital fertility: Chinese in Singapore, 1980-2010.

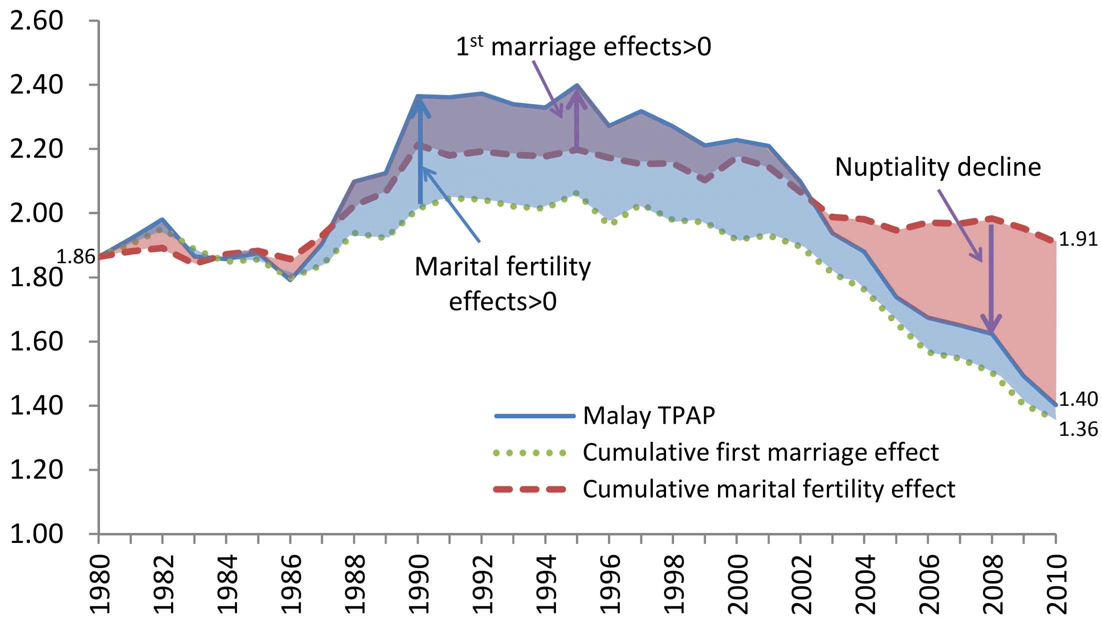


Figure 6. Decomposition result of TPAP into effects of the first marriage and marital fertility: Malay in Singapore, 1980-2010.

Table 1. Decomposition of TPAP into contributions of the 1st marriage and marital fertility effects: Chinese and Malay in Singapore, 1980-2010 overall.

	Years		Δ(2010-1980)
	1980	2010	
I. Chinese			
Change of period measures			
Total period average parity[1)]	1.773	1.008	-0.765
Cum. 1st marriage effect[1)]	1.773	1.390	-0.383
Cum. marital fertility effect[1)]	1.773	1.391	-0.382
Percent distribution of effects			
1st marriage effect[2)]			-50.1
Marital fertility effect[3)]			-49.9
II. Malay			
Change of period measures			
Total period average parity[1)]	1.863	1.403	-0.461
Cum. 1st marriage effect[1)]	1.863	1.358	-0.506
Cum. marital fertitlity effect[1)]	1.863	1.908	0.045
Percent distribution of effects			
1st marriage effect[2)]			-109.7
Marital fertility effect[3)]			9.7

Note: 1) $[TPAP_{2010}-TPAP_{1980}]*B/T$ where B stands for the length of the reproductive years(i.e. age 20-49) and T stands for the length of the period. TPAP should be read as X^a for cumulative 1st marriage effect and X^b for cumulative marital fertility effect, defined in Eq.[6] and Eq.[7], respectively. 2) % ratio of $[X^a_{2010}-X^a_{1980}]$ / $[TPAP_{2010}-TPAP_{1980}]$ where X^a denotes cumulative 1st marriage effect defined in Eq.[6]. 3) % ratio of $[X^b_{2010}-X^b_{1980}]$ / $[TPAP_{2010}-TPAP_{1980}]$ where X^b denotes cumulative marital fertility effect defined in Eq.[7].

Table 2. Ethnic differentials and similarities in the 1st marriage and marital fertility effect on fertility changes.

A. Cumulative marital fertility effect

Period	Simirarity	Dissimilarity	
		Chinese	Malay
1986~1990	Increase*	Decrease 1.74→1.53(-11.6%)	Almost constant 2.21→2.17(-1.8%)
1990~2000			
1999~2000	Increase		
2000~2004	Decrease		
2004~2008	Not Decrease*		

*Patterns differ.

B. Cumulative 1st marriage effect

Period	Simirarity	Dissimilarity	
		Chinese	Malay
1986~1990	Increase		
1990~2000	Little dicrease		
2001~2010		Decrease 1.59→1.39(-13.0%)	Rapid decline 1.93→1.36(-29.6%)