Why empresses have more sons? Maternal instant social condition determines it

Yan-Peng Li1,2,3, Wei Ding4, Zhi-Pang Huang1, Ru-Liang Pan3,5, Na Li1, Guo-Peng Ren1, Liang-Wei Cui3,6, Qing-hua Cai3,7, Wen Xiao1,2,3

Received: 12 January 2022 / Revised: 1 August 2022 / Accepted: 4 August 2022 / Published online: 13 August 2022
© The Author(s) 2022

Abstract
Sexual selection echoed by the sex ratio is a critical issue in evolution and reproductive biology studies, and the second sex ratio (sex ratio at birth, SRB) is an important evaluation indicator for sex regulation. However, broad debates on sex ratio at birth exist due to the lack of a clear spatiotemporal genealogical database. This study explicitly tests the Trivers and Willard’s hypothesis stating that parents with good social conditions tend to show a male-biased SRB. Using a database of Chinese imperial families from 211BC to 1912 (2142 years) which avoids the spatiotemporal confusion of data thanks to its clear boundaries and long timespan, we found that a proportion of males at birth was 0.54. In particular, the results indicate that the empresses generated a significantly higher male-biased SRB than the concubines within the imperial harems (0.61 vs 0.53), while the SRB of concubines was not higher than ordinary people (0.53 vs 0.52). A significant difference of SRB before and after empress coronation (0.48 vs 0.65) was detected, indicating that the change to a higher social status is the leading cause of a biased SRB. These findings suggest that mothers with privileged instant social conditions tend to generate more boys than girls. In other words, a higher maternal social rank during the conception period, instead of rich resources, forms the primary mechanism regulating the SRB.

Significance statement
Adaptive sex ratio has been a debatable topic difficult to clearly verify since the publication of Trivers and Willard Hypothesis in 1973, which proposes that parents who have good conditions should produce more male offspring. The one reason is that the validity and sample size of the databases used contained unavoidable confounding noise, both genealogically and genetically. To overcome these issues, we specifically compiled a historical database of Chinese imperial families, which are characterized by a confined mating harem and unique eunuch system, guaranteeing biological and genetic purity with precise genealogical relationships and genetic linkages between the parents and the offspring. Thus, this is an extraordinary effort to clarify the hypotheses proposed by TWH and other hypotheses.

Keywords Trivers and Willard hypothesis · Sex ratio at birth · Maternal · Instant social condition

Introduction
Sex ratio is a useful parameter for analyzing the dynamic process of sexual selection and social structure (Darwin 1859; Fisher 1930a, b; Hamilton 1967). The secondary sex ratio (sex ratio at birth) is regarded as the key parameter to understand the theory of sex allocation, because primary sex ratio (at conception) is difficult to determine. Theoretically, a sex ratio of offspring is an equilibrium, provided both sexes receive equal parental expenditure and investments. However, a disequilibrium widely exists in reality, either caused by natural selection (Hamilton 1967) or by arbitrary social
interference (birth control), such as the One-Child policy in China between the 1980s and 2015 that caused a skewed sex ratio at the birth (SRB) due to induced abortion of female fetuses (Nie 1999; Wang 2012). From an evolutionary perspective, a deviation of the sex ratio may improve inclusive fitness under natural selection and environmental adaptation principles (Hamilton 1967; Trivers and Willard 1973). A series of studies has indicated that a biased SRB could be closely related to the following facts/factors: resource availability and competition pressures of the parents (Clark 1978; Silk 1983; Dittrich 1998), maternal social status (Simpson and Simpson 1982; Symington 1987; van Schaik et al. 1989; Tanzev et al. 2008; Grech 2019), climate changes (Berkeley and Linklater 2010), war impacts (Polasek et al. 2005; Helle et al. 2009; Ellis and Bonin 2016), socioeconomic status (Catalano 2003; Luo et al. 2017), and natural disasters (Petersen 1972).

Thus, several hypotheses have been proposed for a dynamic SRB. The predominant one is the Trivers and Willard Hypothesis (TWH), which suggests that parents in better condition would be expected to show a bias toward male offspring (Trivers and Willard 1973). This proposition triggered extensive debates with published findings on different animal taxa, including birds (Clutton-Brock et al. 1985; Müller et al. 2002; Liker et al. 2013), mammals (Clark 1978; Brown 2001; Brown and Silk 2002; Sheldon and West 2004; Goswami et al. 2006; Cameron et al. 2007; Berkeley and Linklater 2010; Douhard 2017), insects (Trivers and Hare 1976; West and Sheldon 2002; Reece et al. 2004; Gardner et al. 2007), fishes (Ospina-Alvarez and Pfifer 2008), and humans (Polasek et al. 2005; Garenne 2008; Helle et al. 2009; Ellis and Bonin 2016; Douhard 2017). However, these efforts have aroused further controversies, with both consensus with the TWH (Cameron 2004; Cameron et al. 2007; Berkeley and Linklater 2010; James 2012) or against the TWH (Simpson and Simpson 1982; Gomendio et al. 1990; Hiraiwa-Hasegawa 1993; Leimar 1996; Brown and Silk 2002; West and Sheldon 2002; James 2012). Several scholars, nevertheless, declare that a definitive solid hypothesis does not actually exist (Simpson and Simpson 1982; West and Sheldon 2002; James 2012), and that alternative results were caused by sample size disparity (Palmer 2000; Brown 2001). As a result, different hypotheses have been proposed after the TWH. Among them, resource availability to females may be the key factor for SRB regulation (Clark 1978; Silk 1983), or so may environmental stress (Catalano 2003). The hormone hypothesis points to high hormone levels in females for increased male offspring (James 1980a, b, 1996), while the energy hypothesis suggests that maternal glucose levels at the time of the conception can regulate the SRB of offspring (Cameron 2004; Rosenfeld and Roberts 2004). We believe that the above inconsistencies were due to the neglect of the basic research conditions necessary to integrally test and perfect the TWH. These conditions are the following:

(1) A precise definition of the subject’s condition (controlling factors) is needed, which is not provided by the TWH. In studies about humans, factors such as income, education level, physique, social rank, occupation, and age were proposed (Garenne 2008; Helle et al. 2009; James 2012; Ellis and Bonin 2016; Kolk and Schnettler 2016; Luo et al. 2017; Grech 2019). In studies focusing on other animals, the condition is measured by social rank, physique, habitat, climate, resource occupancy, etc. (Clark 1978; Simpson and Simpson 1982; Clutton-Brock et al. 1985; Brown and Silk 2002; Berkeley and Linklater 2010).

