



# Effects of Socio-demographic Factors on the Decreasing Trend in the Sex Ratio at Birth in Korea, 1997-2017

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**Objectives:** This study investigated the effects of socio-demographic factors on the decreasing trend in the sex ratio at birth from 1997 to 2017 in Korea.

**Methods:** Data from 10 349 602 live births registered with Statistics Korea from 1997 to 2017 were analyzed. The secondary sex ratio (SSR), defined as the ratio of male to female live births, during the study period (1997-1999 [phase I], 2000-2002 [phase II], 2003-2005 [phase III], 2006-2008 [phase IV], 2009-2011 [phase V], 2012-2014 [phase VI], and 2015-2017 [phase VII]) was calculated according to selected socio-demographic factors, such as parental age, education, occupation, and birth order. Logistic regression models were used to estimate odds ratios (ORs) and 95% confidence intervals for a male birth after adjusting for potential confounders.

**Results:** The SSR gradually decreased from 1.10 (in 1998-2000 and 2002) to 1.05 (in 2013-2016). While a decreasing trend in the SSR was not noted among first births, male-biased sex ratios were prominent among third and higher-order births, for which the highest SSR was 1.46 in 1998. Higher birth order was significantly associated with an excess of male births in phases I-VI ( $\geq$  third vs. first, OR range, 1.03 to 1.35). Advanced maternal age was significantly associated with an excess of female births in phases II, III, and V ( $\geq$  40 vs. 20-24 years, OR range, 0.92 to 0.95).

**Conclusions:** This study demonstrated that advanced maternal age and reduction of the artificially-biased SSR among third and higher-order births may partially explain the decreasing trend in the SSR from 1997 to 2017 in Korea.

**Key words:** Birth order, Educational status, Maternal age, Occupations, Sex ratio, Socioeconomic factors

## INTRODUCTION

The sex ratio at birth, or the secondary sex ratio (SSR), is defined as the ratio of male to female live births. Not only has the SSR served as a population health indicator (e.g., for fertility), but it has also played an important role as a social indicator

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(e.g., for son preference, gender equity, and couples' childbearing behavior) in many countries around the world, notably in Asia [1-3]. Korea is an Asian country that has undergone drastic changes in the SSR in the last few decades [4]. In Korea, the SSR began to increase abruptly in the mid-1980s, along with the use of ultrasound for prenatal sex determination [2,3,5]. The SSR then peaked in 1990, with a severely male-biased SSR of 1.165. Since the mid-1990s, the SSR has gradually decreased, reaching an average natural SSR of 1.050 in 2016.

The stability and variability of the SSR have been proposed to be influenced by a variety of endogenous and exogenous factors. It has been suggested that several biological factors, such as parental hormone levels around the time of conception [6-8], follicular phase length [9,10], timing of conception

during the menstrual cycle [7,9], and sperm characteristics [11], may play a role in the natural SSR. In addition, the SSR observed at the population level has been reported to vary according to socio-demographic factors such as parental age [12-15], birth order [12-14,16,17], race/ethnicity [12,14,18], and socioeconomic status (SES) [5,12,15,19-22].

Despite the recent dramatic changes in the SSR observed in Korea, sparse previous research using nationally representative data has investigated the associations of socio-demographic factors with long-term temporal trends in the SSR. A study using national vital statistics data from 1981 to 2004 [5] assessed parental SES, as measured by education and occupation, in relation to the SSR, and suggested that maternal SES may be a more sensitive indicator of variations in the SSR than paternal SES. Of note, the aforementioned study reported that there had been changes in the association between parental SES and the SSR across three equidistant time periods (1981-1984, 1991-1994, and 2001-2004). Namely, before the mid-1980s, higher parental SES was associated with an increased SSR (i.e., an excess of male births). Since then, however, an inverse association between parental SES and the SSR was prominently noted in the early 1990s. With a more extensive evaluation of socio-demographic factors (e.g., parental age, education, occupation, and birth order) in relation to the SSR, the present study aimed to investigate the impact of socio-demographic factors on the decreasing trend in the SSR from 1997 to 2017 in Korea.

## METHODS

### Research Data

Data from all live births registered with Statistics Korea from 1997 to 2017 were obtained from the Microdata Integrated Service (MDIS) [4]. With no missing values for infant sex, a total of 10 349 602 live births were included in the final dataset. Nonetheless, missing values for independent variables (birth order,  $n=44\ 280$  [0.4%]; maternal age,  $n=15\ 519$  [0.1%]; paternal age,  $n=82\ 823$  [0.8%]; maternal education,  $n=64\ 135$  [0.6%]; paternal education,  $n=104\ 555$  [1.0%]; maternal occupation,  $n=171\ 102$  [1.7%]; and paternal occupation,  $n=324\ 730$  [3.1%]) were excluded from the analysis of each variable.

### Statistical Analysis

All live births, the proportions of male and female births and the SSR (among all live births and according to birth order

[first, second, and third and higher-order births]) during the study period were calculated. The linear-by-linear association test was used to test the significance of trends in the proportions of male and female births during the study period. To evaluate changes in the SSR and its associations with socio-demographic factors over time, the study period was divided into 7 phases: 1997-1999 (phase I), 2000-2002 (phase II), 2003-2005 (phase III), 2006-2008 (phase IV), 2009-2011 (phase V), 2012-2014 (phase VI), and 2015-2017 (phase VII). Logistic regression models were used to estimate odds ratios (ORs) and 95% confidence intervals (CIs) for a male birth, after adjusting for parental age ( $\leq 19$ , 20-24, 25-29, 30-34, 35-39, and  $\geq 40$  years), education (primary, secondary, tertiary), occupation (non-manual, manual, and others [students, housewives, etc.]), and/or birth order (first, second, and third or higher). As birth order has been recognized as a factor responsible for imbalances in the SSR, a subgroup analysis was conducted according to birth order. A 2-sided significance level of 0.05 was used to assess statistical significance. Statistical analysis was performed using SPSS version 25 (IBM Corp., Armonk, NY, USA).

