

ANALYSIS OF THE SEX RATIO AT BIRTH IN GREECE, 1960-2006
ARE SYNTHETIC CHEMICALS TO BLAME?

by

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Abstract

Social, economic, demographic, evolutionary or environmental variables have been tested as explanatory factors for differential sex ratios at birth. The aim of this paper is twofold. Firstly, to examine variation in the sex ratio at birth observed in Greece during the last decades; analysis also includes supplementary characteristics like the age and nationality of mother and birth order. The second aim of the paper is to investigate the differentiations across urban and rural areas in order to identify potential environmental incidence. Some of the findings may be interesting from an environmental point of view, as they seem to follow trends that have been partially attributed to hormone disruptors though the issue is treated from a purely demographic view. In line with the other industrialized countries, the sex ratio in Greece follows a net downward trend, especially since 1980. Regional differentiations are proved to be rather important. The sex ratio is considerably higher in rural areas compared to urban centers or Athens Major Area, while the gap is increasing over time. This may be partially attributed to environmental factors, including the exposure to higher concentrations of chemicals with hormonal or anti-hormonal action (hormone disruptors), on the basis of theoretical assumptions and case studies well documented in the literature (e.g. the Seveso accident) as measurement of such exposure at ambient levels presents a very high degree of difficulty.

Introduction

Sex ratio at birth is a demographic indicator defined as the number of newborn baby boys that correspond to 100 newborn baby girls. Besides demography, this ratio is widely used in various disciplines like medicine, biology, environmental studies or sociology while its trends remain a prominent subject of scientific interest, for at least some decades. The fact that the probability of a male birth is consistently higher than that of a female has been known since as early as the mid-17th century and has been confirmed over time. Despite geographical and racial disparities about 105-107 baby boys are born for every 100 baby girls (Davis et al., 1998). This number corresponds to an empirically confirmed “global average” with random fluctuations over time.

In the attempt to identify the explanatory factors behind temporal and geographical variations of sex ratio at birth, a very rich literature has been developed. A large number of different parameters have been empirically tested for being associated with sex ratio at birth and many of them have been found statistically significant. Proposed determinants include: demographic variables, such as mother’s age (Juntunen et al., 1997), family size and birth order (Biggar et al., 1999; James, 1996); social characteristics, like father’s and mother’s occupation (Grant and Metkalf, 2003; Grant and Yang, 2003); economic and political stress factors, such as collapsing economies (Catalano, 2000: 9-15, 2003; Catalano and Bruckner, 2005; Zadzinska et al., 2007), war and other manmade disasters (Ellis and Bonin, 2004) and natural disasters (i.e. earthquakes; Fukuda et al., 1998). In addition nutritional parameters, such as mother’s dietary habits and nutritional status (Mace and Eardely, 2004; Sule and Madugu, 2004) and father’s consumption of alcohol (Dickinson and Parker, 1994) have been examined.

The sex ratio at birth is thought to be determined by a multitude of complex factors concerning both the father and the mother. For each single pregnancy the genes of the father’s sperm determine the sex of the fertilised egg (more precisely, determined by the sex-determining region Y gene located on the Y chromosome). However, the viability of a foetus may be differentially affected by factors acting after conception, depending on its sex, males being more susceptible (Davis et al., 2007). Therefore, factors affecting hormone levels, such as stress or disease, as well as exposure to chemicals that may have hormonal action, may influence the sex ratio at birth.

The latter especially have become the subject of intense scientific interest recently, as a significant decline of the sex ratio at birth has been observed in many industrialised countries recently. A hypothesis has been formulated that some of the more than 100,000 registered and widely used synthetic chemical compounds may be associated with this decline. These compounds, collectively termed as hormone disruptors or xenoestrogens, include well known toxic chemicals such as pesticides, dioxins and polychlorinated biphenyls (PCBs), but also a wide range of chemicals found in many every day products, like preservatives in creams, lotions, personal care products and pharmaceuticals,

detergents, and plasticizers found in plastic food boxes and drinks bottles (Barlow et al., 1999; Sirakov, 2006). Hormone disruptors are known to act as pseudo-estrogens and/or anti-androgens. Moreover, these compounds may differentially affect men and women and subjects of different age – with younger individuals being usually more susceptible, while the timing of exposure may be more critical than the total dose (Davis et al., 2007; Gomez et al., 2002; Jarrel, 2002), further complicating the analysis.