(2) A well-defined study boundary is required. The SRB is an important parameter of reproductive behavior, and the influence of SRB may only occur in certain spatial scales, such as a local reproductive unit or a group (Stevens 1955; Silk 1983). Thus, a specific subject’s condition could be confounded: a person who makes 1000$ per month can be considered a high-income earner in an underdeveloped country, but a low-income one in a developed country. As for the social status, a mayor is supposed to have the highest rank in his city, but he is one of the subordinates of the provincial governor (Dittus 1998; IMF 2015; Luo et al. 2017). Moreover, results can also be influenced by the temporal scale (James 1980a, 1986, 2012). So, an explicit spatiotemporal measurement is needed to define the subject’s condition.

(3) A necessary premise of TWH is that there should be a significant sex difference in reproductive capacity (Trivers and Willard 1973), which is limited in the monogamous system of most human societies (Polasek et al. 2005; Helle et al. 2009; James 2012; Kolk and Schnettler 2016; Morita et al. 2017; Grech 2019). Data uncertainty due to extramarital affairs need to be concerned when null hypotheses is based on parental factors.

(4) Some conclusions from wild animals may be distorted due to poor field observation, lack of continuous following up datasets, and unclear social status (Brown 2001; Cameron 2004; James 2012; Douhard 2017; Grech 2019).

Thus, in order to obtain more solid results, it is critical to use a consistent spatiotemporal database tracing back a long genealogical history. The Chinese imperial family history covers 2142 years starting with the first emperor of the Qin dynasty in 221 BC to the last emperor of the Qing dynasty in 1912 AD (Zhao 1977; Sima and Zhang 1982; Bo 2011). This is a relatively long period representing and ideal
and unique material to fulfill such a requirement and effectively test the TWH. The imperial harem was an enclosed polygynous reproductive system with clear spatiotemporal boundaries, well protected from the influences by the outside (Zhu 1998; Zhang 2009; Miao 2017). The characteristic male-multi-female mating system coupled with high social, political, and economic status gave the emperor the highest reproductive potential and allows us to trace an authentic and genetically pure biological relationships between father, offspring, and mothers (empress and concubines) (Zhu 1998; Zhang 2006), which was also guaranteed by the use of the eunuch system within the harem (Wilson and Roehborn 1999; Tougher 2008). Furthermore, the strict hierarchy of the sociopolitical structure among the mates, in particular between the empresses and concubines, is ideal to test the hypotheses related to SRB, especially in deciding whether parental or maternal part is playing a pivotal role in sexual selection (Zhu 1997; Wan 2004; Miao 2017). Also, compared with genealogical studies on ordinary citizens, the records from imperial families were fully documented by a strict historian system, which guarantees the reliability of the data (Wang 2008). Therefore, compared to monogamous or promiscuous systems where relationships and socioeconomic conditions are confused, the Chinese imperial harem provides an ideal dataset for this study, with long timespan and accurate information (Zhu 1998; Zhang 2006; Liu 2010; Zhao 2018).

Thus, based on such an advantageous database, the primary purpose of this study is to analyze the spatial–temporal imperial mating system development to test the TWH as well as other hypotheses. We focused on whether a male-biased sex ratio at birth (MSRB) appears in a mating system with higher social status and ample resources, and who is the especially the primary determinant of MSRB, father or mother, and then what is a decisive condition, the higher social rank or rich resources.

**Materials and methods**

**Dynasties studied**

The Chinese imperial society started from the Qin dynasty in 221 BC when the first emperor, Qin Shi Huang, united the six kingdoms, and ended with the Qing dynasty in 1912 AD (Zhao 1977; Sima and Zhang 1982; Bo 2011). The 2132 years-lasting imperial periods in Chinese history were featured by a centralized monarchy political and administrative system, in which more than twenty dynasties existed (Fan 1965; Bo 2011). All aspects of the imperial life were recorded by a series of historical books, such as “Hanshu,” “Hou Hanshu,” “Tangshu,” and “Qing History Draft” (Ban 1962; Fan 1965; Tuo and ALuTu 1974; Zhang 1974; Song et al. 1975; Zhao 1977; Sima and Zhang 1982; Liu 2010).

Considering the integrity and robustness of the historical records, we preliminarily selected the following ten dynasties: Qin, Xi Han, Dong Han, Xi Jin, Sui, Tang, Bei Song, Yuan, Ming, and Qing. Among them, we narrowed down the final dataset to the dynasties that lasted more than 100 years, namely the Xi Han, Dong Han, Tang, Bei Song, Ming, and the Qing (Fig. 1). In total, 1597 years representing 74.91% Chinese imperial history were covered, with the shortest dynasty being the BeiSong (167 years) while the longest one was Qing (296 years) (Ban 1962; Fan 1965; Tuo and ALuTu 1974; Zhang 1974; Song et al. 1975; Zhao 1977; Sima and Zhang 1982; Liu 2010).

A dynasty in China always encountered civil wars; foreign incursions, occupations, and devastating rebellions were frequent during the beginning or late period of every dynasty creating upheavals and transformations. During the middle stage, the society was the most stable and prosperous, with the economy and agriculture developing steadily. Such as the ‘HanWu Flourishing Age’ of the Xi Han dynasty (Fan 1965), the “ZhenGuan Flourishing Age” of the Tang dynasty (Song et al. 1975), and the “KangQian Flourishing Age” during the Qing dynasty (Zhao 1977). Based on this information, we divided each of the six dynasties into two stages according to their heyday and low point (Table 1).

It was not possible to record data blind because our study got data via history record.

**Hierarchical structure of Chinese imperial families**

The ancient Chinese imperial society was a monarchy system in which the emperors held supreme autocratic authority, not being challenged by any written laws, legislature, and customs. A clear social hierarchy structure existed (Fig. 2) with absolute authority to control the powers (Sima and Zhang 1982). Emperors governed the whole nation through the Mandate of the Heaven under the legacy of “Pu Tian Zhi Xia Mo Fei Wang Tu,” indicating that all the land and belongings of the nation were governed by the emperors and shared by their families, in particular social resources (Sima and Zhang 1982). Their family details were accurately documented as genealogical records (Huang and Zeng 2016).

