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Period Parity Progression Measures of Fertility in China*

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The recent history of fertility in China is intensely interesting, because China contains the world's largest population, because of the unique circumstances under which fertility change has occurred, and because of the extraordinary extent and rapidity of fertility decline under what would have seemed to most demographers rather inauspicious conditions. Most of what we know about fertility change in China over the past three decades comes from the National One-per-Thousand Fertility Survey conducted in September 1982 by the State Family Planning Commission. Earlier analyses of these data have provided annual series of age-specific birth rates and totals of fertility rates, as well as a rich variety of information on marriage, birth intervals and other topics.[1]

In this paper we present period parity progression based measures of fertility for China as a whole and for rural and urban areas for the years 1955–81. These measures are well suited to the study of Chinese fertility, because Chinese policies and programmes are so clearly and rigorously focussed on parity and birth order. In looking at progression from first to second birth, for example, we see precisely when the demographic effects of the one-child family policy begin, and may judge them in relation to overall fertility decline.[2]

Period parity progression ratios go back to early work by Henry,[3] and in a number of important respects the measures we use are identical with those he proposed. In particular, we compute proportions of women progressing from ith to $(i+1)$th birth for

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[1] *Analysis on China's National One-per-Thousand Population Fertility Sampling Survey* (Beijing: China Population Information Centre, P.O. Box 2444, 1984). The first three chapters provide details of survey design and operations. The survey is nationally representative, but for the exclusion of Tibet and Taiwan. Subsequent chapters provide detailed analyses of various topics. The publication includes a number of very detailed tables that have been analyzed further by others. See in particular A. J. Coale, *Rapid Population Change in China, 1952–1982*, Committee on Population and Demography Report No. 27 (Washington, D.C.: National Academy Press, 1984).

[2] For discussions of Chinese policy and programmes see P. C. Chen, 'Population and birth planning in the People's Republic of China', *Population Reports, Series J*, No. 25, Population Information Program, Johns Hopkins University (Baltimore, 1982) and C. H. Tuan, 'The planned birth policies in China', forthcoming in *Population Policies of Asian Countries*, ed. K. Mahadevan, Asian Forum for Development and Population Studies. See also W. R. Lavely, 'The rural Chinese fertility transition: a report from Shifang Xian, Sichuan', *Population Studies*, **38**, 3 (1984), pp. 365–384, for a detailed and illuminating discussion of fertility trends and population policy in a particular area.

[3] L. Henry, *Fécondité des mariages: nouvelle méthode de mesure, 1953*. English translation, *Fertility of Marriage: A New Method of Measurement*, Population Studies Translation Series No. 3, Economic and Social Commission for Asia and the Pacific (New York: United Nations 1980).

parity cohorts, i.e. for groups of women who have an *i*th birth in a given year, rather than for birth or marriage cohorts, and we calculate them on a period basis. Our ratios differ from Henry's, however, in three important respects. First, because of the nature of the available data, they are directly calculated rather than indirectly estimated. Secondly, the unit to which they refer is the woman rather than the marriage, a subtle distinction which turns out to have important consequences. Thirdly, we calculate, in addition to ratios for progression from first marriage to first birth, first to second birth, and so on, a ratio for progression of a woman from her own birth to her first marriage.[4]

Our parity progression measures thus describe overall, rather than marital fertility, and so are comparable to conventional age-specific birth rates. We compare, for China, totals of fertility rates calculated from period parity progression ratios with similar totals calculated from age-specific birth rates. There is broad agreement between the two measures, but there are also important differences. The series based on age-specific birth rates suggests that the fertility decline of the 1970s was reversed in the early 1980s, with total fertility rising from 2.2 children per woman in 1980 to 2.6 in 1981. The series based on period parity progression ratios gives a very different result, with total fertility falling slightly from 2.70 children per woman in 1980 to 2.65 in 1981.

This raises rather forcefully the distinction between the level of fertility generally conceived, and the level as measured by a particular statistic. We would like to know whether fertility in China did or did not go up sharply in 1981, and it will not suffice to say that the answer depends on what measure of fertility we use. We must ask why the two measures differ, and which provides, in this particular case, the better representation of 'the level of fertility.' The resulting investigation leads us to a number of formal results on the relation between the two approaches to measuring fertility.

The sharp rise in the total of age-specific birth rates in China in 1981 turns out to have been due almost entirely to a sharp rise in first births. This, in turn, was caused by a sharp rise in numbers of first marriages following a loosening of restraints on age at first marriage. These conclusions in themselves are unremarkable. It is well known that changes in age at marriage can distort age-specific birth rates,[5] and also that changes in age at marriage did occur in China at the time.[6] What is surprising is how thoroughly the measures based on parity progression attenuate the distortions inherent in the age-specific rates. Both our empirical results for China and our formal results indicate that, for populations characterized by low and fluctuating fertility, parity-progression based measures provide the better representation of the level of fertility.

PERIOD PARITY PROGRESSION RATIOS

Let A denote any event and B any subsequent event. For example, A may be 'first birth' and B 'second birth', or A 'birth of woman' and B 'birth of first child'. For any given year, define q_E to be the proportion of women experiencing event A in this year who also experience event B in this year, and q_x to be the number of individuals at the beginning

[4] We arrived at this approach to fertility measurement via the reformulation of population dynamics given in G. Feeney, 'Population dynamics based on birth intervals and parity progression', *Population Studies* **37**, 1 (1983), pp. 75–89, discovering Henry's work after the fact. Máire Ní Bhrolcháin arrived at essentially the same ideas independently of both this work and Henry's. See M. Ní Bhrolchain, Period parity progression ratios and birth intervals in England and Wales, 1941–71: "A synthetic life table analysis". *Population Studies* **41** (1), 1987 pp. 103–125.

[5] A general discussion illustrated with empirical data for the U.S. is given in the 'Distributional Distortion' section of N. B. Ryder, 'Components of temporal variations in American fertility', pp. 15–54 in R. W. Hiorns, *Demographic Patterns in Developed Societies* (London: Taylor & Francis Ltd, 1980). See also Coale *op. cit.* in footnote 1, pp. 48–54.

[6] See H. Y. Tien, 'Age at marriage in the People's Republic of China', *The China Quarterly* **93** (1983), pp. 90–107.

of the year who experienced event A between x and $x+1$ years ago exactly, divided into the number of these women who experience event B during the year, $x = 0, 1, \ldots$.[7] We calculate the period ratio for progression from event A to event B for the given year as

$$1-(1-q_E)(1-q_0)(1-q_1)\ldots. \tag{1}$$

This statistic tells us the proportion of persons who experience event A in the given year and who would progress to event B if they experienced the rates of progression q_E and q_x, $x = 0, 1, \ldots$, observed in the given year. Note that these values all refer to a particular year, and to progression from event A to event B, though this has not been incorporated explicitly in the notation here.

For any given year, let p_M denote the period ratio for progression from birth to first marriage, p_{M1} the period ratio for progression from first marriage to first birth, and p_i 'the period ratio for progression form ith to $(i+1)$th birth, $i = 1, 2, \ldots$.[8] Let p_0 denote the product $p_M p_{M1}$, which may be interpreted as the proportion of all women in an hypothetical birth cohort who ever have a first birth.[9] The statistics $p_0, p_1, p_2, \ldots$ are our period parity progression ratios and we calculate an index of total fertility from them by[10]

$$p_0+p_0p_1+p_0p_1p_2+\ldots. \tag{2}$$

The idea behind this formula is to consider an hypothetical birth cohort of women who experience the parity progression ratios p_i and ask how many children these women will have, on average, at the end of their reproductive lives. The expression follows from elementary algebra.[11]

[7] See the Appendix for the way in which these rates were derived from the survey data. Here, and throughout, the ideas of measuring 'progression from A to B' simply extend by analogy familiar ideas of mortality measurement, for which event A is birth and event B death. In this case, for example, the q_x values defined here are the arithmetic complements of the 'survivorship ratios' used in population projection, though defined for single years rather than for five-year groups. Similarly, Formula (1) is seen to be a variation on the life table expression of l_x in terms of q_x values. Lexis-diagram representations extend to the general case of progression from event A to event B by considering the population of persons who have experienced event A but not (yet) event B, and replacing the age axis by an axis representing time elapsed since the occurrence of event A.

[8] Note that the statistics $p_1, p_2, \ldots$, give proportions of women progressing to next birth independently of any changes in marital status that may occur between the two births.

[9] This formulation is suitable where first marriage always or nearly always precedes first birth, as in China. Pre-marital fertility need not cause any difficulty, however. We simply define p_0 directly as the ratio for progression from birth of a woman to the birth of her first child, ignoring marriage.

[10] This is formally identical to a formula given by Henry, *op. cit.* in footnote 3, p. 128 in the English version, so it is important to note that terms have a different meaning. Henry's formula refers to legitimate births, with birth order defined within marriage, and the result is an average number of children per marriage. Formula (2) refers to all births, with birth order defined for women independently of marriage, and the result is an average number of births per woman. Our p_0 represents the proportion of women born who ever have a first birth, where as Henry's a_0 represents the proportion of women marrying who ever proceed to a first birth within this marriage. Our values of $p_1, p_2, \ldots$, refer to the proportions of women having a first, second, ... birth who ever have a second, third, ... birth, independently of any changes in marital status that may occur between successive births. Henry's $a_1, a_2, \ldots$ evidently refer only to births that occur within a particular marriage.

[11] For a group of women who have completed reproduction, let n_i denote the number of women with exactly i children and N_i the number with i or more children. The average number of children born is by definition

$$\bar{n} = (n_1+2n_2+\ldots)/N_0.$$

Moving N_0 to the left, the sum on the right may be written as

$$\begin{array}{l} n_1+n_2+\ldots \\ \quad\;\; n_2+\ldots \end{array}$$

which, summing across rows, equals $N_1+N_2+\ldots$, so that the mean equals $N_1/N_0+N_2/N_0+\ldots$. The first term here is p_0, the second may be expressed as p_0p_1, and so on, which yields (2).

Though calculation may proceed directly from (2), it is far more efficient to rewrite the formula in the 'nested' form $(\ldots((p_n+1)p_{n-1}+1)\ldots+1)p_0$, where p_n is the last progression ratio used in the calculation. Thus we begin with the value p_n, add one and multiply by p_{n-1}, add one and multiply by p_{n-2}, and so on, the last operation being multiplication by p_0.