### Ethics Statement

As all of the data used were de-identified, this study was classified as exempt research by the Institutional Review Board of Daegu Catholic University Medical Center.

## RESULTS

Table 1 shows all live births, the proportions of male and female births, and the SSR from 1997 to 2017 in Korea. During the study period, the highest SSR (1.10) was observed in the late 1990s and the early 2000s. The SSR gradually decreased from 1.10 (in 1998-2000 and 2002) to 1.05 (in 2013-2016). When the SSR was calculated according to birth order, the decreasing trend in the SSR was not noticeable among first births. Among third and higher-order births, however, male-biased sex ratios were prominent in the late 1990s and the early 2000s (with the highest SSR being 1.46 in 1998), demonstrating a remarkable decrease in the SSR during the study period (Table 1).

The number of all live births and the SSR according to socio-demographic factors in phases I-VII are presented in Table 2. The proportion of mothers aged  $\geq 35$  years increased from 5.9% in phase I to 26.3% in phase VII; and that of fathers aged

**Table 1.** All live births, the proportions of male and female births, and the secondary sex ratio (SSR), 1997-2017, Korea

Variables	Year																				
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
All live births (n)	668 344	634 790	614 233	634 501	554 895	492 111	490 543	472 761	435 031	448 153	493 189	465 892	444 849	470 171	471 265	484 550	436 455	435 435	438 420	406 243	357 771
Male (%)***	52.0	52.4	52.3	52.4	52.2	52.4	52.1	52.0	51.9	51.8	51.5	51.5	51.6	51.7	51.4	51.4	51.3	51.3	51.3	51.2	51.5
Female (%)***	48.0	47.6	47.7	47.6	47.8	47.6	47.9	48.0	48.1	48.2	48.5	48.5	48.4	48.3	48.6	48.6	48.7	48.7	48.7	48.8	48.5
SSR	1.08	1.10	1.10	1.10	1.09	1.10	1.09	1.08	1.08	1.07	1.06	1.06	1.06	1.07	1.06	1.06	1.05	1.05	1.05	1.05	1.06
Birth order																					
First	1.05	1.06	1.06	1.06	1.05	1.07	1.05	1.05	1.05	1.06	1.04	1.05	1.05	1.06	1.05	1.05	1.05	1.06	1.06	1.04	1.07
Second	1.06	1.08	1.08	1.07	1.06	1.07	1.07	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.05	1.05	1.04	1.05	1.04	1.05	1.06
≥Third	1.36	1.46	1.43	1.44	1.42	1.41	1.37	1.33	1.28	1.22	1.16	1.17	1.14	1.11	1.09	1.09	1.08	1.07	1.06	1.07	1.06

With no missing values for infant sex, all live births (n = 10 349 602) registered with Statistics Korea from 1997 to 2017 were included in the final dataset. Nonetheless, the SSR according to birth order was calculated after excluding missing values for birth order (n = 44 280 [0.4%]) from the analysis.

\*\*\*  $P_{trend} < 0.001$  calculated by the linear-by-linear association test.

≥ 35 years increased from 17.8% in phase I to 47.2% in phase VII. The distributions of parental education and occupation changed markedly during the same period. For instance, the proportion of college-educated mothers increased from 32.0% to 77.2%, and that of mothers with non-manual jobs increased from 10.1% to 32.4% (Table 2).

Table 3 presents the ORs and 95% CIs for a male birth according to socio-demographic factors among all live births. Higher birth order was significantly associated with an excess of male births in phases I-VI (≥ third vs. first, OR range, 1.03 to 1.35), but not in phase VII. Adolescent mothers had higher odds of a male birth than did mothers aged 20-24 years in phase I (≤ 19 vs. 20-24 years, OR, 1.04; 95% CI, 1.00 to 1.07;  $p < 0.05$ ). However, older mothers had lower odds of a male birth than did mothers aged 20-24 years in phases II, III, and V (≥ 40 vs. 20-24 years, OR range, 0.92 to 0.95). Equivocal findings on the association of maternal SES with the SSR were noted. Namely, less-educated mothers had lower odds of a male birth than did college-educated mothers in phase II (primary vs. tertiary, OR, 0.94; 95% CI, 0.90 to 0.98). Meanwhile, compared with mothers with non-manual jobs, those with manual jobs (OR, 1.03; 95% CI, 1.01 to 1.05) and others (OR, 1.01; 95% CI, 1.00 to 1.02;  $p < 0.05$ ) had higher odds of a male birth in phase III.

The associations between socio-demographic factors and the SSR among first births, second births, and third and higher-order births are shown in Tables 4 and 5, Supplemental Material 1. Comparable findings on the association between maternal age and the SSR were noted among first births (in phase I, ≤ 19 vs. 20-24 years, OR, 1.04; 95% CI, 1.01 to 1.08; in phases II, III, and V, ≥ 40 vs. 20-24 years, OR range, 0.87 to 0.93) relative to the corresponding findings among all live births. Paternal age was also found to be significantly associated with the SSR among first births, indicative of similar opposing directions toward infant sex at both age extremes (i.e., ≤ 19 and ≥ 40 years) (Table 4). However, when the analysis was restricted to third and higher-order births, the findings on the associations between parental age and the SSR were in contrast with the corresponding findings among all live births or first births, indicating that advanced parental age was associated with an excess of male births in phase I (Table 5). In addition, among third and higher-order births, fathers with low SES, as measured by education and occupation, had lower odds of a male birth than did those with high SES, particularly in some early phases (phases I-III) (Table 5).