Each imperial family living in the palace followed a rigid hierarchical frame featured by a reproductive harem where the emperor was married to the empress (the first lady) and multiple concubines (Zhu 1998). The empress held the highest position in the harem’s administration and management and was in charge of the internal governance of the palace (Zhu 1998; Zhang 2009). The concubines were additional mating partners functioning as offspring producers for the emperor. Besides, an emperor could also mate with the Palace maids. Such a mating system and environment
guaranteed an emperor to reach his highest potential of generating offspring.

Data for emperors: among the requirements and tasks, emperors had to supremely rule the whole dynasty for more than 1 year, be aged more than 14 years, and be able to produce offspring (Diamond 1976; DeLamater and Friedrich 2002). Of the six dynasties analyzed, there were 76 emperors who meet requirements listed above. Their average age was 24.10 ± SD 12.36 at the time of coronation. The average period of their regime was 19.40 ± SD 13.42 years, and the average number of female mates they owned was 10.91 ± 15.02 (range 1–92, N = 76), of which 1.31 ± 0.68 were empresses (0–3, N = 74), and 13.31 ± 15.83 were concubines (0–89, N = 54). In total, they produced 1083 offspring, with an average of 14.25 ± 13.91 for each (0–65, N = 76) (Table 2).

Data for empresses: an empress was the highest-ranked mate of the imperial harem, similar to the queens in western society (Zhang 2009). A total of 97 empresses (excluding when this title was only conferred posthumously) belonging to 76 emperors were selected and analyzed in this study. Sixty-four empresses gave birth to 107 male and 68 female offspring. We found accurate canonization time records for 53 empresses that we used to analyze the SRB differentiation before and after the canonization. Forty males and 44 females were produced before canonization, while 32 males and 17 females after canonization (Table 3).

Data for concubines: more than 732 concubines belonging to 76 emperors were recorded and included in the analyses. They generated 483 males and 426 female offspring. They had lower social and political status than the empresses but higher than ordinary people. They respected the empresses by expressing courtesy whenever they met, as they did to the emperors. In addition, the empresses and concubines differed in several aspects, including title, clothing style, bedroom size, treatment, resource supply, medical care, and children's education — empresses were privileged (Zhu 1997, 1998; Zhang 2009).

For example, during the Qing Dynasty, an empress could dispose of ten servants for her daily life, an annual salary and other treatments amounting to 37.30 kg silver, 3000-m silks and satins, 2000-m cloths, and 90 mink skins, enough threads of the golds, silver, woolen, cotton, and other necessary items. A list of standardized daily consumption for an empress included 15 kg pork, one plate of mutton, chicken, and duck, separately, 3 kg rice, 5.5 kg noodles, 5.5 kg fruits, cooking oil, and vegetables. Such supplies increased hugely on the occasion of festivals and birthdays. In turn, the goods received by a concubine were limited to two servants, 1.12 kg silver and 266.64-m silk fabrics each year, and a daily meal of 1.07 kg pork, some rice, and vegetables. Another remarkable difference between empresses and concubines was
Table 1: The information of the heyday of Xi Han dynasty, Dong Han dynasty, Tang dynasty, Bei Song dynasty, Ming dynasty, and Qing dynasty

| Dynasty   | Total number of emperor | Duration (yrs) | Heyday | Appellation | Emperor number | Reigning time | The number of imperial offspring | Low point | Emperor number | Reigning time | The number of imperial offspring |
|-----------|-------------------------|----------------|--------|--------------|----------------|---------------|----------------------------------|-----------|----------------|---------------|---------------------------------|
|           |                         |                |        |              | Emperor        | Empress       | Concubine                        |           | Emperor        | Empress       | Concubine                          |
|           |                         |                |        |              | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female |
| Xi Han    | 14                      | 215            |        | 汉武盛世 Han Wu Flourishing Age 昭宣中兴 Zhao Xuan Flourishing Age | 3    | 95     | 11   | 8     | 2    | 3     | 9    | 5     | 11   | 120    | 44   | 10     | 7    | 6     | 120  | 44     | 7    | 6     |
| Dong Han  | 9                       | 196            |        | 明章之治 Ming Zhang Flourishing Age 永元之隆 Yong Yuan Flourishing Age | 3    | 51     | 19   | 18    | 3    | 0     | 16   | 18    | 6    | 145    | 22   | 15     | 14   | 3     | 145  | 22     | 14   | 3     |
| Tang      | 17                      | 276            |        | 贞观之治 Zhen Guan Flourishing Age 开元盛世 Kai Yuan Flourishing Age | 2    | 69     | 44   | 50    | 4    | 5     | 40   | 45    | 15   | 207    | 156  | 141    | 17   | 8     | 139  | 133    |     |        |
| Bei Song  | 9                       | 167            |        | 仁宗盛治 Ren Zong Flourishing Age | 1    | 42     | 3    | 13    | 0    | 0     | 3    | 13     | 8    | 125    | 72   | 68     | 15   | 14    | 57   | 54     |     |        |
| Ming      | 15                      | 294            |        | 永宣盛世 Yong Xuan Flourishing Age | 3    | 36     | 16   | 15    | 7    | 6     | 9    | 9     | 12   | 258    | 84   | 62     | 16   | 9     | 68   | 54     |     |        |
| Qing      | 12                      | 296            |        | 康乾盛世 Kang Qian Flourishing Age | 3    | 137    | 63   | 38    | 7    | 4     | 56   | 34     | 9    | 159    | 56   | 55     | 15   | 10    | 41   | 45     |     |        |
| Total     | 76                      | 1597           |        |               | 15   | 430    | 156  | 142   | 23   | 18    | 133  | 124    | 61   | 1167   | 434  | 351    | 84   | 50    | 350  | 302    |     |        |
| Offspring's SRB |               |               |        |               | 0.52 | 0.56   | 0.52 | 0.52  | 0.52 | 0.52  | 0.55 | 0.63    | 0.54 | 0.54   |     |        |     |        |     |        |     |        |     |        |     |        |
the reward received when the newborn babies survived the first month: 37.3 kg silver and 3333-m cloth for the empress while concubines would receive only 1.87 kg silver and 333.3-m cloth (Zhang 2009).

Moreover, the eunuch system applied in the palace guaranteed no male servant had the sexual influence on the emperor’s reproductive potential and purity — biologically and genetically, all the kids in the harem are offspring of the emperors (Wilson and Roehrborn 1999; Tougher 2008).