When p_0 is expressed as $p_M p_{M1}$, the factor p_M may be taken out of the sum, yielding

$$p_M\{p_{M1}+p_{M1}p_1+p_{M1}p_1p_2+\ldots\}. \tag{3}$$

If non-marital fertility is negligible, the term in curly brackets represents the average number of children born to married women. The total fertility is the product of the proportion of women ever marrying and the average number of children born to married women, a simple and natural relationship. Compare the fertility indices introduced by Coale,[12] which satisfy $I_f = I_m I_g$, the terms representing, respectively, total fertility, marriage and marital fertility. The factors in (3) are direct measures of the quantities represented, rather than indices involving an empirical standard, and they are independent of age for populations in which fertility is low and childbearing occurs well before the end of the reproductive age span.[13]

PERIOD PARITY PROGRESSION RATIOS FOR CHINA: 1955–81

In Figure 1 we show period progression ratios for China as a whole. The figures are given in Table 1, which should be read in conjunction with the figure. Some features of the graph are already known from previous work on the 1982 survey: the extreme depression in fertility during the famine of 1959–61, the relatively minor dip in 1967 following the beginning of the cultural revolution, and the sharp decline in fertility during the 1970s.[14] Other aspects, however, are new.

Progression to first marriage is virtually constant over the entire period at between 0.98 and 0.99. There is a very slight dip in 1959, quite negligible compared to the lows in progression to births of first and higher orders that occur two years later, in 1961. Progression ratios to births of first and higher orders all reach lows in 1961, having declined sharply over the preceding four years, and all rise very rapidly during the following two years. Progression ratios from marriage to first birth drop to slightly lower levels than those from first to second birth, 0.800 compared with 0.818. Beyond this, however, falls in the progression ratios become larger for each successive parity. The progression ratio from seventh to eighth birth falls to about 50 per cent, from around 90 per cent in the mid-1950s.

Progression ratios from first to second birth are high and stable during the late 1960s, with some 98 per cent of women with a first birth continuing to a second. A very slight decline occurs during the 1970s, bringing the level down to 96 per cent in 1979. It then drops sharply to 86 per cent in 1981 following the introduction of the one-child family policy

Progression ratios to births of second and higher orders fall sharply during the 1970s, with some erratic movements during the last years. There is an element of sampling variation here, more important at higher parities where numbers of births are smaller, but a good part of the erratic movement is probably real. Thus, progression ratios to births of orders three to seven all decline sharply between 1979 and 1980, presumably as a result of intensified birth planning efforts associated with the one-child family policy, and then recover slightly in 1981.

[12] See A. J. Coale, 'Factors associated with the development of low fertility: an historic summary', United Nations, *World Population Conference, 1965*, vol. 2, pp. 205–209, and also A. J. Coale, 'The decline of fertility in Europe from the French revolution to World War II', pp. 3–24 in *Fertility and Family Planning*, eds. S. J. Behrman, Leslie Corsa, Jr. and Ronald Freedman (Ann Arbor, 1966).

[13] See J. Trussell, J. Menken and A. J. Coale, 'A general model for analyzing the effect of nuptiality on fertility', pp. 7–27 in *Nuptiality and Fertility: Proceedings of a Seminar Held in Bruges (Belgium) 8–11 January 1979*, ed. L. T. Ruzicka (Ordina Editions, Liège, no date).

[14] See Wencheng Xiao, Menghua Li and Liyeng Wang, 'Changes in the total fertility rate since the 1950s', pp. 58–62 in China Population Information Centre, *op. cit.* in footnote 1, and A. J. Coale, p. 5 and chapter 4, *op cit.* in footnote 1.

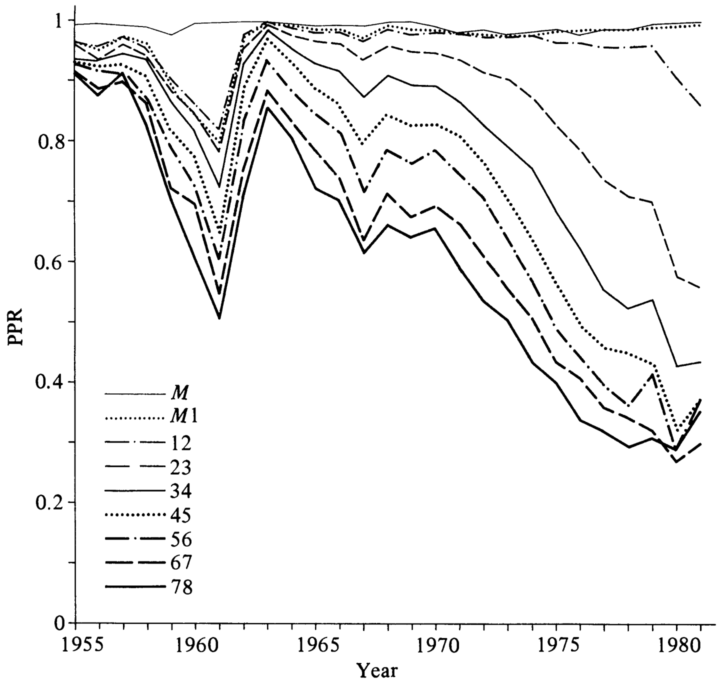


Fig. 1. China period parity progression ratios.

Table 1. *Period parity progression ratios for China, 1955–81*

Year	Progression ratio (× 1000)									TFR
	p_M	p_{M1}	p_1	p_2	p_3	p_4	p_5	p_6	p_7	
1981	998	993	859	561	437	374	372	300	352	2.65
1980	997	988	905	574	428	325	287	270	291	2.70
1979	994	991	959	700	539	431	414	322	309	3.20
1978	986	989	957	710	526	451	363	343	295	3.16
1977	986	984	957	736	553	458	396	359	320	3.23
1976	980	986	965	784	625	496	444	411	340	3.47
1975	983	986	964	825	683	567	489	437	400	3.73
1974	980	986	977	872	756	635	569	509	433	4.14
1973	973	975	973	902	792	701	638	556	506	4.37
1972	984	977	972	913	826	765	707	609	534	4.73
1971	981	978	978	934	865	809	744	661	589	5.08
1970	991	984	981	947	891	827	784	692	655	5.43
1969	997	985	977	948	892	823	762	675	642	5.41
1968	998	990	985	957	908	844	784	716	662	5.68
1967	991	969	966	935	873	793	713	639	614	4.98
1966	992	985	980	961	916	860	813	740	702	5.75
1965	990	982	979	964	929	886	845	786	720	5.96
1964	993	991	986	977	956	931	886	832	806	6.52
1963	998	996	996	992	982	964	934	887	855	7.16
1962	998	971	974	952	926	888	830	751	708	5.78
1961	996	800	818	781	726	648	603	547	507	2.83
1960	994	843	860	843	817	772	727	693	605	3.63
1959	976	886	903	882	866	815	788	721	699	4.27
1958	989	962	953	941	933	907	864	861	825	5.83
1957	992	971	972	959	945	926	910	898	912	6.37
1956	995	951	956	935	932	921	916	886	876	5.98
1955	991	965	962	960	937	932	928	915	913	6.33

Source: National One-per-Thousand Fertility Survey. Progression ratios calculated from formula (1), TFRs from formula (2). See text for further explanation.

The extreme right column in Table 1 shows the total of fertility rates calculated from Formula (2), but excluding terms containing p_8 and progression ratios of higher orders. This truncation introduces a minor nuisance into what would otherwise be a perfectly straightforward calculation. It arises because we only know values of progression ratios up to p_7. Progression ratios of higher orders are unstable due to small numbers of women reaching higher parities, despite the large size of the sample. Our totals thus exclude fertility due to births of ninth and higher orders.

If we attempt to obtain a secular trend for the series in Table 1, we find a gentle downward trend in progression ratios to third and higher orders between 1955 and 1970 together with a slight upward trend in progression ratios to first marriage and to first and second births. The net effect of these changes is to bring the total of fertility rates down from 6.4 children per woman in 1955 to 5.4 in 1970. The really substantial decline begins in 1970 and reduces the figure to 2.6 children per woman in 1981, a decline of slightly over one-half in eleven years. Progression ratios to first marriage and from marriage to first birth are virtually constant during this period, and progression ratios to second birth decline only slightly at the very end of the period, but those to higher orders fall sharply. Progression ratios from second to third birth, p_2, fall from 0.95 in 1970 to 0.56 in 1981; p_3 falls from 0.89 to 0.44 over the same period, p_4 from 0.83 to 0.37.

URBAN AND RURAL AREAS COMPARED

In Figure 2 we show period parity progression ratios for urban areas. The values plotted are given in Table 2. The broad pattern of change is the same in urban areas as in the country at large. The principal difference lies in the more rapid decline of fertility. Between 1963 and 1981, fertility in the urban areas declined from 6.6 to 1.3 children per

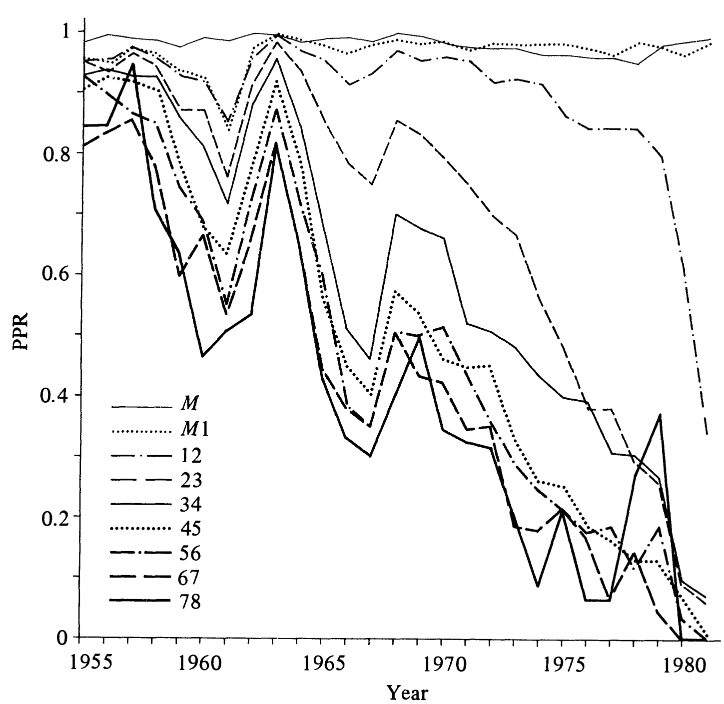


Fig. 2. China urban period parity progression ratios.