**Table 2.** Number (%) of all live births and the secondary sex ratio (SSR) according to socio-demographic factors, phases I-VII (1997-2017), Korea

Factors	Phase I (1997-1999)		Phase II (2000-2002)		Phase III (2003-2005)		Phase IV (2006-2008)		Phase V (2009-2011)		Phase VI (2012-2014)		Phase VII (2015-2017)	
	n (%)	SSR	n (%)	SSR	n (%)	SSR	n (%)	SSR	n (%)	SSR	n (%)	SSR	n (%)	SSR
<b>Birth order</b>														
First	939 622 (49.0)	1.06	799 481 (47.8)	1.06	703 234 (50.7)	1.05	735 410 (52.6)	1.05	705 094 (51.1)	1.06	699 087 (51.6)	1.05	629 423 (52.5)	1.06
Second	789 459 (41.2)	1.07	704 099 (42.1)	1.07	550 561 (39.7)	1.07	529 109 (37.9)	1.06	530 942 (38.5)	1.06	515 013 (38.0)	1.05	452 703 (37.8)	1.05
≥ Third	186 883 (9.8)	1.42	170 248 (10.2)	1.43	132 573 (9.6)	1.33	132 360 (9.5)	1.18	143 438 (10.4)	1.11	139 542 (10.3)	1.08	117 041 (9.8)	1.06
<b>Maternal age (y)</b>														
<19	16 596 (0.9)	1.09	12 850 (0.8)	1.16	10 436 (0.7)	1.23	9505 (0.7)	1.17	8747 (0.6)	1.14	8328 (0.6)	1.09	5675 (0.5)	1.06
20-24	288 937 (15.1)	1.06	187 268 (11.2)	1.07	119 261 (8.5)	1.07	90 767 (6.5)	1.06	74 097 (5.4)	1.07	67 841 (5.0)	1.04	55 360 (4.6)	1.05
25-29	1 193 360 (62.3)	1.08	994 225 (59.3)	1.08	744 384 (53.3)	1.07	675 262 (48.1)	1.06	593 712 (42.9)	1.06	465 280 (34.3)	1.05	352 074 (29.3)	1.06
30-34	302 325 (15.8)	1.15	359 695 (21.5)	1.14	389 583 (27.9)	1.10	445 627 (31.7)	1.07	474 561 (34.3)	1.06	541 619 (39.9)	1.06	471 875 (39.3)	1.05
35-39	100 531 (5.2)	1.18	106 235 (6.3)	1.17	115 087 (8.2)	1.13	164 238 (11.7)	1.08	205 774 (14.9)	1.07	238 391 (17.6)	1.06	279 039 (23.2)	1.06
≥40	13 316 (0.7)	1.17	16 329 (1.0)	1.11	16 890 (1.2)	1.05	19 206 (1.4)	1.06	27 587 (2.0)	1.03	34 421 (2.5)	1.04	37 789 (3.1)	1.05
<b>Paternal age (y)</b>														
<19	3506 (0.2)	1.08	2859 (0.2)	1.10	1749 (0.1)	1.15	1744 (0.1)	1.13	1812 (0.1)	1.07	2195 (0.2)	1.12	1454 (0.1)	1.06
20-24	65 473 (3.4)	1.07	41 340 (2.5)	1.07	30 589 (2.2)	1.05	24 141 (1.7)	1.07	18 004 (1.3)	1.07	18 877 (1.4)	1.04	18 635 (1.6)	1.05
25-29	867 827 (45.4)	1.07	646 478 (38.7)	1.07	433 353 (31.3)	1.07	372 500 (26.7)	1.05	328 157 (23.9)	1.06	253 074 (18.9)	1.06	183 052 (15.4)	1.05
30-34	635 037 (33.2)	1.09	622 546 (37.3)	1.10	563 132 (40.7)	1.07	539 307 (38.7)	1.07	497 992 (36.3)	1.06	510 735 (38.1)	1.05	424 920 (35.7)	1.06
35-39	283 316 (14.8)	1.16	288 079 (17.2)	1.15	283 261 (20.5)	1.11	364 916 (26.2)	1.07	402 899 (29.4)	1.06	407 262 (30.4)	1.06	408 748 (34.3)	1.05
≥40	57 752 (3.0)	1.18	69 941 (4.2)	1.16	72 037 (5.2)	1.12	92 580 (6.6)	1.08	123 201 (9.0)	1.07	149 057 (11.1)	1.05	153 242 (12.9)	1.05
<b>Maternal education</b>														
Tertiary	612 075 (32.0)	1.09	677 940 (40.6)	1.09	719 786 (52.0)	1.07	848 217 (60.8)	1.06	926 333 (67.3)	1.06	984 537 (72.8)	1.05	919 686 (77.2)	1.06
Secondary	1 282 075 (67.0)	1.09	982 347 (58.8)	1.10	658 151 (47.5)	1.09	540 741 (38.8)	1.07	444 517 (32.3)	1.06	362 477 (26.8)	1.05	268 644 (22.5)	1.06
Primary	19 968 (1.0)	1.15	11 336 (0.7)	1.08	6451 (0.5)	1.09	5897 (0.4)	1.05	5999 (0.4)	1.04	4941 (0.4)	1.08	3349 (0.3)	1.05
<b>Paternal education</b>														
Tertiary	853 725 (44.7)	1.09	835 419 (50.0)	1.10	801 831 (58.0)	1.08	897 188 (64.5)	1.06	949 255 (69.3)	1.06	981 365 (73.3)	1.06	897 062 (75.9)	1.06
Secondary	1 029 600 (53.8)	1.09	816 953 (48.9)	1.10	569 791 (41.2)	1.08	486 489 (35.0)	1.07	414 615 (30.3)	1.06	353 762 (26.4)	1.05	282 702 (23.9)	1.06
Primary	28 680 (1.5)	1.13	17 381 (1.0)	1.11	10 003 (0.7)	1.08	7643 (0.5)	1.09	5281 (0.4)	1.03	3736 (0.3)	1.05	2566 (0.2)	1.06
<b>Maternal occupation</b>														
Non-manual	194 014 (10.1)	1.08	192 712 (11.9)	1.08	220 268 (16.1)	1.06	286 841 (20.7)	1.06	344 788 (25.2)	1.06	390 957 (29.0)	1.06	381 754 (32.4)	1.06
Manual	57 274 (3.0)	1.10	59 316 (3.7)	1.10	58 491 (4.3)	1.10	66 799 (4.8)	1.06	70 815 (5.2)	1.05	88 684 (6.6)	1.05	94 298 (8.0)	1.06
Others	1 660 404 (86.9)	1.09	1 362 958 (84.4)	1.10	1 090 656 (79.6)	1.08	1 031 490 (74.5)	1.07	953 453 (69.6)	1.06	868 559 (64.4)	1.05	703 969 (59.7)	1.05
<b>Paternal occupation</b>														
Non-manual	994 165 (52.8)	1.09	886 310 (54.1)	1.09	786 655 (58.2)	1.08	843 079 (62.0)	1.06	850 672 (63.6)	1.06	814 617 (62.2)	1.06	714 677 (62.4)	1.05
Manual	803 812 (42.7)	1.09	677 015 (41.3)	1.10	508 165 (37.6)	1.09	456 752 (33.6)	1.06	429 552 (32.1)	1.06	450 378 (34.4)	1.05	400 047 (34.9)	1.06
Others	84 348 (4.5)	1.09	74 047 (4.5)	1.08	57 379 (4.2)	1.06	59 914 (4.4)	1.07	57 815 (4.3)	1.06	44 736 (3.4)	1.05	30 737 (2.7)	1.04