It has been established with specific case studies of small cohorts with high exposure that certain classes of widespread chemicals may disrupt the hormone balance of humans and other animals and lead, among else, to a decrease of the sex-ratio (de Gomez et al., 2002; James, 1998; Moshammer et al., 2000). Most eminent among them are the studies of those exposed to dioxin (tetrachlorodibenzo-*p*-dioxin, TCDD) released during an accident at a pesticides production plant in Seveso, Italy in 1976. No deaths or serious health damage was reported. However, serious exposure of the father almost doubled his chance of fathering a girl, compared to the sex ratio of the rest of Italy. Mother's exposure however did not significantly affect the sex of her offspring (Figa-Talamanca et al., 2003b; Mocarelli et al., 2000). Similar were the findings of de Gomez et al. (2002) in the study of the effect of PCBs and the products of their thermal decomposition, during the event of PCBs contamination of cooking oil in Yucheng, Taiwan, 1979. Occupational exposure of workers to plasticizers in Japan has also been associated to a highly significant decline in the sex ratio at birth of their offspring (Okubo et al., 2000), while a recent study in Greece on workers in a shipyard, found a significantly lower chance of fathering a boy for sandblasters / painters and ship carpenters – those groups being most exposed to chemicals (Alexopoulos and Alamanos, 2007). Moreover, a retrospective analysis of five different studies of heavily polluted residential areas in Scotland from 1975 to 1983 demonstrated a strong decline of the sex ratio at birth (Williams et al., 1995). This simple demographic factor has therefore been proposed as a sentinel health indicator. It is suggested that it may be used to assess the impact of environmental factors on the endocrine system and human reproductive health, as it seems unlikely to attribute its decline to secular variations of known sex ratio determinants (Davis et al., 1998; 2007).

During the last decades a general decline of the sex ratio at birth is being registered in a large number of countries (Grech, 2003; Parazzini et al., 1998). Several studies on different countries have shown that the births of baby boys follow a downward trend in most industrialized countries, including the USA (Davis et al., 2007; Marcus et al., 1998; Mathews and Hamilton, 2005), Canada (Allan et al., 1997; Dodds and Armson, 1997), Japan (Davis et al., 2007; Imaizumi and Murata, 1981), Denmark (Moller, 1996), the Netherlands (Van der Pal-de Bruin, 1997), Italy (Astolfi and Zonta, 1999; Figa-Talamanca et al., 2003a,b) and Spain (Guitierrez-Adan et al., 2000). It should be noted that this trend, though widespread, is not universal across the industrialised world. Contrary to

the common trend, Ireland registers an increase in the proportion of male births (Moynihan and Breathnach, 1999), while in Australia increases in the proportion of male births are also registered, albeit not statistically significant (Lancaster and Day, 1998). It is also worth noting that declining sex ratios are not exclusively reserved to industrially advanced countries. Male births have decreased in most of the Latin American countries, with the exception of Peru and Uruguay (Feitosa and Krieger, 1992), as well as in Iran (Ansari-Lari and Saadat, 2002).

This paper intends to provide an analysis of the trend of sex ratio at birth in Greece over the past 50 years and an insight to potential explanatory factors for its temporal and geographic variation. It presents information on the overall trends of the sex ratio at birth; it examines the impact of certain demographic variables, including mother's age and nationality, birth order and legitimacy; finally, it tests for differences across geographic regions mainly distinguishing between urban and rural areas. The aim of this paper is twofold: first, to provide trends and variations of sex ratio at birth and second, to shed light on potential explanatory factors, related either to the so-called "westernization" of the demographic behaviour or the environmental incidence. In the following parts of the paper, time trends are examined by linear regression controlling for demographic factors. The exploration of eventual explanatory factors is completed with the analysis of regional disparities; the discussion is then narrowed down to the comparison between urban and rural sex ratios and the compatibility of data with various explanatory hypotheses, including that of environmental incidence is questioned.