Table 2. *Period parity progression ratios for urban areas of China, 1955–81*

Year	Progression ratio (× 1000)									TFR
	p_M	p_{M1}	p_1	p_2	p_3	p_4	p_5	p_6	p_7	
1981	993	986	339	62	73	8	0	0	0	1.33
1980	988	967	611	99	92	69	33	0	0	1.60
1979	981	979	799	259	168	131	185	44	373	1.96
1978	951	987	847	291	205	132	115	143	273	2.02
1977	960	966	846	382	207	166	186	66	67	2.09
1976	960	977	845	381	293	189	176	169	62	2.14
1975	967	983	867	481	300	255	212	213	214	2.33
1974	966	983	913	560	332	259	245	178	85	2.52
1973	977	982	926	669	483	329	290	185	201	2.86
1972	976	986	922	701	508	453	360	352	315	3.01
1971	974	970	956	751	521	451	438	344	325	3.14
1970	982	985	959	795	663	466	513	423	344	3.53
1969	994	982	954	836	679	539	498	434	499	3.73
1968	999	989	971	855	702	577	507	506	405	3.96
1967	986	980	933	750	560	404	349	351	302	3.16
1966	992	967	917	785	616	452	383	380	328	3.26
1965	989	978	955	855	686	565	598	443	430	3.83
1964	983	987	969	937	847	790	720	655	650	5.01
1963	996	996	992	985	959	920	872	809	822	6.58
1962	997	977	958	916	886	788	727	658	534	4.98
1961	987	847	852	765	715	636	549	533	507	2.98
1960	991	925	919	871	812	776	684	667	465	4.18
1959	976	934	929	870	858	784	741	597	636	4.35
1958	986	965	959	943	926	904	849	779	705	5.67
1957	988	973	972	966	925	920	865	855	944	6.17
1956	994	950	954	933	937	926	897	835	845	5.86
1955	981	956	948	950	924	905	924	812	844	5.79

Source: National One-per-Thousand Fertility Survey. Progression ratios calculated from formula (1), TFRs from formula (2). See text for further explanation.

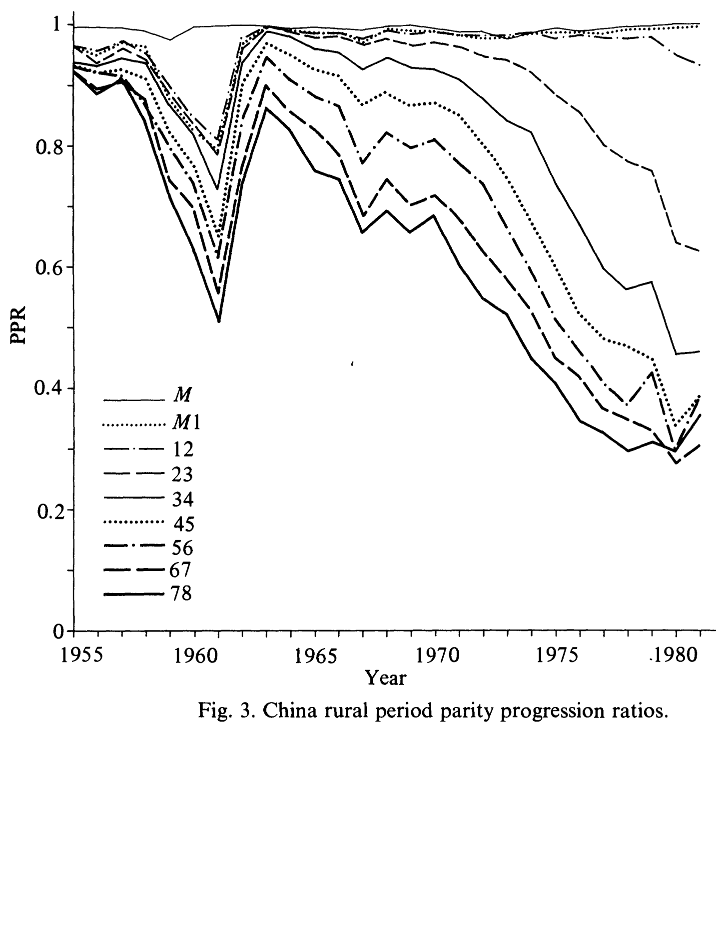


Fig. 3. China rural period parity progression ratios.

Table 3. *Period parity progression ratios for rural areas of China, 1955–81*

Year	Progression ratio (× 1000)									TFR
	p_M	p_{M1}	p_1	p_2	p_3	p_4	p_5	p_6	p_7	
1981	999	993	930	623	460	386	379	305	354	2.91
1980	999	990	949	638	454	337	293	274	294	2.92
1979	997	992	978	759	572	448	422	328	310	3.41
1978	994	989	974	775	560	471	371	349	296	3.40
1977	991	985	975	800	596	478	407	367	325	3.49
1976	988	987	980	856	670	521	459	419	344	3.79
1975	991	986	977	883	736	600	510	449	406	4.07
1974	986	986	985	921	812	674	592	527	447	4.52
1973	976	975	908	939	839	742	665	578	520	4.72
1972	986	977	979	945	873	802	737	624	544	5.10
1971	984	979	981	962	909	849	771	681	606	5.47
1970	992	984	984	969	926	871	809	713	675	5.82
1969	998	986	981	966	928	864	794	700	657	5.77
1968	997	990	988	976	944	889	821	747	690	6.10
1967	989	968	973	964	927	862	770	683	656	5.51
1966	992	987	987	980	955	914	867	787	746	6.33
1965	993	984	984	978	958	926	880	827	758	6.41
1964	995	991	989	983	969	949	908	855	827	6.78
1963	999	996	997	993	985	970	944	898	861	7.26
1962	999	970	976	958	933	902	846	765	733	5.92
1961	998	793	811	784	729	650	614	551	506	2.81
1960	995	821	844	836	818	770	734	698	626	3.49
1959	976	875	897	883	868	820	797	743	709	4.24
1958	990	962	952	940	934	908	868	874	839	5.86
1957	993	970	972	958	947	927	916	906	908	6.40
1956	995	951	957	936	932	919	919	891	885	6.01
1955	994	966	966	962	939	935	929	923	922	6.42

Source: National One-per-Thousand Fertility Survey. Progression ratios calculated from formula (1), TFRs from formula (2). See text for further explanation.

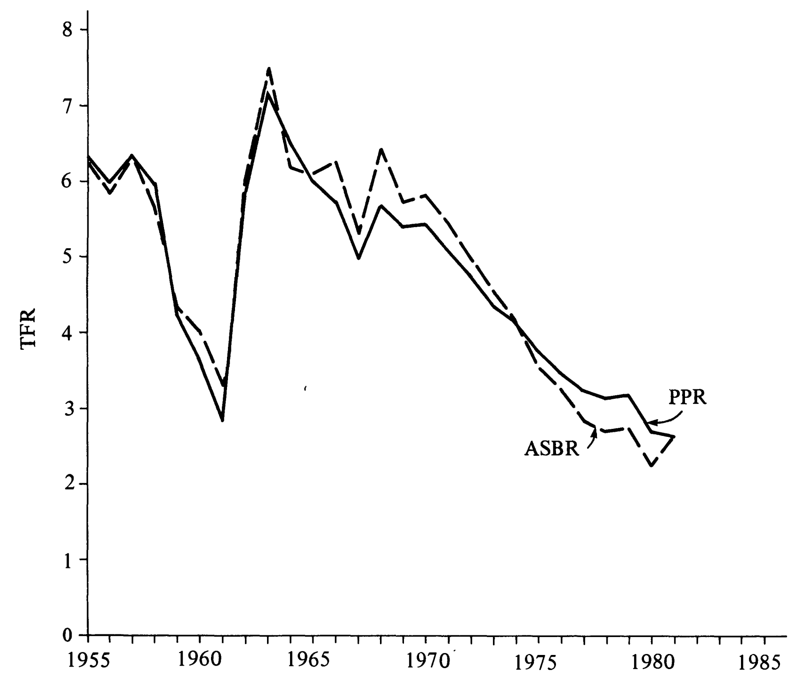


Fig. 4. Comparison of TFRs.

woman (TFR column of Table 2). Fertility in China as a whole fell from 7.2 to 2.6 children per woman.

The difference is particularly striking for progression ratios to second birth. Between 1978, when the one-child family policy was introduced, and 1981, progression ratios to second birth in urban areas fell from 0.847 to 0.339, a drop of 60 per cent.

Progression ratios to births of third and higher orders in urban areas had dropped virtually to zero by 1981, so that total fertility is essentially determined by the first two terms of Formula (1), $p_M p_0$ and p_1. Non-marriage and childlessness being virtually nil, progression from first to second birth is the dominating factor.

In Figure 3 and Table 3 we show the situation for rural areas. Since these contain some 80 per cent of the total population, the picture for rural areas necessarily looks much the same as the same as that for all areas. There are, however, two points to note. First, progression ratios to first birth fell significantly during the last two years of the series, from 0.978 in 1979 to 0.949 in 1980 and to 0.930 in 1981. This is not a large decline, but it is a distinct break with past experience. It suggests that the one-child family policy has made some progress in the rural areas, though it is conceivable that the result could owe more to imperfections in the urban and rural classification than to a change in genuinely rural areas. Secondly, the rise in progression ratios to births of higher orders seen in Figure 1 is due entirely to the rise in the rural areas shown in Figure 3. In the urban areas, these ratios have declined.

COMPARISON OF TOTAL FERTILITY

In Figure 4 we compare the total fertility obtained from the parity progression ratios given in Table 1 with that obtained from age-specific birth rates.[15] The similarity between the two series is remarkable, considering the completely different nature of the calculations that produce them. The two series show generally similar levels of fertility and move together closely over most of the period considered.

There are, however, two significant differences. The total fertility obtained from age-specific birth rates is significantly higher than that obtained from parity progression ratios during the late 1960s, but significantly lower during the late 1970s. In 1968, for example, total fertility obtained from age-specific birth rates is 6.4 children per woman compared with the parity-progression-based value of 5.7, a difference of 0.7. In 1979, the figures are 2.7 and 3.2 respectively, a difference of 0.5 children per woman. The differences exceed ten per cent in both cases, and are of opposite signs. The age-based figures thus exaggerate the decline in fertility, compared with those based on parity progressions.