Missing values were excluded from the analysis of each variable (birth order, n=44 280 [0.4%]; maternal age, n=82 823 [0.8%]; paternal age, n=64 135 [0.6%]; paternal education, n=104 555 [1.0%]; maternal occupation, n=171 102 [1.7%]; and paternal occupation, n=324 730 [3.1%]).

**Table 3.** Odds ratios (ORs) and 95% confidence intervals (CIs) for a male birth according to socio-demographic factors among all live births, phases I-VII (1997-2017), Korea

Variables	Phase I (1997-1999)	Phase II (2000-2002)	Phase III (2003-2005)	Phase IV (2006-2008)	Phase V (2009-2011)	Phase VI (2012-2014)	Phase VII (2015-2017)
<b>Birth order</b>							
First	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Second	1.02 (1.01, 1.02)*	1.01 (1.00, 1.02)*	1.02 (1.01, 1.02)*	1.01 (1.00, 1.02)*	1.00 (1.00, 1.01)	0.99 (0.99, 1.00)	1.00 (0.99, 1.01)
≥Third	1.34 (1.33, 1.36)*	1.35 (1.34, 1.37)*	1.28 (1.26, 1.29)*	1.13 (1.12, 1.15)*	1.06 (1.05, 1.08)*	1.03 (1.01, 1.04)*	0.99 (0.97, 1.00)
<b>Maternal age (y)</b>							
<19	1.04 (1.00, 1.07)*	1.02 (0.98, 1.06)	1.00 (0.95, 1.06)	0.98 (0.93, 1.03)	0.97 (0.92, 1.03)	1.02 (0.96, 1.08)	0.99 (0.92, 1.07)
20-24	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
25-29	1.00 (1.00, 1.01)	0.99 (0.98, 1.00)	0.99 (0.98, 1.01)	1.00 (0.99, 1.02)	1.00 (0.99, 1.02)	1.01 (0.99, 1.02)	0.99 (0.97, 1.01)
30-34	1.01 (1.00, 1.02)	0.99 (0.98, 1.00)	1.00 (0.98, 1.01)	1.00 (0.99, 1.02)	1.00 (0.98, 1.02)	1.02 (1.00, 1.03)	1.00 (0.98, 1.02)
35-39	1.01 (0.99, 1.02)	0.99 (0.97, 1.01)	1.00 (0.98, 1.02)	1.00 (0.98, 1.02)	1.00 (0.98, 1.02)	1.02 (1.00, 1.04)	0.99 (0.97, 1.02)
≥40	1.00 (0.96, 1.04)	0.94 (0.91, 0.98)*	0.92 (0.89, 0.95)*	0.97 (0.94, 1.01)	0.95 (0.92, 0.98)*	0.99 (0.97, 1.02)	1.00 (0.97, 1.03)
<b>Paternal age (y)</b>							
<19	0.99 (0.92, 1.06)	1.00 (0.92, 1.09)	1.11 (1.00, 1.23)	1.07 (0.96, 1.19)	1.04 (0.94, 1.16)	1.06 (0.96, 1.17)	1.00 (0.89, 1.12)
20-24	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
25-29	0.99 (0.98, 1.01)	0.99 (0.97, 1.01)	1.01 (0.99, 1.04)	0.98 (0.95, 1.00)	0.98 (0.95, 1.02)	1.01 (0.98, 1.04)	1.00 (0.97, 1.03)
30-34	0.99 (0.97, 1.01)	1.00 (0.97, 1.02)	1.00 (0.97, 1.03)	0.98 (0.95, 1.01)	0.98 (0.95, 1.01)	1.00 (0.97, 1.03)	1.00 (0.96, 1.03)
35-39	1.00 (0.98, 1.02)	1.00 (0.98, 1.02)	1.00 (0.97, 1.03)	0.97 (0.95, 1.00)	0.98 (0.95, 1.01)	1.00 (0.97, 1.03)	1.00 (0.97, 1.04)
≥40	0.99 (0.96, 1.01)	0.98 (0.96, 1.01)	0.99 (0.96, 1.02)	0.97 (0.94, 1.00)	0.99 (0.95, 1.02)	1.00 (0.97, 1.03)	1.01 (0.97, 1.04)
<b>Maternal education</b>							
Tertiary	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Secondary	1.00 (0.99, 1.01)	1.00 (1.00, 1.01)	1.00 (0.99, 1.00)	1.00 (0.99, 1.00)	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)
Primary	1.00 (0.97, 1.03)	0.94 (0.90, 0.98)*	0.99 (0.94, 1.05)	0.96 (0.91, 1.02)	1.00 (0.95, 1.06)	1.03 (0.97, 1.09)	1.02 (0.94, 1.09)
<b>Paternal education</b>							
Tertiary	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Secondary	0.99 (0.98, 1.00)*	0.99 (0.98, 1.00)*	0.99 (0.99, 1.00)	1.00 (0.99, 1.01)	0.99 (0.98, 1.00)*	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)
Primary	0.99 (0.96, 1.02)	0.98 (0.95, 1.01)	0.97 (0.93, 1.02)	1.02 (0.97, 1.07)	0.96 (0.91, 1.02)	1.00 (0.93, 1.07)	0.99 (0.91, 1.07)
<b>Maternal occupation</b>							
Non-manual	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Manual	0.98 (0.96, 1.00)	0.99 (0.97, 1.01)	1.03 (1.01, 1.05)*	1.00 (0.98, 1.02)	1.00 (0.98, 1.01)	0.99 (0.98, 1.01)	1.00 (0.99, 1.02)
Others	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)	1.01 (1.00, 1.02)*	1.00 (0.99, 1.01)	1.00 (1.00, 1.01)	1.00 (0.99, 1.00)	1.01 (1.00, 1.02)
<b>Paternal occupation</b>							
Non-manual	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Manual	0.99 (0.99, 1.00)	1.00 (1.00, 1.01)	1.00 (0.99, 1.01)	1.00 (0.99, 1.00)	1.00 (0.99, 1.01)	0.99 (0.99, 1.00)	1.00 (0.99, 1.00)
Others	1.00 (0.99, 1.02)	1.00 (0.98, 1.01)	0.99 (0.97, 1.00)	1.00 (0.99, 1.02)	1.01 (0.99, 1.02)	0.99 (0.98, 1.01)	1.01 (0.99, 1.03)