Datasets and Methods

Datasets used in this study are based on birth certificates registered in Greece, during the years 1960-2006. The analysis relies on data recorded by the National Vital Statistics Report, published annually by the National Statistics Service of Greece (ESYE). The first objective of this paper is to present sex ratios at birth for Greece from 1960 to 2006 and examine their trend. Linear regression was used to calculate the association of annual male to female ratio with time.

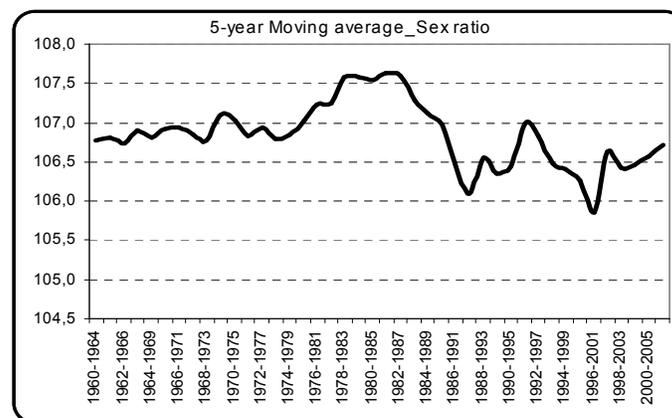
At a second level, this work aims to identify some explanatory factors. Vital statistics data, though valuable for providing information about the entire population, are somewhat limited in the amount of information they collect. Using the basic information collected, our analysis provides an insight into the impact of potential explanatory parameters proposed in the literature, like the age of mother (data available from 1965 onwards), birth order (from 1980), parents' marital status (from 1960), urbanisation level (from 1960) and mother's ethnicity (a new factor introduced in 2004). The comparison of sex ratios at birth between different age classes, social or geographic groups is used so as to identify significant deviations from the reference category, defined as the baseline

group. Since our analysis is based on the complete count of male and female births during the period examined, data are not subject to sampling error. Yet the number of male births that actually occurred may be regarded as one of many possible outcomes and, in this respect, it may be subject to random variations. For every demographic parameter examined as a possible explanatory factor of sex ratio variations, we define a reference category. Contingency tables and χ^2 tests with one degree of freedom have been used to test whether disparities in male birth probability across different population groups have occurred randomly or not. For all sub-groups odds ratios and 95% confidence intervals have been calculated. Additionally, two discrete non-parametric tests, the Mann-Whitney test and the χ^2 test, have been applied to assess geographic differentiations across regions, ie. between urban and rural areas. Statistical analysis was performed using the statistical software SPSS v15.

Sex ratio trends since 1960

During the years 1960-2006, the sex ratio at birth in Greece varied between 104.3 and 108.2; the lowest value occurred in 1977 and the highest in 2001. The annual number of “excess” males ranged from 2,302 in 1996 to 5,634 in 1961¹. During the examined period, out of a total number of about 6 million births, newborn baby-boys outnumbered baby-girls by 194,177. This figure corresponds to an annual mean surplus of more than 4,100 newborn boys.

Figure 1.



To evaluate trends in the sex ratio over time, the main independent variable was time and it has been modelled as a linear term (year). For the whole period concerned, an apparent albeit not statistically significant decline in sex ratio was found. With the aid of Figure 1,

¹For any country, the “excess” number of newborn males in a specific time period depends not only on the sex ratio but also on the total number of births during this period.

the examined period was divided into two discrete sub-periods. During the years 1960-1979, the sex ratio at birth registered a slight but not statistically significant upward trend. This upward trend, common to most industrialised countries in the decades of '50s – '70s, is probably attributed to the rapid medical progress experienced in Greece in that period, which considerably limited the risks of pregnancy complications and perinatal deaths. Male infants, traditionally more vulnerable to mortality risks than female embryos and neonates, were more favoured by this progress, leading to a slight increase of the observed sex ratio (Davis et al., 1998; Jarrell, 2002). In contrast to the previous period, data from 1980 onwards show a statistically significant decline in the sex ratio at birth of about 0.047% ($p=0.03$) annually. The regression equation describing the sex ratio variation over time is $y=107.45-0.047x$ ($r=-0.40$). These findings largely confirm the results of the scant literature referring to the sex ratio changes in Greece (Parazzini et al., 1998; Alexopoulos and Alamanos, 2007). It is worth noting that despite this recent trend, sex ratio in Greece remains relatively high, compared to other industrialized countries, fluctuating around the value of 106 baby boys for every 100 baby girls, possibly reflecting the relative lag of Greece in industrialisation and “westernisation”.