The second difference concerns the trend of fertility during the last two years of the series. The age-based figures suggest that the long decline in fertility was reversed in 1981, with the total rising substantially from 2.2 children per woman in 1980 to 2.6 in 1981. The parity-based totals, however, appear to show that though the fertility decline slowed during these years, fertility continued to fall from 2.70 to 2.65 children per woman. Did fertility increase, or did it decline? Which total is the better measure of fertility, and why? In the following sections we consider these questions, but first there is a technicality to be cleared up.

The comparisons given are not quite exact because the total of age-specific birth rates is based on all births, whereas that based on parity progression ratios excludes births of ninth and higher orders. During recent years, when total fertility amounts to between two and three children per woman, the contribution of births of ninth and higher orders

[15] China Population Information Centre, 1984, *op cit.* in footnote 2, pp. 159–161, 168 and 171.

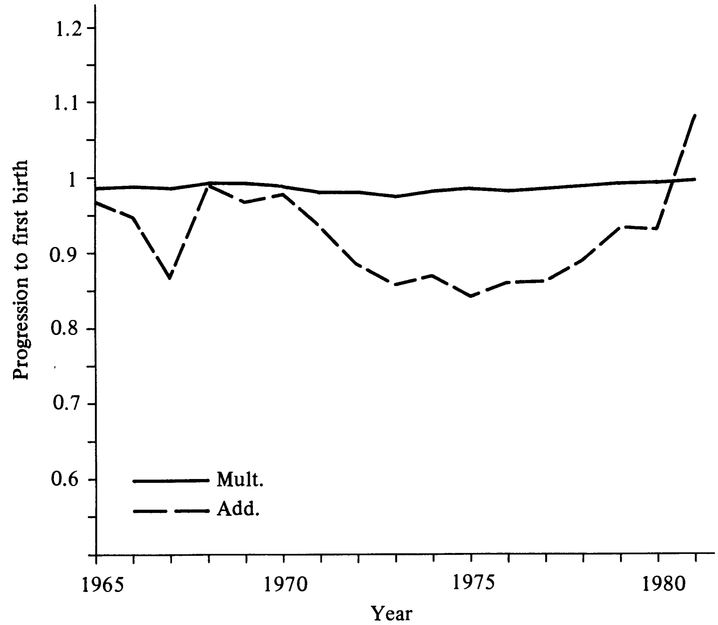


Fig. 5. Comparison of progression to first birth.

is miniscule and can easily be ignored, but how important were such births in the more distant past, when total fertility was around six children per woman?

The simplest way to answer this question is to recompute the total of age-specific birth rates excluding births of ninth and higher orders. The results of this calculation are shown in Table 4 together with the two series of totals plotted in Figure 4. In 1965,[16] the total of age-specific birth rates based on all births was 6.08 children per woman, compared with 5.81 children per woman when births of ninth and higher orders are excluded. This suggests that when total fertility is about six children per woman births of ninth and higher orders account for about one-quarter of a child per woman. This is not a negligible quantity, certainly, but is too small to change the broad picture of fertility change indicated by the series.

ADDITIVE AND MULTIPLICATIVE BIRTH-ORDER COMPONENTS

Consider the parity progression ratio based on Formula (2) above, for total fertility:

$$F_p = p_0 + p_0 p_1 + p_0 p_1 p_2 + \dots .$$

The term p_0 represents the proportion of women in the cohort who ever have a first birth, the term $p_0 p_1$ the proportion who ever have a second birth, and so on. We may thus think of the F_p as being a sum of multiplicative components representing the contribution of births of each order.[17] Each component is (i) non-negative, (ii) less than or equal to

[16] 1965 is the earliest year for which age-specific birth rates can be calculated to exact age 50. The reference date for the survey data is 1 July 1982 exactly, and the oldest women included were aged 67 last birthday. Women aged 68 exactly at mid-1982 reached exact age 50 in mid-1964, 18 years earlier, whence the age-specific birth rates computed for 1964 and earlier years exclude the fertility of women who reached exact age 50 before the middle of 1964. Rates given for earlier years in the Appendix tables of the survey report are based on imputations of rates for older age groups for years before 1965.

[17] The designation 'multiplicative' is natural in view of the multiplication involved in both formulaes (1) and (2). It seems to have been first used in this context by N. B. Ryder in *Progressive Fertility Analysis*, World Fertility Survey Technical Bulletin, No. 8 (Voorburg: International Statistical Institute, 1982), p. 37.

Table 4. *Comparison of period parity progression ratio TFRs and age-specific birth rate TFRs: China, 1955–81*

Year	Parity progression ratio TFR	Age-specific birthrate TFR (truncated)	Age-specific birthrate TFR
1981	2.65	2.62	2.63
1980	2.70	2.23	2.24
1979	3.19	2.72	2.74
1978	3.16	2.67	2.72
1977	3.23	2.78	2.84
1976	3.47	3.15	3.24
1975	3.73	3.46	3.57
1974	4.14	4.02	4.17
1973	4.37	4.37	4.54
1972	4.73	4.74	4.98
1971	5.08	5.22	5.44
1970	5.43	5.58	5.81
1969	5.41	5.48	5.72
1968	5.68	6.17	6.45
1967	4.98	5.08	5.31
1966	5.75	5.97	6.26
1965	5.96	5.81	6.08
1964	6.52	—	6.18
1963	7.16	—	7.50
1962	5.78	—	6.02
1961	2.83	—	3.29
1960	3.63	—	4.02
1959	4.27	—	4.30
1958	5.83	—	5.68
1957	6.37	—	6.40
1956	5.98	—	5.85
1955	6.33	—	6.26

Sources: First column from the TFR column of Table 1. Second column from the TFR column of Table 6 below. Third column from 'Analysis on China's national one-per-thousand population fertility sampling survey', China Population Information Centre, 1984, Appendix 1, pp. 159–161', for 1955–79; Appendix 2, p. 168, for 1980, and Appendix 3, p. 171, for 1981.

unity, and (iii) greater than or equal to the components for any birth of higher order. These conditions are demographically sensible, for (i) births of any order represent an increment to the population which may be zero (ii) a woman can have at most one birth of any given order, and (iii) a woman cannot have a birth of a higher order without previously having had a birth of a lower order.

The total fertility based on age-specific birth rates may also be expressed as a sum of birth order components. It is defined as

$$F_a = m_{15}+m_{16}+\ldots+m_{49}, \tag{4}$$

where $m_x = B_x/W_x$ is the age-specific birth rate at age x at a given time. Here we imagine an hypothetical birth cohort of women who experience the age-specific birth rates m_x and ask how many children these women will have had, on the average, at the end of reproduction. Since each m_x may be expressed as the sum of age-order-specific birth rates $m_{x,i} = B_{x,i}/W_x$, the right hand side of (4) may be written[18]

[18] As in the discussion in the Appendix, we deal with cohort-period rates. Thus W_x denotes the number of women aged x in completed years at the beginning of the year and $B_{x,i}$ the number of ith births to these women during the year.

$$\begin{array}{c} m_{15,1}+m_{16,1}+\ldots+m_{49,1}+ \\ m_{15,2}+m_{16,2}+\ldots+m_{49,2}+ \\ \vdots \end{array} \tag{5}$$

Assuming these age-order-specific birth rates apply to the hypothetical cohort, we see at once that the sum of the first row, i.e. the sum of the first birth rates $m_{x,1}$, represents the proportion of women who ever have a first birth.[19] Similarly, the sum of the terms in the second row, represents the proportion of women who ever have a second birth, and so on.

We have thus expressed F_a as a sum of additive birth-order components. These are necessarily non-negative, but will not necessarily be less than unity, nor will the component for any given birth order necessarily be less than the component for the preceding birth order. The first birth component, for example, may exceed unity if women in several birth cohorts concentrate their first births in the same time period, and it is possible, though empirically unlikely, to have more births of order $i+1$ than of order i occur during any given time period.[20]

EMPIRICAL COMPARISON OF BIRTH-ORDER COMPONENTS

We can now extend the empirical comparison of the two series of totals by a comparison of their respective birth order components. In Table 5 we show the multiplicative birth-order components of the parity-progression-ratio-based total fertility shown in Table 1, in Table 6 the additive birth-order components of the total of age-specific birth rates shown in the second column of Table 4.

Compare first the additive and the multiplicative components for first births. The multiplicative series given in the first column of Table 5 are generally between 0.95 and 0.99. The minimum value between 1955 and 1981 was 0.797, in 1961. Between 1965 and 1981, however, the minimum was 0.949, in 1973, and the maximum 0.991, in 1981. The range for these latter years was thus about four per cent. For the additive series in the first column of Table 6, the minimum was 0.687, in 1975, the maximum, in 1981, 1.163. The range was thus nearly 50 per cent, more than ten times that of the multiplicative series. Moreover, the additive total in 1981 exceeded unity.

The plot of the two series in Figure 5 shows the stability of the multiplicative and the volatility of the additive series. In general, there appears to be a tendency for the additive series to magnify the fluctuations which occur in the multiplicative series. Thus, the dip in the multiplicative series from 0.977 in 1966 to 0.961 in 1967 translates into a dip from 0.897 to 0.735 in the additive. When the multiplicative series rose from 0.949 in 1973 to 0.991 in 1981, the additive series increased from 0.717 to 1.163.

In Figure 6 we compare the multiplicative second-birth components from the second column of Table 5 with the corresponding additive figures from the second column of Table 6. As in the case of the first-birth components, the multiplicative series is relatively stable, the additive one relatively volatile. The additive values exceed unity in 1965, 1966,

[19] This interpretation is well known in the literature, though it seems not to have found its way into textbooks. See for example W. Brass, *Methods for Estimating Fertility and Mortality from Limited and Defective Data* (Chapel Hill: University of North Carolina, 1975), p. 30; and D. Bloom and A. Pebley, 'Voluntary childlessness: a review of evidence and implications', *Population Research and Policy Review* (1982), p. 205 and note 4. An analogous measure based on first marriage rates with all women in the denominator is used by A. J. Coale, *op. cit.* in footnote 1, chapter 3.

[20] The observation that values in excess of unity may result from summing first birth rates with total women in the denominator goes back at least to P. K. Whelpton, *Cohort Fertility* (Princeton University Press, Princeton 1954; re-issued in 1973 by Kennikat Press, Port Washington, New York), p. 9 in the 1973 re-issue.