Logistic regression models were used to estimate ORs and 95% CIs for a male birth, after adjusting for birth order, parental age, education, and occupation.

\* $p < 0.05$ .

## DISCUSSION

The present study used data from the national birth registry to evaluate the effects of selected socio-demographic factors on the decreasing trend in the SSR from 1997 to 2017 in Korea. This study revealed that higher birth order was a strong predictor of an excess of male births in 1997-2014, but not in 2015-

2017 (Table 3), possibly reflecting the reduction of an artificially-biased SSR among third and higher-order births over time [3]. In fact, the analysis according to birth order showed that changes in the SSR during the study period were not prominent among first births, but were noteworthy among third and higher-order births. Imbalances in the SSR observed in some Asian countries, such as China and India, are thought to

**Table 4.** Odds ratios (ORs) and 95% confidence intervals (CIs) for a male birth according to socio-demographic factors among first births, phases I-VII (1997-2017), Korea

Variables	Phase I (1997-1999)	Phase II (2000-2002)	Phase III (2003-2005)	Phase IV (2006-2008)	Phase V (2009-2011)	Phase VI (2012-2014)	Phase VII (2015-2017)
<b>Maternal age (y)</b>							
< 19	1.04 (1.01, 1.08)*	1.02 (0.98, 1.07)	1.00 (0.94, 1.06)	0.98 (0.93, 1.04)	0.97 (0.92, 1.03)	1.02 (0.95, 1.08)	0.98 (0.90, 1.06)
20-24	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
25-29	1.00 (0.99, 1.02)	0.99 (0.98, 1.00)	0.99 (0.98, 1.01)	1.01 (0.99, 1.02)	1.01 (0.99, 1.03)	1.00 (0.98, 1.03)	1.01 (0.98, 1.03)
30-34	1.00 (0.99, 1.02)	0.99 (0.98, 1.01)	1.00 (0.98, 1.01)	1.00 (0.98, 1.02)	1.00 (0.98, 1.02)	1.01 (0.99, 1.04)	1.02 (0.99, 1.04)
35-39	0.97 (0.94, 1.00)	0.97 (0.94, 1.00)	0.97 (0.94, 1.00)	0.99 (0.97, 1.02)	0.99 (0.96, 1.02)	1.00 (0.98, 1.03)	0.99 (0.96, 1.02)
≥ 40	0.95 (0.89, 1.01)	0.87 (0.82, 0.93)*	0.90 (0.85, 0.95)*	0.98 (0.93, 1.04)	0.93 (0.89, 0.98)*	0.99 (0.94, 1.03)	1.00 (0.96, 1.05)
<b>Paternal age (y)</b>							
< 19	0.96 (0.89, 1.04)	1.00 (0.92, 1.09)	1.12 (1.00, 1.24)*	1.07 (0.96, 1.19)	1.04 (0.93, 1.16)	1.05 (0.95, 1.16)	1.00 (0.88, 1.13)
20-24	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
25-29	0.99 (0.97, 1.01)	0.99 (0.97, 1.02)	1.02 (0.99, 1.05)	0.97 (0.94, 1.00)	0.98 (0.94, 1.01)	1.00 (0.96, 1.04)	0.98 (0.95, 1.02)
30-34	0.98 (0.96, 1.00)	1.00 (0.97, 1.02)	1.01 (0.98, 1.04)	0.98 (0.95, 1.01)	0.97 (0.94, 1.01)	0.99 (0.96, 1.03)	0.98 (0.94, 1.02)
35-39	0.98 (0.95, 1.00)	0.99 (0.96, 1.02)	1.00 (0.97, 1.04)	0.96 (0.93, 1.00)*	0.97 (0.94, 1.01)	0.99 (0.96, 1.03)	0.99 (0.95, 1.03)
≥ 40	0.98 (0.94, 1.02)	0.96 (0.92, 1.00)	0.97 (0.93, 1.02)	0.96 (0.92, 1.00)*	0.98 (0.94, 1.02)	0.98 (0.95, 1.02)	1.01 (0.97, 1.06)
<b>Maternal education</b>							
Tertiary	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Secondary	0.99 (0.98, 1.01)	1.00 (0.99, 1.01)	0.99 (0.98, 1.01)	1.00 (0.99, 1.01)	0.99 (0.98, 1.01)	1.00 (0.99, 1.02)	1.01 (0.99, 1.02)