Chinese historical recording system

The official historical written record system in China started at the dawn of the Chinese civilization (2717 BC). Historians working around the emperors were involved in significant events and routine administration, imperial family affairs, and recorded the emperor’s words and deeds at any time. Chinese historians had a good tradition of “writing the truth without fear or favor” (Liu 2010; Zhao 2018). Sima Qian, who wrote “史记 / Historical Records,” became the historians’ moral and virtue model. In other words, such objective records ensure the reliability of historical records used for this study.

Data collection

The dataset was compiled by including the emperor’s birth-day and inauguration date, sex, and birth date for each of his kids. His empress and concubines ranked in a hierarchical family with different titles (Liu 2010; Zhao 2018). The emperors and empresses who had been conferred a posthumous title and had no offspring were excluded. All the data were verified through the “General Draft of Qing History” and “Twenty-Four Histories” (Ban 1962; Tuo and ALuTu 1974; Zhang 1974; Song et al. 1975; Liu 2010; Shun and Shun 2010) (Tables 2, 3).

SRB definition

The portion of males/offspring at birth time theoretically tends to be 0.5 (Hamilton 1967). To detect male or female bias in the sex ratio at birth (SRB), we used the following equation:

\[
\text{SRB} = \frac{\text{number of male offspring}}{\text{number of male and female offspring}}
\]

An SRB value of 0.50 indicates a perfect balance between the number of male and female offspring. If the value is larger than 0.50, SRB is regarded as male-biased (MSRB).

In this study, three different SRBs are used: SRB_{emperor} for the emperor, SRB_{empress} for the empress, and SRB_{concubines} for the concubines.

Data analysis

The significance of male-biased SRBs was evaluated with a Binomial Test that includes four types.

(1) The difference between SRB_{emperor}, SRB_{empress}, and SRB_{concubines}, separately:

\[
Z = \frac{p' - p_0}{\sqrt{p_0q/n}}
\]

where \( p' = \) SRB, \( p_0 = 0.50 \) (equal number between males and females), \( q = 1-p_0 \), \( n = \) sample size.

(2) The difference between SRB_{emperor}, SRB_{empress}, SRB_{concubines}, and the average Chinese SRB in the 1960s and 1970s the first available census data under the current government regime before the One-Child Policy, which was 0.514 (Nie 1999; Wang 2012).

(3) SRB difference before and after the canonization of the empresses, similar to (2) but only compared between the two groups.

(4) SRB difference between each dynasty’s heyday and low point, similar to (3).

Analyses were conducted using R Statistics version 1.1.442 (R Development Core Team 2016).

Results

MSRB in the imperial family

Seventy-six emperors produced 1084 offspring (mean ± SD: 14.45 ± 13.87, range 0–65); ninety-seven empresses generated 175 kids (mean ± SD: 2.02 ± 1.97, range 0–7); and more than 732 concubines had 909 children. An emperor had 7.15 times more kids than his mates (Table 2).

According to Table 2, the SRB_{emperor} was significantly male-biased (\( N = 1084, 590 \) males and 494 females, \( 0.54 \) vs \( 0.50 \), \( Z = 2.92, p = 0.002 \)). The same ratio for empresses (SRB_{empress}) was 0.61 (107 males and 68 females), which appears to be significantly male-biased as well (\( N = 175, 0.61 \) vs \( 0.50, Z = 2.95, p = 0.002 \)). Concubines had an SRB_{concubines} of 0.53 (483 males and 426 females), also male-biased at a significant level (\( N = 909, 0.53 \) vs \( 0.50, Z = 1.89, p = 0.032 \)).

The difference between SRB of empresses and concubines was also significant: 0.61 vs 0.53, (\( N_{empress} = 175, N_{concubines} = 909, Z = 1.95, p = 0.026 \)).
SRB differentiation between imperial families and ordinary people

The average Chinese SRB in the 1960s and 1970s, the first available census data under the current government regime before the One-Child Policy, was 0.514 (Wang 2012), a significantly smaller rate than those of the whole imperial families (\(N = 1084, 0.54 \text{ vs } 0.514, Z = 1.99, p = 0.025\)), and of the SRBempress (0.61 vs 0.514, \(N = 175, Z = 2.58, p = 0.006\)). However, a comparison between SRBconcubine and ordinary citizens did not reach a significant level (0.53 vs 0.514, \(N = 909, Z = 1.04, p = 0.155\)).

SRBs before and after empress coronation

The SRBempress before the coronation was not a male-biased SRB (40 males and 44 females, \(Z = -0.44, p = 0.67\)) but became biased after the coronation (32 males vs 17 females, \(Z = 2.14, p = 0.02\)) (Table 2). This difference reached a significant level (0.48 vs 0.65, \(N_{\text{before coronation}} = 84, Z = 1.97, p = 0.02\)).

MSRB in the heyday of the dynasties

Emperor MSRB during the heyday was not significantly higher than that of the low point (heyday 0.52 vs low point 0.55, \(Z = 1.16, p = 0.245\)). The same statistical result applies to the scenarios of the empresses and concubines (empress: heyday 0.56 vs low point 0.62, \(Z = 1.14, p = 0.253\); concubines: heyday 0.52 vs low point 0.54, \(Z = 0.279, p = 0.780\)).

Discussion

As expected, the results based on a consistent spatiotemporal database recording 2142 years of imperial biological history provided solid scientific evidence and baseline information to clarify some critical hypotheses related to the SRB, which were initially proposed by TWH and debated by others. They offer new evidence to define an instant social condition (ISC).