Table 5. *Multiplicative birth-order components of the TFR: China, 1955–81*

	Birth order							
Year	1	2	3	4	5	6	7	8
1981	991	852	478	209	78	29	9	3
1980	985	891	511	219	71	20	5	2
1979	985	946	662	357	154	64	21	6
1978	975	933	662	348	157	57	20	6
1977	970	928	682	377	173	68	25	8
1976	966	932	731	457	227	101	41	14
1975	969	934	771	526	298	146	64	26
1974	966	943	823	622	395	225	114	50
1973	949	924	833	660	462	295	164	83
1972	961	934	853	704	539	381	232	124
1971	960	939	877	758	613	456	301	177
1970	975	956	905	807	667	522	362	237
1969	983	961	911	812	669	510	344	221
1968	988	973	931	846	713	559	400	265
1967	961	928	867	757	601	428	273	168
1966	977	957	920	843	725	589	436	306
1965	973	952	918	854	756	639	502	362
1964	983	970	948	906	843	747	621	501
1963	993	990	982	965	930	869	771	659
1962	969	943	899	832	739	614	461	326
1961	797	652	509	369	240	144	79	40
1960	838	720	607	496	383	278	193	117
1959	865	782	689	597	486	383	276	193
1958	952	906	853	796	722	624	537	443
1957	962	935	897	847	785	714	641	585
1956	946	904	846	788	726	665	569	516
1955	956	921	884	828	771	716	655	597

Source: Computed from Table 1.

Table 6. *Additive birth-order components of the TFR: China, 1955–81*

	Birth order							
Year	1	2	3	4	5	6	7	8
1981	1,163	637	338	202	121	79	44	31
1980	867	570	333	207	109	70	42	31
1979	866	682	450	299	179	127	69	43
1978	779	636	469	305	215	131	87	49
1977	726	619	510	344	243	167	110	65
1976	722	685	574	421	300	218	151	81
1975	687	702	645	490	382	266	181	111
1974	741	808	724	586	464	341	232	129
1973	717	859	749	671	547	401	263	164
1972	769	882	770	751	623	467	304	175
1971	870	904	856	859	705	492	336	199
1970	956	989	945	915	703	555	365	241
1969	935	834	1,016	896	698	520	352	227
1968	980	1,045	1,180	967	742	587	416	253
1967	735	967	984	759	623	480	322	211
1966	897	1,226	1,035	858	727	596	395	240
1965	936	1,194	933	824	726	577	393	227

Source: National One-per-Thousand fertility survey. See text for explanation.

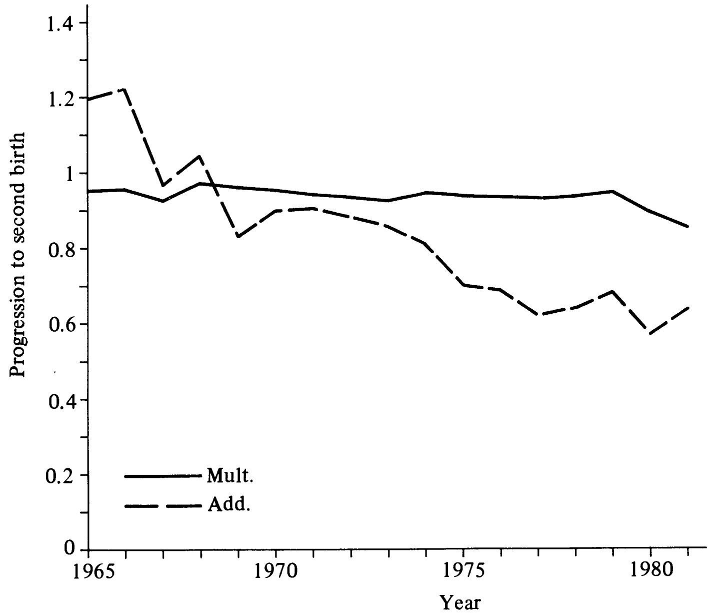


Fig. 6. Comparison of progression to second birth.

and 1968. The multiplicative series suggests a period of virtual stability until 1979, when there was a sharp turn downward, evidently the effect of the one-child family policy. The additive series suggests an erratic decline over the whole period. The two series move in opposite directions between 1980 and 1981, with the multiplicative values falling from 0.891 to 0.852 and the additive rising from 0.570 to 0.637.

In Figure 7 we make the same comparison for the third-birth components, and reach roughly the same conclusions. Comparisons for births of higher orders may be made directly from Tables 5 and 6. It is interesting to note that the additive components for these births are far larger than the corresponding multiplicative components. For eighth births in 1981, for example, the additive component was 0.031, compared to a multiplicative component of 0.003. The difference is inconsequential in its effect on total fertility, of course, because both values are so small.

Particular interest attaches to the trend of fertility in 1980 and 1981, and Tables 5 and 6 may also be studied from this point of view. Considering first the multiplicative birth-order components in Table 5, we see that the first-birth component increased from 0.985 to 0.991, but that the components for second, third and fourth births fell, respectively, from 0.891 to 0.852, 0.511 to 0.478, and 0.219 to 0.209. The components for births of fifth and higher orders rose, but without much effect (less than one per cent) on total fertility because the proportion of births of these orders is so low. The overall result of these changes was to reduce total fertility from 2.70 in 1980 to 2.65 in 1981.

The additive components in Table 6 tell a completely different story. That for first births leaps from 0.867 in 1980 to 1.163 in 1981, an increase of 0.296 children per woman. This alone accounts for 77 per cent of the increase in total fertility between 1980 and 1981. The second-birth component increases by 0.067, from 0.570 to 0.637, which accounts for an additional 17 per cent of the increase in the total. The remaining components have relatively little effect.

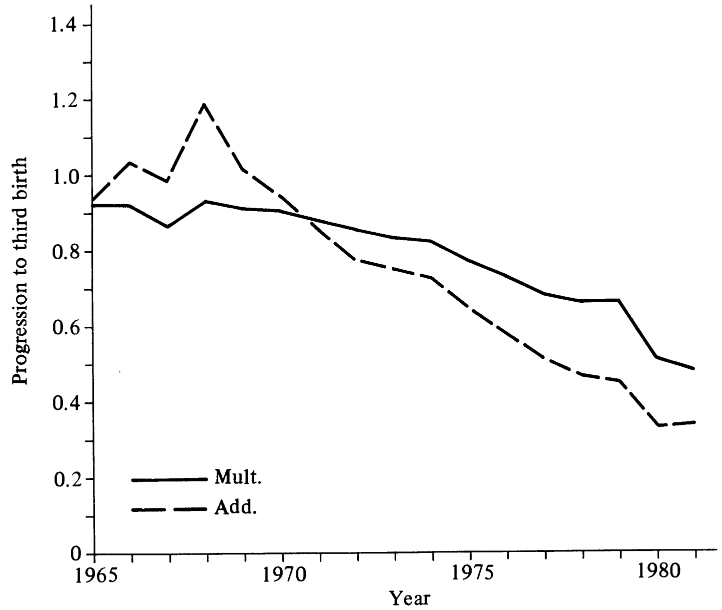


Fig. 7. Comparison of progression to third birth.

FORMAL ANALYSIS OF THE FIRST-BIRTH COMPONENT

The empirical comparisons of the previous section suggest that the multiplicative birth-order components comprising the period parity-based total fertility behave substantially better than the additive components of the age-based total fertility. We now ask why this is so, and begin with a close look at the first birth component. In doing so we shall assume for simplicity that the multiplicative measure of progression to first birth is calculated directly from information on the births of women and their first children, without intermediate information on marriage. The reason for this deviation from the empirical results given above, which do incorporate marriage, will become clear in due course.

Working from the conventional formula for F_a (Equation 4) and its birth order elaboration (5), we calculate the proportion of women ever progressing to a first birth as

$$p_{0,A} = \frac{B_{15,1}}{W_{15}} + \frac{B_{16,1}}{W_{16}} + \ldots + \frac{B_{49,1}}{W_{49}}. \tag{6}$$

This formula defines the additive first-birth component $p_{0,A}$ in terms of first-birth rates that take first births to women aged x, $B_{x,1}$ as their numerator and all women aged x, W_x, as their denominator.

In contrast, the multiplicative first-birth component following from Formula (1) is

$$p_{0,M} = 1 - \left\{1 - \frac{B_{15,1}}{W_{15,0}}\right\}\left\{1 - \frac{B_{16,1}}{W_{0,16}}\right\} \ldots \left\{1 - \frac{B_{49,1}}{W_{49,0}}\right\}, \tag{7}$$

where $W_{x,0}$ denotes women aged x, who have not had children, i.e. of parity zero. This formula defines the multiplicative first-birth component $p_{0,M}$ in terms of first-birth rates whose numerators are the same as those in Formula (6), but whose denominators are numbers of women aged x, of parity zero, rather than all women aged x. Note that, referring to Formula (1) above, $B_{x,1}/W_{x,0} = q_{x,0}$; the numerators and denominators are written out explicitly in (7) to facilitate comparison with (6).

To establish a relation between (6) and (7) observe first that

$$\frac{B_{x,1}}{W_x} = \frac{B_{x,1}}{W_{x,0}}\frac{W_{x,0}}{W_x} = q_{x,0}\frac{W_{x,0}}{W_x}. \tag{8}$$

The additive expression (6) may thus be rewritten

$$p_{0,A} = q_{15,0}\frac{W_{15,0}}{W_{15}} + q_{16,0}\frac{W_{16,0}}{W_{16}} + \ldots + q_{49,0}\frac{W_{49,0}}{W_{49}} \tag{9}$$

where we now write the first-birth rates $B_{x,1}/W_{x,0}$ as $q_{x,0}$. This says that the additive $p_{0,A}$ values may be regarded as weighted averages of the first-birth rates $q_{x,0}$, where the weights are the proportions of women of parity zero at each age.

To relate this to the multiplicative expression (7), observe that (7) may be rewritten as

$$\begin{aligned} p_{0,M} = {} & q_{15,0} \\ & + q_{16,0}(1-q_{15,0}) \\ & + q_{17,0}(1-q_{15,0})(1-q_{16,0}) \\ & \vdots \\ & + q_{49,0}(1-q_{15,0})\ldots(1-q_{49,0}). \end{aligned} \tag{10}$$

This formula expresses the proportion of women who ever have a first birth as the sum of the proportions who have a first birth at each age. The equality of (7) and (10) thus follows on demographic arguments. Alternatively, or as a check on the demographic reasoning, equality may be proved formally by induction on the index of the last term in both formulas.