Primary	1.03 (0.97, 1.08)	0.98 (0.92, 1.05)	0.99 (0.91, 1.07)	0.92 (0.85, 0.99)*	0.98 (0.91, 1.05)	1.03 (0.94, 1.12)	0.98 (0.88, 1.10)
<b>Paternal education</b>							
Tertiary	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Secondary	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)	1.01 (1.00, 1.02)	0.99 (0.98, 1.00)	0.99 (0.98, 1.01)	0.99 (0.98, 1.01)
Primary	1.04 (1.00, 1.08)	1.03 (0.97, 1.08)	0.98 (0.92, 1.05)	1.05 (0.98, 1.12)	0.98 (0.90, 1.07)	1.01 (0.91, 1.11)	1.01 (0.90, 1.14)
<b>Maternal occupation</b>							
Non-manual	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Manual	0.98 (0.95, 1.01)	0.99 (0.97, 1.02)	1.03 (1.00, 1.06)*	1.00 (0.98, 1.02)	0.99 (0.97, 1.02)	1.00 (0.98, 1.02)	1.01 (0.99, 1.03)
Others	0.99 (0.98, 1.01)	1.00 (0.99, 1.01)	1.01 (1.00, 1.02)	1.00 (0.99, 1.01)	1.01 (1.00, 1.02)	1.00 (0.99, 1.01)	1.01 (1.00, 1.02)
<b>Paternal occupation</b>							
Non-manual	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Manual	0.99 (0.98, 1.00)	1.00 (0.99, 1.01)	1.01 (1.00, 1.02)	1.00 (0.99, 1.01)	1.00 (0.99, 1.02)	1.00 (0.98, 1.01)	0.99 (0.98, 1.00)
Others	1.01 (0.99, 1.03)	1.00 (0.98, 1.02)	0.99 (0.97, 1.01)	1.00 (0.98, 1.02)	1.01 (0.99, 1.03)	0.99 (0.97, 1.01)	1.02 (0.99, 1.04)

Logistic regression models were used to estimate ORs and 95% CIs for a male birth, after adjusting for parental age, education, and occupation.

\* $p < 0.05$ .

be attributed to son preference and prenatal sex selection against females [2,3,5], which are social trends considered to be influenced by economics and cultural transmission [23,24]. As Korea has undergone drastic economic development and cultural changes during the last few decades, changes in sex selection practices, along with the implementation of policies against these practices, may have contributed to the rapid normalization of the artificially-biased SSR in Korea [24-26].

In addition, consistent with some—but not all—previous studies [12-15], the present study revealed that maternal age was significantly associated with differences in the SSR among

all live births. Specifically, this study suggests that advanced maternal age ( $\geq 40$  years) may be associated with a lower SSR, whereas young maternal age ( $\leq 19$  years) may be associated with a higher SSR (Table 3). Similarly, in a study using data from the national birth registry from 1940 to 2002 in the United States, the 2 oldest maternal age groups (40-44 and  $\geq 45$  years) had the lowest SSR (both 1.04) [14]. Another study using United States linked birth-infant death data from 1983 to 2001 found that mothers aged 15-19 years were more likely to give birth to sons than mothers aged 20-34 years, whereas mothers aged  $\geq 35$  years were more likely to give birth to daughters

**Table 5.** Odds ratios (ORs) and 95% confidence intervals (CIs) for a male birth according to socio-demographic factors among third and higher-order births, phases I-VII (1997-2017), Korea