MSRB in imperial families

The results listed in Table 1 show that the SRBemperor is 0.55, and those for the SRBempress and SRBconcubine are 0.61 and 0.53, separately. Thus, the imperial family members, considered together and individually, generated larger MSRB. This phenomenon clarifies the hypothesis that a good social and economic condition results in MSRBs (Trivers and Willard 1973). The fact that empresses show significantly larger MSRB than concubines and ordinary Chinese implies that a...
| ID | Dynasty | Emperor     | Stage       | Reigning time | Ascended Age | Offspring number | Number of empresses | Number of concubines |
|----|---------|-------------|-------------|---------------|--------------|------------------|---------------------|---------------------|
|    |         |             |             |               |              | Emperor          | Empress          | Concubine          |
|    |         |             |             |               |              | male | female | male | female | male | female |
| 1  | XiHan   | 刘Xã/LiuZhiJia | Low point   | -             | -            | 4    | 1      | 1    | 0      | 3    | 1      | 1    | 0    |
| 2  |         | 刘 воп/LiuBang | Low point   | 12            | 51           | 8    | 1      | 1    | 1      | 7    | 0      | 1    | 4    |
| 3  |         | 刘盈/LiuYing  | Low point   | 8             | 16           | 6    | 0      | 0    | -      | 6    | 0      | 1    | -    |
| 4  |         | 刘靈/LiuGong  | Low point   | 4             | -            | 0    | 0      | 0    | 0      | 0    | 0      | 1    | -    |
| 5  |         | 刘安/LiuHong  | Low point   | 5             | -            | -    | -      | -    | -      | 0    | 0      | 1    | -    |
| 6  |         | 刘恒/LiuHeng  | Low point   | 23            | 23           | 4    | 2      | 2    | 1      | 2    | 1      | 1    | 2    |
| 7  |         | 刘启/LiuQi    | Low point   | 16            | 32           | 14   | 3      | 1    | 3      | 13   | 0      | 2    | 5    |
| 8  |         | 刘彻/LiuChe   | Heyday      | 55            | 16           | 6    | 6      | 1    | 3      | 5    | 3      | 2    | 8    |
| 9  |         | 刘弗陵/LiuFuLing | Heyday     | 14            | 8            | 0    | 0      | 0    | 0      | 0    | 0      | 1    | 1    |
| 10 |         | 刘询/LiuXun   | Heyday      | 26            | 18           | 5    | 2      | 1    | 0      | 4    | 2      | 3    | -    |
| 11 |         | 刘凝/LiuShi   | Low point   | 17            | 27           | 3    | 2      | 1    | 0      | 2    | 2      | 1    | -    |
| 12 |         | 刘荣/LiuAo    | Low point   | 27            | 20           | 5    | 1      | 1    | 1      | 4    | 0      | 2    | -    |
| 13 |         | 刘欣/LiuXin   | Low point   | 7             | 20           | 0    | 0      | 0    | 0      | 0    | 0      | 1    | -    |
| 14 |         | 刘衎/LiuKan   | Low point   | 6             | 9            | 0    | 0      | 0    | 0      | 0    | 0      | 1    | -    |
| 15 | DongHan | 刘宣/LiuXiu   | Low point   | 33            | 30           | 11   | 5      | 10   | 3      | 1    | 2      | 2    | -    |
| 16 |         | 刘据/LiuZhuang | Heyday     | 19            | 30           | 9    | 11     | 0    | 0      | 9    | 11     | 1    | -    |
| 17 |         | 刘荡/LiuDa    | Heyday      | 14            | 18           | 8    | 3      | 2    | 0      | 6    | 3      | 1    | -    |
| 18 |         | 刘病/LiuZhao  | Heyday      | 18            | 10           | 2    | 4      | 1    | 0      | 1    | 4      | 2    | -    |
| 19 |         | 刘祜/LiuHu    | Low point   | 20            | 13           | 1    | 0      | 1    | 0      | 1    | 0      | 1    | -    |
| 20 |         | 刘保/LiuBao   | Low point   | 20            | 11           | 1    | 3      | 1    | 0      | 3    | -      | -    | -    |
| 21 |         | 刘志/LiuZhi   | Low point   | 22            | 15           | 0    | 3      | 0    | 0      | 0    | 3      | 3    | -    |
| 22 |         | 刘定/LiuHong  | Low point   | 22            | 13           | 2    | 1      | 1    | 0      | 1    | 1      | 2    | -    |
| 23 |         | 刘协/LiuXie   | Low point   | 32            | 9            | 7    | 3      | 2    | 0      | 5    | 3      | 2    | -    |
| ID | Dynasty | Emperor     | Stage     | Reigning time | Ascended Age | Offspring number | Offspring number | Offspring number | Offspring number | Number of empresses | Number of concubines |
|----|---------|-------------|-----------|---------------|--------------|------------------|------------------|------------------|------------------|----------------------|----------------------|
|    |         |             |           |               |              | Emperor male    | Emperor female   | Empress male     | Empress female   | Concubine male      | Concubine female     |
| 24 | Tang    | 李渊/LiYuan | Low point | 9             | 53           | 22               | 19               | 4                | 1                | 18                   | 18                   |
| 25 | 黎世民/LiShiMin | 24         | 29         |               |              | 14               | 21               | 3                | 4                | 11                   | 17                   |
| 26 | 李治/LiZhi | Low point  | 35         | 22            |              | 8                | 3                | 4                | 1                | 4                    | 2                    |
| 27 | 李旦/LiDan | Low point  | 7          | 23            |              | 6                | 11               | 2                | 4                | 4                    | 7                    |
| 28 | 李隆基/LiLongJi | Heyday    | 45         | 28            |              | 30               | 29               | 1                | 1                | 29                   | 28                   |
| 29 | 李亨/LiXiang | Low point  | 7          | 46            |              | 14               | 7                | 2                | 0                | 12                   | 7                    |
| 30 | 李豫/LiYu  | Low point  | 18         | 37            |              | 20               | 18               | 1                | 0                | 19                   | 18                   |
| 31 | 李适/LiShi | Low point  | 27         | 38            |              | 11               | 11               | 1                | 1                | 10                   | 10                   |
| 32 | 李纯/LiChun | Low point  | 16         | 28            |              | 20               | 18               | 0                | 0                | 20                   | 18                   |
| 33 | 李恒/LiHeng | Low point  | 5          | 26            |              | 5                | 8                | 1                | 0                | 4                    | 8                    |
| 34 | 李湛/LiZhan | Low point  | 3          | 16            |              | 5                | 3                | 0                | 0                | 5                    | 3                    |
| 35 | 李宪/LiAng | Low point  | 15         | 19            |              | 2                | 4                | 0                | 0                | 2                    | 4                    |
| 36 | 李炎/LiYan | Low point  | 7          | 37            |              | 5                | 7                | -                | -                | 5                    | 7                    |
| 37 | 李忱/LiChen | Low point  | 14         | 27            |              | 11               | 11               | 0                | 0                | 11                   | 11                   |
| 38 | 李漼/LiCui | Low point  | 15         | 27            |              | 8                | 8                | 0                | 0                | 8                    | 8                    |
| 39 | 李yız/LiXuan | Low point | 16         | 12            |              | 2                | 2                | -                | -                | 2                    | 2                    |
| 40 | 李 профессиональн/ Ye | Low point  | 13         | 22            |              | 17               | 11               | 2                | 1                | 15                   | 10                   |
| 41 | BeiSong | 赵匡胤/ZhaoKuangYin | Low point | 17         | 34            | 4                | 6                | 3                | 2                | 1                    | 4                    |
| 42 | 赵光义/ZhaoGuangYi | Low point | 22         | 38            |              | 9                | 7                | 2                | 0                | 7                    | 7                    |
| 43 | 赵恒/ZhaoHeng | Low point | 26         | 30            |              | 6                | 2                | 1                | 0                | 5                    | 2                    |
| 44 | 赵柬/ZhaoZhen | Low point | 42         | 13            |              | 3                | 13               | 0                | 0                | 3                    | 13                   |
| 45 | 赵曙/ZhaoShu | Low point | 5          | 32            |              | 4                | 4                | 4                | 2                | 0                    | 2                    |
| 46 | 赵煦/ZhaoXu | Low point | 19         | 20            |              | 14               | 10               | 1                | 1                | 13                   | 9                    |
| 47 | 赵抃/ZhaoXu | Low point | 16         | 10            |              | 1                | 4                | 1                | 1                | 0                    | 3                    |
| 48 | 赵佶/ZhaoJi | Low point | 26         | 19            |              | 31               | 34               | 2                | 7                | 29                   | 27                   |
| 49 | 赵桓/ZhaoHuan | Low point | 2          | 26            |              | 3                | 1                | 1                | 1                | 2                    | 0                    |
Table 2 (continued)