Now it is obvious that (9) and (10) will be equal if

$$\left.\begin{aligned} \frac{W_{15,0}}{W_{15}} &= 1 \\ \frac{W_{16,0}}{W_{16}} &= 1-q_{15,0} \\ \frac{W_{17,0}}{W_{17}} &= (1-q_{15,0})(1-q_{16,0}) \\ &\vdots \\ \frac{W_{49,0}}{W_{49}} &= (1-q_{15,0})\ldots(1-q_{48,0}). \end{aligned}\right\} \tag{11}$$

We refer to the quantities on the left as the age schedule of proportions of women of parity zero, and if (11) holds we say that this schedule is in equilibrium with respect to the first-birth rates $q_{x,0}$ on the right. Observe that this equilibrium will occur in any population in which first-birth rates remain the same for a sufficiently long period (a period equal to the length of the reproductive age span will always suffice), because the terms on the right in (11) may then be read as cumulating the experience of individual cohorts.

Expressed in these terms, what we have shown is that the additive calculation (6) gives the same result as the multiplicative calculation (7) provided the schedule of proportions of women of parity zero is in equilibrium with respect to the rates of progression to first birth. Formula (10) shows in these terms that the multiplicative first birth component $p_{0,M}$ may always be written as $\Sigma_x q_{x,0} w_{x,0}$ where the $w_{x,0}/w_x$ are in equilibrium with the $q_{x,0}$.

Consider now a population that has in the past experienced constant first birth rates $q_{x,0}$, with a corresponding ultimate progression to first birth of $p_{0,M}$ so that the age schedule of proportions of women of parity zero at the beginning of the current year is in equilibrium with respect to these rates. Suppose that in the current year, however, first-birth rates decline and thereafter remain constant. Suppose for simplicity that the rates decline by a constant factor k at each age, and consider the results of the additive and the multiplicative calculations in the current year.

By Formula (9) above, the additive first-birth component $p_{0,A}$ may be expressed as

$$\sum_x (kq_{x,0})\, w_{x,0}. \tag{12}$$

This is obtained by applying the new rates $(kq_{x,0})$ for the current year to the age schedule of proportions of women of parity zero $(w_{x,0})$ corresponding to the old rates $q_{x,0}$. Because the rates have changed only in the current year, the age schedule of proportions of women of parity zero at the beginning of the year $w_{x,0}$ will be in equilibrium with the old rates.

The multiplicative first-birth component $p_{0,M}$ may be expressed as

$$\sum_x (kq_{x,0})\, w'_{x,0} \tag{13}$$

where the $w'_{x,0}$ are in equilibrium with respect to the new rates $(kq_{x,0})$. This is so because we can always write the multiplicative value in this way by choosing the age schedule of proportions of women of parity zero on the right to be in equilibrium with respect to the rates on the left.

Since by assumption the new rates are uniformly lower than the old rates, we see from (11) that $w'_{x,0} > w_{x,0}$ for all x, whence the additive value (12) will be lower than the multiplicative value (13), i.e. the additive value will be too low.

In subsequent years, the age schedule of proportions of women of parity zero will slowly converge to the new equilibrium schedule for two reasons. First, the cohorts in reproductive ages at the time of the change will gradually be replaced by new cohorts that have experienced the new rates only, so that proportions of women of parity zero are in equilibrium with respect to the new rates. Secondly, the old cohorts will move towards equilibrium, though they will never reach it, as they begin to experience the new, rather than the old, rates.

We have thus sketched the following picture of the relation between the additively calculated proportion of women progressing to first birth given by (6) and the multiplicatively calculated value given by (7). The two rates will be equal for any year in which the age schedule of zero parity women is in equilibrium with the first-birth rates $q_{x,0}$. This equilibrium will occur, in particular, whenever first-birth rates in a population remain fixed for a period equal to the length of the reproductive age span. Given a single decline in first-birth rates, the additive measure will exaggerate the decline, falling more than the multiplicative measure. Then, in the years following the decline, it will slowly rise as the age schedule of women of parity zero converges to equilibrium with the new first-birth rates. Complete convergence requires as many years as there are in the reproductive age span, after which the additive and multiplicative values will again be equal. Similar remarks apply to a single increase in first-birth rates.

We conclude that the additive calculation distorts the true situation, by exaggerating actual changes in the level of progression to first birth, and by showing a rising or falling trend when in fact the level is constant. The explanation for the erratic behaviour of the additive measure is simply that it does not relate events to the correct exposure: first births are related to all women, rather than to those of parity zero, who are the only ones capable of having a first birth. The additive measure (6) changes whenever the proportions of women of parity zero in the denominators W_x change, independently of any change in rates at which such women progress to first birth.

SIMULATION RESULTS FOR THE FIRST-BIRTH COMPONENT

The conclusions of the preceding section are qualitative only and refer only to a single rise or fall in first-birth rates. To get an indication of magnitudes and for more complex patterns of change we proceed to simulation. Given (*a*) an initial age schedule of proportions of women of parity zero and (*b*) schedules of first-birth rates for a series of years, we may calculate (*c*) multiplicative values of $p_{0,M}$ for each year directly from the schedules of first birth rates and (*d*) additive values of $p_{0,A}$ by projecting the initial age schedule of women of parity zero forward year by year and calculating first-birth rates with all women in the denominator from the projected values.

To specify the schedules of first-birth rates we assume that each schedule may be expressed as the product of a 'standard' schedule of rates and a constant that may change from year to year. Thus we take $q_{x,0}(t)$ to be $q_{x,0}k(t)$ and so have to specify only the standard schedule $q_{x,0}$ and the values of $k(t)$. To obtain the latter we specify a series of values $p_{0,M}(t)$ and then solve

$$p_{0,M}(t) = 1 - \prod_x \{1 - k(t)\, q_{x,0}\}, \tag{14}$$

for $k(t)$ by numerical methods.[21] We take the initial age schedule of women of parity zero to be that which is in equilibrium with the first-birth rates for the first year, calculating them from Formula (11) of the preceding section with the $q_{x,0} = q_{x,0}k(1)$. The input to the simulation calculations is thus reduced to a standard schedule of first-birth rates and a time series of $p_{0,M}$.

The idea of the projection is to begin with an age distribution W_x for all women and an age distribution $W_{x,0}$ for women of parity zero and to project both of these distributions forward by applying first birth rates to the numbers of women of parity zero, ignoring mortality during the reproductive ages. It turns out, however, that the projection may be done directly on the age schedule of proportions of women of parity zero $W_{x,0}/W_x$, for

$$(1 - q_{x,0})\frac{W_{x,0}}{W_x} = \frac{W_{x,0} - q_{x,0}\, W_{x,0}}{W_x} = \frac{W_{x+1,0}}{W_{x+1}}. \tag{15}$$

[21] We use Newton's method, rearranging the above equation to get

$$f(k) = \ln(1 - p_0) - \sum_x \ln[1 - k(t)\, q_{x,0}] = 0.$$

The derivative of f is given by

$$f'(k) = \sum_x q_{x,0}/[1 - k(t)\, q_{x,0}].$$

We choose an initial value of k, k_0, say, and then compute iteratively

$$k_{i+1} = k_i + f(k_i)/f'(k_i).$$

Convergence is very rapid. For the present calculations k_0 was taken to be 1, five iterations were performed in all cases, and residual values were on the order of 10^{-17}.

The projection equations are thus simply

$$w_{15}(t+1) = 1, \tag{16a}$$

$$w_{x+1}(t+1) = w_x(t)\{1-k(t)\,q_{x,0}\} \quad (x = 15, \ldots, 49), \tag{16b}$$

where $w_x(t) = W_{x,0}(t)/W_x(t)$ and it is assumed that no woman marries before her 15th birthday. Beginning with values of $w_x(1)$ computed from the rates $q_{x,0}\,k(1)$ by using Formula (11) of the preceding section, we use these equations for $t = 1, \ldots, n$, where n is the number of values of $k(t)$ available, computing the additive $p_{0,A}$ values and, as a check, the multiplicative $p_{0,M}$ values as we go,

$$p_{0,A}(t) = \sum_x k(t)\,q_{x,0}\,w_x(t), \tag{17a}$$

$$p_{0,M}(t) = 1-\prod_x\{1-k(t)\,q_{x,0}\}. \tag{17b}$$

Figure 8A shows what happens in the case of a single fall in p_0 from 0.95 to 0.90. We see that the additively calculated p_0 drops by three times that amount, to 0.75, and recovers over the following decade to about 0.88. Convergence to 0.90, not shown in the plot, takes another decade. Figure 8B shows the result of a smaller single drop, from 0.95 to 0.94. The pattern is much the same. It is interesting that the magnitude of the distortion is greater than in the previous case, with the additively calculated p_0 falling to 0.90, five times as far as the decline in the multiplicative value. Figure 8C shows a linear decline of p_0 from 0.95 to 0.90 over five years, at a rate of one percentage point per year. The divergence of the additively calculated values is not as great as in Figure 1, where a drop of the same magnitude occurs in a single year, but it is substantial, magnifying the actual change by about 2.8. Convergence to the correct value begins only after the decline has stopped and occurs over decades, as in Figure 1. Finally, Figure 8D shows the same linear decline over ten years instead of five years. The distortion is slightly smaller, but still substantial. We conclude from these simulations that the distortions of the additive measure of progression to first birth are both substantial in magnitude and prolonged in effect.