Variables	Phase I (1997-1999)	Phase II (2000-2002)	Phase III (2003-2005)	Phase IV (2006-2008)	Phase V (2009-2011)	Phase VI (2012-2014)	Phase VII (2015-2017)
<b>Maternal age (y)</b>							
< 19	0.53 (0.31, 0.91)*	0.54 (0.29, 1.00)	1.18 (0.57, 2.42)	1.93 (0.35, 10.61)	-	0.72 (0.28, 1.86)	0.94 (0.39, 2.27)
20-24	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
25-29	1.14 (1.07, 1.21)*	1.04 (0.97, 1.11)	1.05 (0.96, 1.15)	0.97 (0.87, 1.08)	0.95 (0.85, 1.07)	0.97 (0.86, 1.08)	0.96 (0.85, 1.09)
30-34	1.24 (1.16, 1.32)*	1.10 (1.02, 1.18)*	1.11 (1.01, 1.22)*	1.02 (0.92, 1.14)	1.02 (0.91, 1.13)	0.98 (0.87, 1.09)	0.97 (0.86, 1.10)
35-39	1.25 (1.17, 1.34)*	1.09 (1.01, 1.17)*	1.11 (1.01, 1.22)*	1.02 (0.92, 1.14)	1.01 (0.91, 1.14)	0.99 (0.89, 1.11)	0.96 (0.85, 1.09)
≥ 40	1.29 (1.18, 1.41)*	1.06 (0.97, 1.16)	1.00 (0.90, 1.11)	0.95 (0.84, 1.07)	0.99 (0.88, 1.11)	0.98 (0.87, 1.11)	0.94 (0.83, 1.07)
<b>Paternal age (y)</b>							
< 19	0.74 (0.07, 8.38)	3.78 (0.41, 34.61)	-	3.23 (0.33, 31.39)	-	1.83 (0.42, 7.98)	0.47 (0.08, 2.68)
20-24	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
25-29	1.26 (1.06, 1.49)*	0.94 (0.76, 1.17)	0.92 (0.74, 1.15)	1.25 (0.99, 1.58)	1.05 (0.83, 1.35)	1.10 (0.87, 1.39)	0.93 (0.75, 1.15)
30-34	1.33 (1.12, 1.58)*	1.00 (0.81, 1.24)	0.93 (0.75, 1.16)	1.22 (0.97, 1.53)	1.04 (0.82, 1.33)	1.11 (0.88, 1.40)	0.89 (0.72, 1.09)
35-39	1.37 (1.15, 1.62)*	1.03 (0.83, 1.28)	0.98 (0.79, 1.23)	1.24 (0.98, 1.56)	1.06 (0.83, 1.35)	1.09 (0.87, 1.38)	0.92 (0.75, 1.13)
≥ 40	1.34 (1.13, 1.60)*	1.02 (0.82, 1.27)	0.95 (0.76, 1.18)	1.22 (0.97, 1.54)	1.05 (0.82, 1.34)	1.09 (0.86, 1.37)	0.91 (0.74, 1.12)
<b>Maternal education</b>							
Tertiary	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Secondary	1.04 (1.01, 1.07)*	1.03 (1.00, 1.06)*	1.04 (1.01, 1.07)*	0.99 (0.96, 1.02)	1.01 (0.98, 1.03)	0.99 (0.97, 1.02)	0.99 (0.97, 1.02)
Primary	0.97 (0.91, 1.04)	0.95 (0.88, 1.04)	1.00 (0.89, 1.12)	0.98 (0.85, 1.12)	1.01 (0.87, 1.17)	1.03 (0.87, 1.22)	1.02 (0.85, 1.22)
<b>Paternal education</b>							
Tertiary	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Secondary	0.95 (0.93, 0.98)*	0.94 (0.92, 0.97)*	0.91 (0.89, 0.94)*	0.96 (0.94, 0.99)*	0.98 (0.95, 1.00)	0.99 (0.96, 1.01)	1.01 (0.98, 1.04)
Primary	0.87 (0.82, 0.93)*	0.84 (0.78, 0.90)*	0.90 (0.82, 0.99)*	0.91 (0.81, 1.01)	0.85 (0.75, 0.97)*	0.94 (0.80, 1.09)	0.98 (0.81, 1.17)
<b>Maternal occupation</b>							
Non-manual	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Manual	0.93 (0.88, 0.99)*	0.96 (0.90, 1.02)	0.99 (0.93, 1.06)	0.95 (0.90, 1.01)	1.02 (0.96, 1.08)	0.99 (0.94, 1.04)	0.99 (0.94, 1.05)
Others	0.98 (0.94, 1.03)	0.99 (0.95, 1.04)	1.01 (0.96, 1.06)	0.99 (0.95, 1.03)	0.99 (0.96, 1.03)	0.98 (0.95, 1.01)	0.99 (0.96, 1.03)
<b>Paternal occupation</b>							
Non-manual	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Manual	0.96 (0.94, 0.98)*	0.98 (0.96, 1.00)	0.99 (0.96, 1.01)	0.99 (0.97, 1.01)	1.00 (0.98, 1.03)	1.00 (0.97, 1.02)	1.01 (0.99, 1.04)
Others	0.94 (0.90, 0.99)*	0.93 (0.88, 0.97)*	0.94 (0.89, 0.99)*	0.96 (0.92, 1.01)	1.00 (0.96, 1.05)	1.01 (0.96, 1.06)	1.02 (0.97, 1.08)

Logistic regression models were used to estimate ORs and 95% CIs for a male birth, after adjusting for parental age, education, and occupation.

\* $p < 0.05$ .

[15]. Contrary to the present study, however, several studies, particularly those conducted in Western countries, have suggested that higher birth order may be associated with a decreased SSR, given that older age at childbearing tends to be associated with higher birth order [12,14]. For instance, the aforementioned study conducted in the United States showed that seventh and eighth and higher-order births had the lowest SSR (both 1.03) [14].

Of note, the present study revealed that the association of parental age with the SSR differed by birth order. This may have resulted from a mixture of the biological and artificial effects

of this factor on the SSR (i.e., a mixture of naturally-varied and artificially-biased SSR), which may differ by birth order. The SSR among first births, which appeared to be within the natural range of variability, was found to be significantly associated with parental age at both extremes ( $\leq 19$  and  $\geq 40$  years), reflecting the potential biological impact of this factor on infant sex (Table 4). Meanwhile, the SSR for third and higher-order births, which appeared to be severely male-biased, particularly in the late 1990s (phase I), showed opposite results in terms of its association with parental age compared with the corresponding results among first births (Table 5). Among third and

higher-order births in the late 1990s, as parental age increased, the odds of a male birth increased, implying possible birth cohort effects on the magnitude of son preference and couples' childbearing behavior [3,24,27].