| ID | Dynasty | Emperor       | Stage   | Reigning time | Ascended Age | Offspring number | Number of empresses | Number of concubines |
|----|---------|---------------|---------|---------------|--------------|------------------|---------------------|----------------------|
|    |         |               |         |               |              | Emperor          | Empress             | Concubine            |
|    |         |               |         |               |              | male | female | male | female | male | female |
| 50 | Ming    | 朱元璋/ZhuYuanZhang | Low point | 31 41 | 26 | 16 | 5 | 2 | 21 | 14 | 1 | 21 |
| 51 | 明        | 朱允炆/ZhuYunWen     | Low point | 5 22 | 2 | 0 | 2 | 0 | 0 | 0 | 1 | 0 |
| 52 | 明        | 朱棣/ZhuLi            | Heyday   | 23 43 | 4 | 5 | 3 | 2 | 1 | 3 | 1 | 20 |
| 53 | 明        | 朱高炽/ZhuGaoZhi      | Heyday   | 2 47 | 10 | 7 | 3 | 1 | 7 | 6 | 1 | 10 |
| 54 | 明        | 朱瞻基/ZhuZhanJi      | Heyday   | 11 28 | 2 | 3 | 1 | 3 | 1 | 0 | 2 | 12 |
| 55 | 明        | 朱祁镇/ZhuQiZhen      | Low point | 15 9 | 9 | 8 | 2 | 1 | 7 | 7 | 2 | 19 |
| 56 | 明        | 朱祁钰/ZhuQiYu        | Low point | 9 22 | 1 | 2 | 1 | 2 | 0 | 0 | 1 | 4 |
| 57 | 明        | 朱见深/ZhuJianShen    | Low point | 24 18 | 14 | 5 | 0 | 0 | 14 | 5 | 2 | 16 |
| 58 | 明        | 朱佑樘/ZhuYouTang     | Low point | 19 18 | 2 | 3 | 2 | 1 | 0 | 2 | 1 | 0 |
| 59 | 明        | 朱厚照/ZhuHouZhao     | Low point | 17 15 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 7 |
| 60 | 明        | 朱厚熜/ZhuHouCong     | Low point | 46 15 | 8 | 5 | 0 | 0 | 8 | 5 | 3 | 89 |
| 61 | 明        | 朱载垕/ZhuZaiHou      | Low point | 7 20 | 4 | 6 | 0 | 0 | 4 | 6 | 1 | 17 |
| 62 | 明        | 朱载垕/ZhuYiJun       | Low point | 49 10 | 8 | 10 | 0 | 1 | 8 | 9 | 1 | 18 |
| 63 | 明        | 朱由校/ZhuYouXiao     | Low point | 8 16 | 3 | 2 | 1 | 0 | 2 | 2 | 1 | 8 |
| 64 | 明        | 朱由检/ZhuYouJian     | Low point | 18 19 | 7 | 6 | 3 | 2 | 4 | 4 | 1 | 5 |
| 65 | 皇        | 塔克世/TaKeShi        | Low point | - - | 5 | 1 | 3 | 1 | 2 | 0 | 1 | 2 |
| 66 | 清        | 努尔哈赤/NuErHaChi    | Low point | 11 58 | 16 | 9 | 4 | 0 | 12 | 9 | 1 | 14 |
| 67 | 清        | 皇太极/HuangTaiJi     | Low point | 17 36 | 11 | 16 | 1 | 3 | 10 | 13 | 1 | 13 |
| 68 | 清        | 顺治/SunZhi          | Low point | 19 6 | 8 | 9 | 2 | 0 | 6 | 9 | 2 | 35 |
| 69 | 清        | 康熙/KangXi           | Heyday   | 62 8 | 36 | 20 | 2 | 1 | 34 | 19 | 3 | 63 |
| 70 | 清        | 雍正/YongZheng        | Heyday   | 14 45 | 10 | 7 | 1 | 0 | 9 | 7 | 1 | 27 |
| 71 | 清        | 乾隆/QianLong        | Heyday   | 61 29 | 17 | 11 | 4 | 3 | 13 | 8 | 2 | 39 |
| 72 | 清        | 嘉庆/JiaQing         | Low point | 25 37 | 5 | 9 | 3 | 3 | 2 | 6 | 2 | 15 |
| 73 | 清        | 道光/DaoGuang        | Low point | 31 39 | 9 | 10 | 1 | 3 | 8 | 7 | 2 | 21 |
| 74 | 清        | 咸丰/XianFeng       | Low point | 12 20 | 2 | 1 | 1 | 0 | 1 | 1 | 2 | 16 |
| 75 | 清        | 同治/TongZhi         | Low point | 14 6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 |
| 76 | 清        | 光绪/GuangXu         | Low point | 35 5 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| **Total** |  |  |  |  |  | 590 | 494 | 107 | 68 | 483 | 426 | 97 | 732 |
| ID | Dynasty | Emperor     | Number of empresses per emperor | Empress’s family name | Empress’s offspring number | Number of offspring of empress | Before | After |
|----|---------|-------------|---------------------------------|-----------------------|---------------------------|--------------------------------|--------|-------|
|    |         |             |                                 |                       |                           |                                 | Male   | Female|
|    |         |             |                                 |                       |                           |                                 | Female |       |
|    |         |             |                                 |                       |                           |                                 | Male   | Female|
|    |         |             |                                 |                       |                           |                                 | Male   | Female|
| 1  | XiHan   | 刘执嘉/LiuZhiJia | 1                           | Wang                  | 1 0 1                    | -                              | -      | -     |
| 2  |         | 刘邦/LiuBang    | 1                           | Lv                    | 1 1 2                    | 1 1 0                          | 0      | 0     |
| 3  |         | 刘盈/LiuYing    | 1                           | Zhang                 | 0 0 0                    | -                              | -      | -     |
| 4  |         | 刘恭/LiuGong    | 1                           | -                     | 0 0 0                    | -                              | -      | -     |
| 5  |         | 刘弘/LiuHong    | 1                           | Lv                    | - - -                    | -                              | -      | -     |
| 6  |         | 刘恒/LiuHeng    | 1                           | Dou                   | 2 1 3                    | -                              | -      | -     |
| 7  |         | 刘启/LiuQi      | 2                           | Bo                    | 0 0 0                    | -                              | -      | -     |
| 8  |         | 刘彻/LiuChe     | 2                           | Chen                  | 0 0 0                    | -                              | -      | -     |
| 9  |         | 刘弗陵/LiuFuLing| 1                           | ShangGaun             | 0 0 0                    | -                              | -      | -     |
| 10 |         | 刘询/LiuXun     | 3                           | Xu                    | 1 0 1                    | 1 0 0                          | 0      | 0     |
| 11 |         | 刘奭/LiuShi     | 1                           | Wang                  | 1 0 1                    | 1 0 0                          | 0      | 0     |
| 12 |         | 刘骜/LiuAo      | 2                           | Xu                    | 1 1 2                    | -                              | -      | -     |
| 13 |         | 刘欣/LiuXin     | 1                           | Zhao                  | - - -                    | -                              | -      | -     |
| 14 |         | 刘衎/LiuKan     | 1                           | Fu                    | - - -                    | -                              | -      | -     |
| 15 | DongHan | 刘秀/LiuXiu     | 2                           | Guo                   | 5 1 6                    | 0 0 5                          | 1      | 1     |
| 16 |         | 刘庄/LiuZhuang  | 1                           | Ma                    | 0 0 0                    | -                              | -      | -     |
| 17 |         | 刘炟/LiuDa     | 1                           | Dou                   | 2 0 2                    | -                              | -      | -     |
| 18 |         | 刘炟/LiuZhao   | 2                           | Yin                   | - - -                    | -                              | -      | -     |
| 19 |         | 刘协/LiuHu     | 1                           | Yan                   | 0 0 0                    | -                              | -      | -     |
| 20 |         | 刘zzle/LiuBao   | -                           | Liang                 | 1 - 1                    | -                              | -      | -     |
| 21 |         | 刘喆/LiuZhi     | 3                           | Liang                 | - - -                    | -                              | -      | -     |
| 22 |         | 刘宏/LiuHong    | 2                           | Song                  | 0 0 0                    | -                              | -      | -     |
| 23 |         | 刘协/LiuXie     | 2                           | Fu                    | 2 0 2                    | -                              | -      | -     |