THE PROBLEM OF BIRTHS OF HIGHER ORDERS

The relationship between the additive and multiplicative birth order components for births of higher order turns out to be a good deal more difficult. It is easy enough to write

$$m_{x,2} = \frac{B_{x,2}}{W_x} = \frac{B_{x,2}}{W_{x,1}}\frac{W_{x,1}}{W_x} = b_{x,1}\,w_{x,1} \tag{18}$$

and so express the age-specific second birth rates $m_{x,2}$ in (5) in terms of age-parity-specific birth rates $b_{x,1}$ which differ from $m_{x,2}$ in excluding from the denominator all but women of parity one, and of what may be called the age schedule of proportions of such women. The problem is that this relates the $m_{m,2}$ to the age-parity-specific birth rates $b_{x,1}$ rather than to the birth rates specific to parity and previous birth interval rates $q_{x,1}$ that define the period parity progression ratio, so that we can then face the problem of relating these two sets of rates. This in turn suggests that we introduce rates specific for all three variables, age, previous birth interval and parity,

$$q_i(a, x) = B_{i+1}(a, x)/W_i(a, x), \tag{19}$$

where $W_i(a, x)$ is the number of women of parity i aged a last birthday whose last child was born x years earlier and $B_{i+1}(a, x)$ is the number of $(i+1)$th births to these

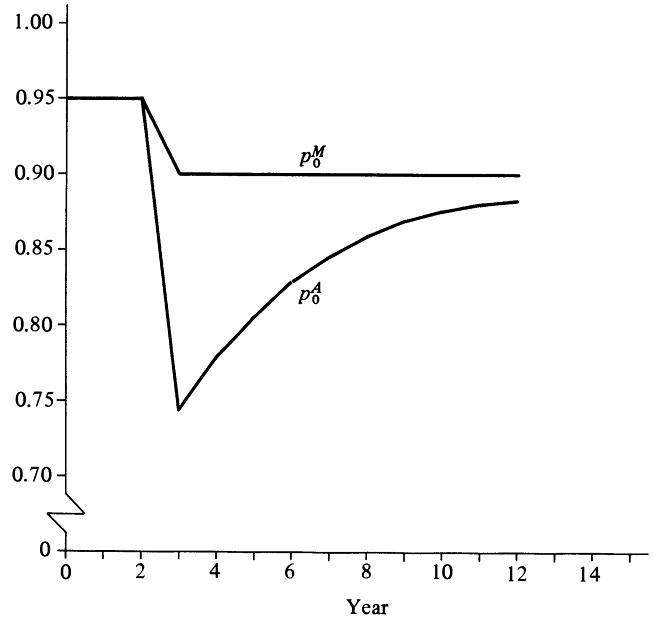


Fig. 8A. Simulation 1: Big spike.

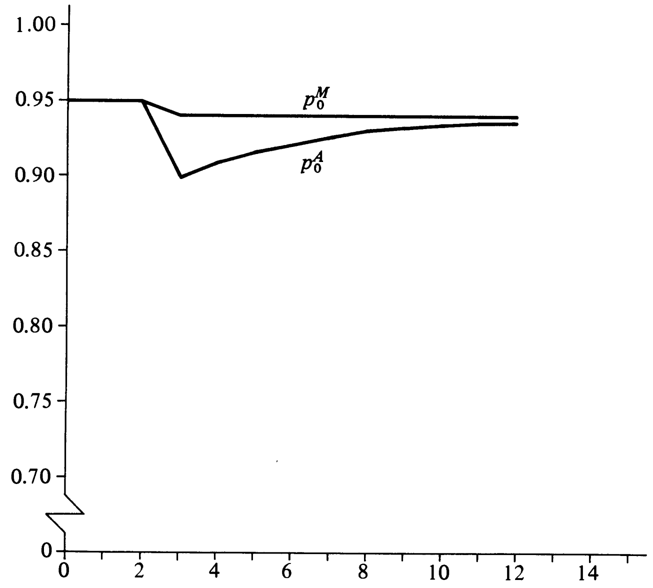


Fig. 8B. Simulation 2: Little spike.

women during the year. The age-parity-specific rates and the parity birth-interval specific rates are then regarded as determined by these rates in combination with the distribution of the women in the population by age and parity.

It is no doubt possible to extend the analysis of the preceding sections to births of higher orders along these lines, but it is evident that the task will not be easy. The first step would be to develop the purely formal results. Though the formulae will evidently become a good deal more complex, they will certainly yield to determined efforts.

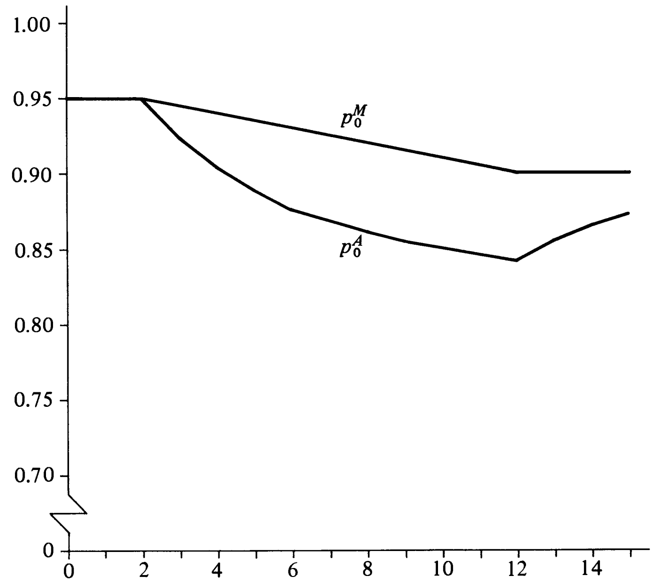


Fig. 8C. Simulation 3: Fast linear.

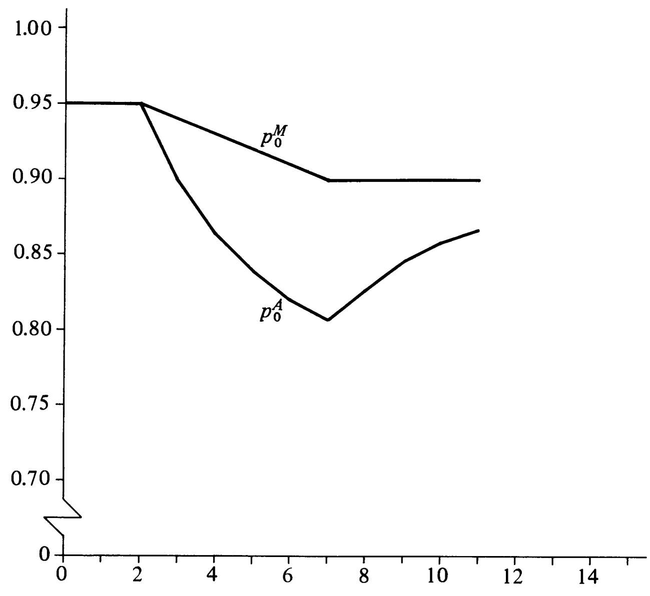


Fig. 8D. Simulation 4: Slow linear.

Even in the relatively simple case of first births, however, the formal results by themselves do not go very far. It is obvious, for example, that we may express both the age-parity-specific birth rates $b_{x,i}$ and the parity-birth-interval specific birth rate $q_{x,i}$ as sums of the rates (19) suitably weighted by the proportions of women in various age, parity and birth interval categories, but this in itself conveys little useful information about the relationship between them. With 35 single years of age and 10 birth interval categories, the relation involves 350 parameters, all varying from one year to the next in a way that depends on the previous values of the rates (19). Useful results along these lines will require two additional elements, simulation and the development of suitable models.

A final and perhaps critical difficulty will be the lack of data. Date of previous birth is rarely included on birth certificates, and few, if any, of the world's vital registration systems provide data that could be used for such a calculation. Even China's One-per-Thousand Survey, with its huge sample size, would be strained by the direct calculation of rates specific for age, parity and birth interval.[22]

DISCUSSION

Period parity progression measures make most sense in populations with low and controlled fertility. Under conditions of natural fertility, the proportion of women progressing from ith to $(i+1)$th birth reflects primarily the age at which women have their ith birth, and the decline in parity progression ratios with increasing parity reflects the dependence of rates of progression on age. Age being the operative factor, there is no obvious reason to introduce parity. With controlled fertility, however, declining parity progression ratios with increasing parity reflect decisions on the part of women, or couples, not to have more children. Low fertility means that all births may occur at ages well below the point where age has a significant effect on fertility. This is an empirical matter, of course, and the delay of childbearing to sufficiently late ages in the reproductive age span will, of course, require us to take account of age.[23]

Period parity progression ratios cannot be calculated as readily from currently available data as can age-specific or age-order-specific birth rates, and this is perhaps their most obvious disadvantage. It is a venial one, however, in that one of the more important functions of demographic analysis is to say what data should be collected. It, nonetheless, poses a practical difficulty, at present and in the immediate future, for anyone wanting to compute these measures. The difficulty is reduced to some extent by the availability of indirect estimation procedures.[24]

It is, of course, possible in principle to define rates which would take account of age *and* parity and birth order *and* interval since last birth, as indicated in the preceding section. Before introducing so demanding an elaboration of the descriptive framework, however, we need to ask whether the results so obtained are likely to be worth the additional effort.

Finally, we must say a few words about the relation of period parity progression ratios to the fertility measures introduced by Whelpton.[25] The introduction of parity and order

[22] Rates specific for age, parity and duration and parity are used by N. B. Ryder, *op. cit.* in footnote 17, but for five-year groups rather than for single years. See also the very interesting paper by A. Palloni, 'Assessing the effects of intermediate variables on birth-interval-specific measures of fertility', *Population Index*, **50**, 4 (1984), pp. 623–657. Our interest in current trends makes single-year periods essential, and this makes the choice of any but single years of age for age and birth interval highly problematic.

[23] See J. Menken, 'Age and fertility: how late can you wait?' *Demography*, **22**, 4 (1985), pp. 469–483.

[24] See G. Feeney, *op. cit.* in footnote 28 below, pp. 131–133, and also G. Feeney and Y. Saito, 'Progression to first marriage in Japan: 1870–1980', Research Paper Series No. 24, Nihon University Population Research Institute (Tokyo, 1985).

[25] The original work is reported in P. K. Whelpton, *Cohort Fertility*, *op. cit.* in footnote 20. It is updated and expanded in R. L. Heuser, *Fertility Tables for Birth Cohorts by Color: United States, 1917–73*, DHEW Publication No. (HRA)76-1152 (Rockville, Maryland: National Center for Health Statistics, 1976). Despite the title of Whelpton's book, the fertility rates in question are not peculiarly cohort rates. Like age-specific fertility rates, they are, taken individually, neither period nor cohort. Rather, their aggregation over time periods (cohorts) results in period (cohort) fertility measures. It has become semi-standard usage to refer to the birth rates $q_{a,i} = B_{a,i+1}/W_{a,i}$ as 'birth probabilities'. It may be too much to hope that this usage will be abandoned, but it should at least be pointed out that it is confused in several respects and inconsistent with modern statistical usage. The rates in question are proportions which, given a suitably defined probability model, may be taken as estimates of probabilities. The same remarks apply, of course, to life table 'probabilities' of death. To confuse matters further, the designation 'birth probabilities' has come to connote age-parity-specific birth rates that take (i) women of the appropriate parity, rather than all women, and (ii) numbers of women, or rather person-years lived by women, for their denominator.

of birth into the measurement of fertility involves two related but distinct aspects, the explicit introduction of parity and birth order as such, and the relating of numbers of ith births to numbers of women of parity $i-1$. The age-order-specific birth rates of Formula (4) above accomplish the first but not the second. Whelpton's rates, which are the $b_{x,i}$ values of the preceding section, take account of both points and are in this sense comparable to the period parity progression ratio measures used here. The difference is that Whelpton's rates are specific for parity and age, whereas ours are specific for parity and previous birth interval.