Uncertain associations of parental SES with the SSR were noted among all live births and in the subgroup analysis according to birth order (Tables 3-5, and Supplemental Material 1). In comparison with a previous study using national vital statistics data from 1981 to 2004 [5], the present study did not clearly show that maternal SES was a more sensitive indicator of variation in the SSR than paternal SES during the study period. Instead, among third and higher-order births, low-SES fathers (SSR range, 1.21 to 1.32; data not shown) were found to have lower odds of a male birth than high-SES fathers (SSR range 1.37 to 1.49; data not shown), particularly in the late 1990s and early 2000s (phases I-III) (Table 5). This finding may be interpreted as reflecting the artificial effect of SES on the SSR, as high-SES fathers may have better access to sex selection techniques than low-SES fathers having a third and higher-order child.

In terms of the biological effect of SES on the SSR, the Trivers-Willard (TW) hypothesis, a long-established hypothesis regarding the SSR, theorizes that parents in good condition tend to produce more sons, whereas parents in poor condition tend to produce more daughters from the perspective of evolutionary biology [28]. According to the TW hypothesis, high-SES parents are more likely to have sons, while low-SES parents are more likely to have daughters, allegedly due to higher male mortality during the gestational period [12,19,20,22]. However, the existing evidence on the TW hypothesis is controversial, with inconsistent findings on the association between parental SES and the SSR [12,15,19-22]. For instance, in a study conducted in Sweden, more than 3 000 000 births between 1960 and 2007 were analyzed to examine various dimensions of parental SES (i.e., earnings, post-transfer income, wealth, parental wealth, education, and occupation) in relation to the SSR, and no substantive relationship was found between parental SES and the SSR [21]. In another study using Swedish national data for the years 1862 through 1991 [20], in contrast, economic contractions were found to be significantly associated with alterations in the SSR at the population level, implying a potential role of ambient social stressors such as economic stress in affecting the SSR [19,20,22,29].

Nonetheless, the biological mechanisms by which parental socio-demographic factors might influence the SSR are ob-

scure. Another prevailing hypothesis regarding the SSR is the hormonal hypothesis proposed by James [6-8], who postulated that parental hormone levels around the time of conception are potential determinants of offspring sex. According to this hypothesis, high levels of estrogen (in the mother) and testosterone (in either parent) are associated with an excess of male births, whereas high levels of follicle-stimulating hormone and luteinizing hormone are associated with an excess of female births [6,7]. In light of age-related hormonal changes in humans, parental age may function as a biological determinant of the SSR. While the hormonal hypothesis applies to the determination of sex ratio at conception or the primary sex ratio, the economic stress hypothesis proposed by Catalano applies to subsequent adjustments to the primary sex ratio via sex-selective fetal loss [8,19,20]. Namely, since maternal economic stress around the time of conception causes increased testosterone secretion from the adrenal glands, it may increase the likelihood of conceiving a male according to the hormonal hypothesis. If maternal economic stress persists during the gestational period, however, it may increase the risk of spontaneous abortion, which disproportionately affects male embryos and fetuses according to the economic stress hypothesis. As such, prolonged economic stress experienced by mothers may compensate for the male-biased primary sex ratio, or could even result in an excess of female births [29].

The major limitations of the present study should be taken into account when interpreting the observed results. Although the present study utilized national birth registry data that covered nearly all births in the nation, the information regarding the parents, such as age and SES, may have been inaccurate. As for the information on infants, the SSR is not considered to be affected by recall bias. With sole dependence on information included in the national birth registry, various dimensions of parental SES (e.g., earnings, wealth, etc.) were not evaluated. For the same reason, further investigations of other potential determinants of temporal trend in the SSR (e.g., environmental factors such as exposure to endocrine disruptors [30]) were unfeasible. Normative changes related to the observed trend in the SSR were not quantitatively assessed, meaning that this study did not address how much normative changes have contributed to the decreasing trend in the SSR during the study period. Furthermore, although the study results were interpreted as reflecting a mixture of the biological and artificial effects of factors affecting the SSR, the SSR may not be an accurate indicator for evaluating changes in sex selec-



tion practices and policies targeting these practices within a population. As recently proposed, the sex selection propensity, which incorporates other relevant factors (e.g., family size and birth order) together with the SSR, may serve as a more accurate indicator of these changes [1].

In conclusion, the present study demonstrated that advanced maternal age and the reduction of the artificially-biased SSR among third and higher-order births may partially explain the decreasing trend in the SSR from 1997 to 2017 in Korea. The artificial effect of birth order on the SSR appeared to exceed the biological effect of birth order on the SSR from 1997 to 2014, but this was no longer the case starting in the mid-2010s (2015-2017; phase VII). The rapid normalization of the artificially-biased SSR in Korea in the last few decades is perceived to be a desirable phenomenon, with favorable social implications regarding gender equity and couples' childbearing behavior. Along with various socio-demographic factors, potential environmental factors affecting the SSR at the population level need more research attention to ensure the stability of the SSR within its natural range of variability.

## SUPPLEMENTAL MATERIALS

Supplemental material is available at <https://doi.org/10.3961/jpmph.20.282>.

## CONFLICT OF INTEREST

The author has no conflicts of interest associated with the material presented in this paper.

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## AUTHOR CONTRIBUTIONS

All work was done by JB.

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