**Table 3** The list and offspring’s information of the empress of Xi Han dynasty, Dong Han dynasty, Tang dynasty, Bei Song dynasty, Ming dynasty, and Qing dynasty.
| ID | Dynasty | Emperor       | Number of empresses per emperor | Empress’s family name | Empress’s offspring number | Number of offspring of empress |
|----|---------|---------------|---------------------------------|-----------------------|---------------------------|--------------------------------|
|    |         |               |                                 |                       | Before coronation         | After coronation               |
|    |         |               |                                 |                       | Male | Female | Total | Male | Female | Male | Female |
| 24 | Tang    | 李渊/LiYuan   | 1                               | Dou                   | 4    | 1      | 5     | -    | -      | -    | -      |
| 25 |        | 李世民/LiShiMin | 1                              | ZhangSun              | 3    | 4      | 7     | 2    | 2      | 1    | 1      |
| 26 |        | 李治/LiZhi    | 2                               | Wang                  | 4    | 1      | 5     | 1    | 1      | 3    | 1      |
| 27 |        | 李旦/LiDan    | 2                               | Liu                   | 1    | 2      | 3     | 1    | 1      | 0    | 1      |
| 28 |        | 李隆基/LiLongJi | 1                             | Wang                  | 1    | 1      | 2     | -    | -      | -    | -      |
| 29 |        | 李亨/LiXiang  | 1                               | Zhang                 | 2    | 0      | 2     | -    | -      | -    | -      |
| 30 |        | 李豫/LiYu    | 1                               | Shen                  | 1    | 0      | 1     | -    | -      | -    | -      |
| 31 |        | 李适/LiShi    | 1                               | Wang                  | 1    | 1      | 2     | 1    | 1      | 0    | 0      |
| 32 |        | 李纯/LiChun  | 0                               | -                     | -    | -      | -     | -    | -      | -    | -      |
| 33 |        | 李恒/LiHeng  | 1                               | Wang                  | 1    | 0      | 1     | -    | -      | -    | -      |
| 34 |        | 李湛/LiZhan  | 1                               | Guo                   | 0    | 0      | 0     | -    | -      | -    | -      |
| 35 |        | 李昂/LiAng   | 0                               | -                     | -    | -      | -     | -    | -      | -    | -      |
| 36 |        | 李炎/LiYan   | 0                               | -                     | -    | -      | -     | -    | -      | -    | -      |
| 37 |        | 李忱/LiChen  | 0                               | -                     | -    | -      | -     | -    | -      | -    | -      |
| 38 |        | 李ResponseStatus/LiCui | 0 | -      | -    | -      | -     | -    | -      | -    | -      |
| 39 |        | 李僖/LiXuan  | -                               | -                     | -    | -      | -     | -    | -      | -    | -      |
| 40 |        | 李晔/LiYe    | 1                               | He                    | 2    | 1      | 3     | -    | -      | -    | -      |
| 41 | Beisong | 赵匡胤/ZhaoKuangYin | 1 | He     | 3    | 2      | 5     | -    | -      | -    | -      |
| 42 |        | 赵光义/ZhaoGuangYi | 1 | Li     | 2    | 0      | 2     | -    | -      | -    | -      |
| 43 |        | 赵恒/ZhaoHeng | 1                               | Guo                   | 1    | 0      | 1     | -    | -      | -    | -      |
| 44 |        | 赵禥/ZhaoZhen | 2                               | Guo                   | 0    | 0      | 0     | -    | -      | -    | -      |
| 45 |        | 赵構/ZhaoShu | 1                               | Gao                   | 4    | 2      | 6     | 4    | 2      | 0    | 0      |
| 46 |        | 赵顼/ZhaoXu  | 1                               | Xiang                 | 1    | 1      | 2     | 1    | 1      | 0    | 0      |
| 47 |        | 赵岳/ZhaoXu  | 2                               | Meng                  | 0    | 1      | 1     | 0    | 1      | 0    | 0      |
| 48 |        | 赵僖/ZhaoJi  | 2                               | Liu                   | 1    | 0      | 1     | -    | -      | -    | -      |
| 49 |        | 赵桓/ZhaoHuan | 1                               | Zhu                   | 1    | 1      | 2     | 1    | 1      | 0    | 0      |
| ID | Dynasty | Emperor          | Number of empresses per emperor | Empress’s family name | Empress’s offspring number | Number of offspring of empress |
|----|---------|------------------|---------------------------------|-----------------------|---------------------------|------------------------------|
|    |         |                  |                                 |                       |                           | Before coronation | After coronation |
|    |         |                  |                                 |                       |                           | Male | Female | Male | Female | Male | Female |
| 50 | Ming    | 朱元璋/ZhuYuanZhang | 1                              | Ma                    | 5             2             7   | 5       0       2       0 |
| 51 |         | 朱允炆/ZhuYunWen  | 1                              | Ma                    | 2             0             2   | 1       0       1       0 |
| 52 |         | 朱棣/ZhuLi       | 1                              | Xu                    | 3             2             5   | 3       4       0       0 |
| 53 |         | 朱高炽/ZhuGaoZhi | 1                              | Zhang                 | 3             1             4   | 3       1       0       0 |
| 54 |         | 朱瞻基/ZhuZhanJi- | 2                              | Hu                    | 0             2             2   | 0       2       0       0 |
|    |         |                  |                                 | Sun                   | 1             1             2   | 1       1       1       0 |
| 55 |         | 朱祁鎮/ZhuQiZhen | 2                              | Qian                  | 0             0             0   | 0       0       0       0 |
|    |         |                  |                                 | Zhou                  | 2             1             3   | 1       0       1       1 |
| 56 |         | 朱祁銓/ZhuQiYu   | 1                              | Wang                  | 1             2             3   | 0       1       0       0 |
| 57 |         | 朱见深/ZhuJianShen | 2                          | Wu                    | 0             0             0   | 0       0       0       0 |
|    |         |                  |                                 | Wang                  | 0             0             0   | 0       0       0       0 |
| 58 |         | 朱佑樘/ZhuYouTang | 1                              | Zhang                 | 2             1             3   | 0       2       0       1 |
| 59 |         | 朱厚照/ZhuHouZhao | 1                              | Xia                   | 0             0             0   | 0       0       0       0 |
| 60 |         | 朱厚熜/ZhuHouCong | 3                              | Chen                  | 0             0             0   | 0       0       0       0 |
|    |         |                  |                                 | Zhang                 | 0             0             0   | 0       0       0       0 |
|    |         |                  |                                 | Fang                  | 0             0             0   | 0       0       0       0 |
| 61 |         | 朱载垕/ZhuZaiHou | 1                              | Chen                  | 0             0             0   | 0       0       0       0 |
| 62 |         | 朱翊钧/ZhuYiJun  | 1                              | Wang                  | 0             1             1   | 0       0       1       1 |
| 63 |         | 朱由校/ZhuYouXiao | 1                              | Zhang                 | 1             0             1   | 0       0       1       0 |
| 64 |         | 朱由检/ZhuYouJian | 1                              | Zhou                  | 3             2             5   | 0       0       3       2 |
Table 3 (continued)