The role of demographic determinants

The statistically significant decline in the sex ratio at birth observed in Greece is along the lines of recent trends observed in most industrialised countries (Davis et al., 2007; Grech, 2003; Parazzini et al., 1998). The main research question of this study concerns the potential explanatory factors behind this trend. The aim of this section is to examine the role of certain demographic determinants on the variation of sex ratio at birth in Greece during the last five decades (Table 1).

Table 1. Sex ratio variations in respect to various demographic variables

	Sex ratio	RR	95% CI	p-value
<i>Mother's age</i>				
<19	106.0	0.989	0.982 to 0.997	0.003
20-24	106.8	0.998	0.994 to 1.003	0.667
25-29	107.0	1	<i>Reference category</i>	
30-34	106.7	0.997	0.993 to 1.002	0.18
35-39	107.0	1.001	0.994 to 1.008	0.93
40-44	107.0	0.999	0.987 to 1.011	0.43
45-49	102.8	0.950	0.907 to 0.992	0.004
50+	109.8	1.005	0.878 to 1.133	0.31
<i>Birth order</i>				
1 st	107.0	1	<i>Reference category</i>	
2 nd	106.6	0.996	0.991 to 1.002	0.168
3 ^d	107.6	1.005	0.998 to 1.013	0.64
4 th	106.4	0.995	0.984 to 1.006	0.45
5 th or more	108.2	1.013	0.996 to 1.030	0.18

<i>Mother's marital status</i>				
In-marriage	106.8	1	<i>Reference category</i>	
Out-marriage	107.1	1.003	0.989 to 1.017	0.60
<i>Mother's ethnicity</i>				
Greek	106.3	1	<i>Reference category</i>	
Foreigner	108.6	1.02	0.993 to 1.048	0.026

The age of mother

Relevant literature suggests that sex ratio varies significantly with mother's age (Mathews and Hamilton, 2005; Smith and Behren, 2005). In the crude Greek data, the probability of a male birth increases with age, for mothers between 20 and 40 years of age. Reduced sex ratios have been linked to the very young and elder age-groups: mothers below 19 years of age and those above 40 report the lowest proportions of male births, though sex ratio remains on average higher than 100. The pattern of sex ratio variation as a function of mother's age remains relatively stable along the years, within the examined period, with the exception of elder ages. More specifically, it seems that since 1980, the sex ratio decline after the age of 40 has become less marked compared to the period 1965-1979, probably due to the improvements of obstetrics. This has significantly reduced pregnancy and accouchement complications, associated with elder mothers. Such complications are known to variably affect baby boys (Davis et al., 1998; Figa-Talamanca et al., 2003b; Ulizzi, 1983). Besides its lower average value, sex ratio at birth for the age groups situated at the extremes of childbearing years registered particularly large annual variations. Table 1 presents the mean value of sex ratio at birth for each age group along with two sided 95% confidence intervals.

To test whether sex ratio varies significantly across different ages, the '25-29' age class has been chosen as reference category. Table 1 shows the comparison of sex ratios between the reference category and the other age classes. For two of them differences are highly significant; odds ratio is 0.989 for mothers younger than 20 ($\chi^2=8.8$, d.f.=1 and $p=0.003$) and 0.950 for those between 45-49 years of age ($\chi^2=8.18$, d.f.=1 and $p=0.004$). In other words, the probability that the lower sex ratios observed among younger mothers as well as for those from 45 to 49 years have occurred by chance is less than 0.01. Based on the χ^2 test, sex ratio variations across the other age groups may be merely imputed to randomness.

The shift towards an older fertility pattern that has been registered in Greece during the last 25 years, has increased the mean age at maternity by about 5 years, from the age of 25.4 to 29.8. In the same time, the share of children born to mothers younger than 20 years has shrunk from 12.6% in 1980 to less than 3.0% in 2006, while the proportion of children born to mothers from 30 to 40 years old increased sharply from 20% to 50%;

births from mothers above 40 years of age increased only slightly from about 1.8% to 3.0%. Therefore, ageing fertility coupled with the findings about sex ratio variations with age would most probably argue for increasing total sex ratios rather than the declining male birth probability currently registered.