Both approaches lead to an index of total fertility, but the calculation from Whelpton's $b_{x,i}$ values is a good deal more difficult than the calculations of formulae (1–2). The reason is that in the former case the likelihood of progressing to a subsequent birth depends on the age at which the previous birth occurred, so that in calculating the progression ratio p_i for progression from ith to $(i+1)$th birth we need to know the age distribution of mothers with ith births, which depends on all the rates $q_{x,j}$ for all $j < i$. Thus, not only is the number of rates involved substantially larger, but each step in the calculation depends on all the preceding steps. The calculation may in fact be viewed as the construction of a life table for age and parity of woman.[26]

As both approaches recognize parity and birth order and properly relate events to exposure, there is no reason to suppose that either is inherently superior. From the point of view of simplicity of calculation, however, the advantage clearly lies with the approach taken here. From this point of view, indeed, the innovation in the parity progression approach lies not in introducing parity, but in abandoning age (though, of course, age is taken into account in connection with first marriage or first birth).

CONCLUSION

That fertility declined sharply in China during the 1970s is by now well known. While the precise extent of the decline depends on how it is measured, it was in any case very substantial. The period-parity-progression-ratio-based total fertility we have used declined from 5.4 children per woman in 1970 to 2.6 in 1981, a decline of over half in little more than a decade.

We have shown that changes in marriage contributed essentially nothing to the decline. Proportions of women ever marrying, measured on a period basis, were practically constant at a level of between 98 and 100 per cent during the entire period. Even in urban areas, where proportions of women ever marrying were lower, they never dropped below 96 per cent.

Nor was any portion of the decline due to childlessness. The survey data indicate that the proportions of women marrying who progressed to a first birth were high and stable at levels close to 100 per cent. Proportions of women who went on to have a second child did begin to decline slightly after 1975, but even in 1979 some 96 per cent of all women were proceeding from first to second births. This dropped to 96 per cent in 1981 following the introduction of the one-child family policy, a substantial decline but still too little and too late to have much effect on the overall decline of the 1970s.

By elimination, then, the decline in overall fertility that did occur was due almost entirely to a decrease in births of third and higher orders. Chinese fertility is thus distinguished in two respects. First, the decline that has occurred is due entirely to control of fertility in marriage, and not, as has sometimes been suspected elsewhere, to rises in age at marriage. Secondly, the current relatively low level of fertility co-exists with

[26] See R. D. Retherford and L. J. Cho, 'Age-parity-specific birth rates and birth probabilities from census or survey data on own children', *Population Studies*, **32**, 2 (1978), pp. 567–581, especially p. 572.

virtually universal marriage and motherhood and with large proportions of women having a second birth.

The fertility decline, in short, has not been associated with any decline in the traditional Chinese emphasis on the family. It should perhaps be noted as well that although the one-child family policy has contributed little to the fertility decline that has occurred so far, further declines in completed fertility would have to result either from an increase in proportions of women never marrying or remaining childless, or from a decrease in the proportion of those who progress from first to second birth.[27]

Our fertility measures have consisted of period parity progression ratios and of total fertility indices calculated from them, as opposed to the usual measures involving age-specific birth rates, and we have devoted some effort to analyzing the relation and relative merits of the two approaches. Where fertility is low and controlled, and where it is possible to calculate them from available data, two substantial arguments favour parity progression measures over age-specific birth rates. First, the decomposition of total fertility into birth order components is evidently a useful device for the study of fertility generally, because the birth order components represent family size, because they reflect the life cycle, and because the birth-order components computed from period parity progression ratios are clearly superior to the components calculated from age-order-specific birth rates.

Secondly, the principal objection to period rates of fertility has been that they may rise or fall merely as a result of changes in the timing of births within birth cohorts, in the absence of any change in the completed family size of these cohorts. Our analysis suggests that this is not so much a property of period measures as such, as of the particular manner of calculating period measures most often employed, the summation of age-specific birth rates. Period parity progression ratios are subject to the same distortion, to be sure, but they are evidently far more robust against cohort timing changes than age-specific birth rates. The empirical results for China show the advantage beyond any doubt, and the formal analysis of first births suggests that it holds generally in populations with low fertility.

APPENDIX

We shall describe the calculation of the rates q_E and q_x for progression from first to second birth. The procedure for other rates is formally identical, but statement in general terms tends to obscure the essentially simple ideas. It is assumed that the survey data provide, as the One-per-Thousand Survey does, year of first birth (Y_a) and year of second birth (Y_b) for each woman, with not stated (NS) and not applicable (NA) codes as appropriate.

The basic idea is to tabulate (*a*) all women who have had a first birth by the time of the survey by Y_a and (*b*) all women who have had a second birth by the time of the survey by Y_a and $Y_b - Y_a$. We refer to these tables as *entries* and *exits*, respectively, thinking of them as representing entries to and exits from the population of women of parity one.

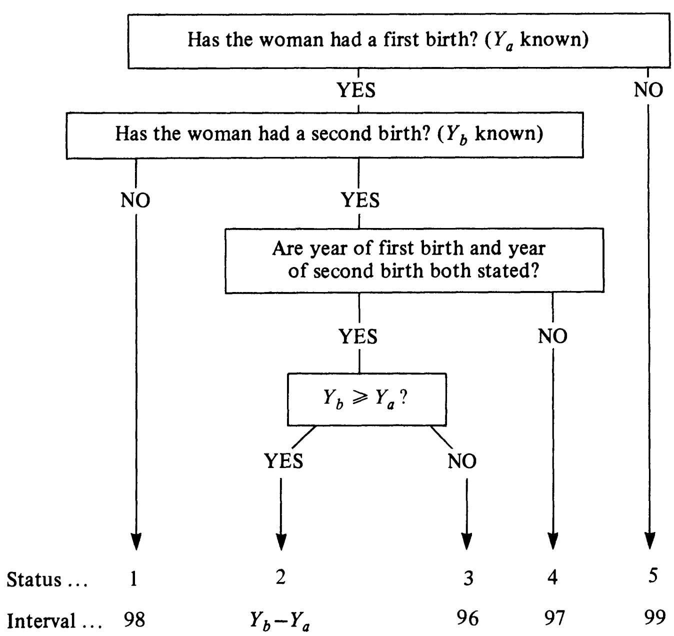
The cell for $Y_a = Y$ in the entries table gives the number of survey women who had a first birth in year Y, and hence the number of first births in year Y to survey women. Note the one–one correspondence between women having first births in any year and first births in this year. This correspondence explains how we can obtain numbers of births by tabulating groups of women.

[27] Note, however, that population growth could be reduced significantly without reducing completed fertility. This is a basic result of Ryder's translation idea, *op. cit.* in footnote 6. Possibilities for reducing population growth in China in this way are explored in J. Bongaarts and S. Greenhalgh, 'An alternative to the one-child family policy in China', *Population and Development Review*, **11**, 4 (1985), pp. 585–617.

The cells in the exits table corresponding to $Y_a = Y$ give the numbers of women, who having had a first birth in year Y, have a second birth in this and each subsequent year. The cell for year $Y_a = Y$ and $Y_b - Y_a = 0$ gives the number of women with a first birth in year Y who have a second birth in the same year, which may reflect twinning as well as a very short birth interval. The cell for $Y_a = Y$ and $Y_b - Y_a = 1$ gives the number of women with a first birth in year Y who have a second birth in the following year, and so on.

The denominators for the rates q_E are given directly by the entries table, the numerators by the cells of the exits table corresponding to $Y_b - Y_a = 0$. The numerators of the rates q_x are given by the remaining cells in the exits table. The denominators are calculated by subtracting from the numbers of women with a first birth each year, taken from the entries table, the numbers of these women who have a second birth in this and subsequent years, taken from the exits table.[28]

The tabulations indicated above do not take account of two problems that may be encountered with actual data, not stated values for year of first or second birth, and stated values where year of second birth precedes year of first birth. To do so we modify them in the following way. First define variables status and interval for every women as indicated in the following chart.



To obtain the entries table we tabulate all women by Y_a and status and sum over status values 1 and 2. This excludes women for whom year of second birth precedes year of first birth (status 3), women for whom year of first birth and/or year of second birth are not reported (status 4), and, of course, women who have not had a first birth (status 5). The same women are excluded from the exits table, obtained by tabulating all women by Y_a and interval and deleting the cells of the table corresponding to interval values 96–99.

Several comments concerning this procedure are warranted. First, the women excluded

[28] Further explanation and a numerical example are given in G. Feeney, 'Parity progression projection,' *International Population Conference, Florence 1985*, International Union for the Scientific Study of Population, vol. 4, pp. 127–129.

from the calculation by the modified procedure are excluded from both the entries and the exits table, so that no bias results. Merely taking account of not stated values in both tabulations would result in, e.g. including in the entries tabulation women for whom Y_a is reported, whether or not Y_b is reported. But women for whom Y_b is not reported will necessarily be excluded from the exits table, and so should be excluded from the entries table as well to avoid downward bias in the calculated rates.

Secondly, the modified tabulations relate to all women. Such tabulations process faster, at least with the computer tabulation package we used, than tabulations that require selection of some sub-group of women, particularly when the sub-group selected varies from one tabulation to the next, as it would here.

Thirdly, the modified tabulations are 'self-editing', in the sense that they take account of possible omission and error in the survey data. They may thus be run on any birth history data, 'clean' or not, and the results will show the extent of errors and omission in the data.

Note finally that although we have been concerned with events of birth and marriage, the procedures apply to any pair of contingent events A and B, 'contingent' meaning that event B cannot occur before event A. Thus the same ideas would apply to, e.g. progression from first marriage to first divorce, progression from entry into graduate school for award of the final degree, and so on.