Ratios by live-birth order

Based on international evidence, findings about the influence of birth order on sex ratio are rather contradictory. No independent effect of maternal birth order has been observed in data from Denmark (Jacobsen et al, 1999); in contrast, significant increases in sex ratio seem to be related to high sex ratios for third order births in the countries of Caucasus (Meslé et al., 2005); furthermore, declining sex ratios for seventh or higher order births have been found in USA (Mathews and Hamilton, 2005).

Our analysis for Greece demonstrates that sex ratio fluctuations become larger after the second child. A first peak is observed at the third order birth and a second more important one at the sixth order birth. However, the trend is not consistent since both peaks are followed by sharp and practically inexplicable declines. Therefore, as they do not follow a specific pattern, these fluctuations seem rather random. No significant effect of birth order on sex ratio has been found, since differences from the first birth, defined as reference category, are not statistically significant (all p -values are steadily above 0.05).

Maternal marital status

The partnership-status hypothesis has been cited as an additional explanatory factor to the large number of variables plausible to determine the sex of a child. Evidence from different countries suggests that the sex ratio at birth is lower among single mothers compared with married or cohabiting couples (Norberg, 2004; Chacon-Puignan and Jaffe, 1996), a trend that is thought to be compatible with the “classical” sex ratio theory, since child breeding maybe more stressful for single mothers.

Despite their recent upward trend, the share of out-of-wedlock births in Greece remains below 6% of total births. During the last 47 years, 119,465 extra marital births have occurred, with overall sex ratio at 107.1. Contrary to the international experience registered in the literature, male birth probability in Greece appears slightly higher among non-married women, though differences in proportions are not statistically significant and may therefore be attributed to pure randomness (Table 1).

Mother's ethnicity

Out of 325,242 births recorded in Greece during the years 2004-2006, 54,074 (16.6%) were children born to foreign mothers. Reported sex ratio at birth for foreigners was

108.56, compared to a value of 106.32 recorded for Greek mothers, the difference between natives and non-natives being statistically significant (Table 1; $\chi^2=4.91$, d.f.=1 and $p=0.027$). The gradually increasing presence of immigrants in the country and the consequent growing share of infants born to non-Greek mothers would be expected to lead to an increase of sex ratio at birth, conversely to current experience.

Geographic variation of sex ratio at birth in Greece and the potential role of environmental factors

On the basis of the data examined in this study, there is not sufficient evidence that the decline in sex ratios, observed in Greece since 1980 may be attributed to demographic parameters. Well on the contrary, it could be argued that if there was an influence of delayed maternity (after the 35th year of age) on male probability that would most probably favour male births and therefore lead to an increasing trend of the sex ratio. On the basis of the very limited data available (2004-2006), the increasing presence of migrant population in Greece would also be expected to have an influence on sex ratio towards a direction opposite to that actually observed. Rephrasing the above, if standardised by fertility age patterns and by population ethnic composition, the sex ratio decline registered between 1980 and 2006 would be even sharper. Additional demographic parameters, such as maternal birth order and partnership status, were not found to exert a statistically significant influence on the sex ratio. Therefore other but demographic parameters are likely to play a more decisive role on sex determination.

Worldwide, in the intense and controversial debate about possible determinants of decreasing male probability, environmental factors are gaining importance as a growing number of studies have correlated environmental hazards to reproduction malfunctions (de Gomez et al., 2002; Figa-Talamanca et al., 2003a; James, 1998; Mocarelli et al., 2000; Moshammer et al., 2000; Okubo et al., 2000).

To gain some insight on the potential plausibility of this hypothesis an analysis of the regional variation of the sex ratio at birth in Greece was carried out, providing some interesting findings. First, a clear divide was found between rural and non-rural areas (Table 2). From 1980 onwards, sex ratio at birth is significantly higher in rural regions compared either to urban areas (p -value <0.02) or Athens Major Area in particular (p -value <0.03). These differences have been found significant using two discrete non-parametric tests, the Mann-Whitney test and the χ^2 test. The observed divergence concerns the urban areas as a whole, without distinctions between metropolitan areas and smaller cities, since no statistically significant difference in male birth probability was found between Athens and the rest of urban centres. A second interesting point refers to timing. The highly significant discrepancies in sex ratio between rural and urban areas are

observed for the last 25 years. Previously, differences were not statistically significant and may be regarded as a random outcome.

Table 2. Tests for the differences in sex ratio across regions

	Mann-Whitney test	χ^2 test
	<i>p-values</i>	
Urban - Rural		
1960-1980	0.74	0.30
1981-2006	0.016	0.001
Urban\ATH - ATH		
1960-1980	0.48	0.389
1981-2006	0.64	0.369
GR\ATH - ATH		
1960-1980	0.94	0.845
1981-2006	0.29	0.002
GR\urban - Urban		
1960-1980	0.38	0.13
1981-2006	0.011	0.001
ATH - Rural		
1960-1980	0.94	0.6548
1981-2006	0.03	0.00

Therefore, if overall declining sex ratios during the period 1980-2006 can be explained by the gradually shrinking share of rural births, how could the growing gap of male birth probability between urban and rural areas be explained?

On the basis of theoretical assumptions and well documented case studies, environmental factors, including the exposure to higher concentrations of chemicals with hormonal or anti-hormonal action (hormone disruptors) may be responsible for altered sex ratios at birth (Alexopoulos and Alamanos, 2007; Astolfi and Zonta, 1999; Figa-Talamanca et al., 2003a; Jarrell, 2002; Mocarelli et al., 2000; Moshammer et al., 2000; Sakamoto et al., 2001). The hypothesis that specific, synthetic, widely spread chemical compounds, such as pesticides, plasticizers, dioxins, PCPs but also every day personal care products, may have a bearing on reproduction mechanism is gaining support. The proposal that changes in environmental and behavioural conditions (mainly age of parenting and family size) disproportionately affect males has been strengthened by divergent trends in sex ratio observed in metropolitan and non-metropolitan centres in Italy (Astolfi and Zonta, 1999), though in another study in the same country many of these variations were not found to be statistically significant. However, the authors argue that their findings, based on aggregate pollution indicators and the overall population, cannot exclude the possibility of an environmental effect on the sex ratio, acting on specific, most exposed populations and over selected sensitive time windows (Figa-Talamaga et al, 2003b). Despite the large and steadily growing literature, the environmental incidence on sex ratio remains theoretical, since measurement of such exposure at ambient levels and for large

populations presents a very high degree of difficulty, including that associated with the analytical costs. Nevertheless, the observed declining trend of sex ratio at birth in many industrialised countries and its geographic differentiation within the same country still requires some convincing explanatory factors, and both environmental and behavioural parameters cannot be excluded.

Conclusions

There is not sufficient evidence that the decline of sex ratios observed in Greece since 1980 can be attributed to demographic parameters. Our analysis suggests that the observed trends of sex ratio at birth cannot be explained by increasing maternal age, changing proportions of specific birth orders or by rising extra-marital births. Well on the contrary, the shift towards an older fertility pattern, as well as the rise in non-marital childbearing would rather argue for elevating sex ratios. The same seems to be the case for the increasing numbers of births by immigrant mothers. The statistically significant reduction of the sex ratio in Greece from 1980 onwards follows the trend observed in other industrialised countries with a lag-phase of about a decade, and it could reflect, at least partly, the increased environmental exposure to toxic chemicals with hormonal action, the lag reflecting the delayed industrialisation and adoption of the related lifestyles in Greece. This view may be further supported by the differences observed between urban and rural areas, with people in the former being more exposed to chemical exposure due to the higher levels of outdoors air pollution, the differentiated consumption habits and the longer hours spent in indoors polluted environments. Nevertheless, the influence of other, non-environmental factors, such as stress due to the faster life pace, or social factors and behavioural conditions (age of parents, father's profession, etc) may not be excluded, on the basis of the findings of this research. Additional explanatory factors may include demographic characteristics, other than those controlled for in this analysis, or cyclical variations over time. Although changing sex ratios cannot be safely attributed to one and single cause, the hypothesis that specific, synthetic, widely spread chemical compounds may be involved can definitely not be excluded.

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