| ID | Dynasty | Emperor        | Number of empresses per emperor | Empress’s family name     | Empress’s offspring number | Number of offspring of empress |
|----|---------|----------------|---------------------------------|---------------------------|---------------------------|-------------------------------|
|    |         |                |                                 |                           | Male          | Female        | Male | Female | Male | Female |
|----|---------|----------------|---------------------------------|---------------------------|---------------|---------------|------|--------|------|--------|
| 65 | Qing    | 塔克世/TaKeShi | 1                               | Xuan                      | 3             | 1             | 4    | -      | -    | -      |
| 66 |努尔哈赤/NuErHaChi | 1 | Yehe Nara                   | 4             | 0             | 4             | 0    | 0      | 4    | 0      |
| 67 |皇太极/HuangTaiJi | 1 | BoErJiJiTe                  | 1             | 3             | 4             | 0    | 1      | 0    | 2      |
| 68 |顺治/SunZhi   | 2 | BoErJiJiTe                  | 0             | 0             | 0             | 0    | 0      | 0    | 0      |
|    |          |                |                                 | DongJia                   | 2             | 0             | 2    | 0      | 0    | 0      |
| 69 |康熙/KangXi  | 3 | HeSheLi                     | 2             | 0             | 2             | 0    | 0      | 2    | 0      |
|    |          |                |                                 | NiuHuRu                   | 0             | 0             | 0    | 0      | 0    | 0      |
|    |          |                |                                 | DongJia                   | 0             | 1             | 1    | 0      | 0    | 0      |
| 70 |雍正/YongZheng | 1 | UlaNara                     | 1             | 0             | 1             | 1    | 0      | 0    | 0      |
| 71 |乾隆/QianLong | 2 | ShaiFuCha                   | 2             | 2             | 4             | 1    | 2      | 1    | 0      |
|    |          |                |                                 | Nara                      | 2             | 1             | 3    | 0      | 0    | 2      |
|    |          |                |                                 | XieTaLa                   | 1             | 2             | 3    | 1      | 2    | 0      |
| 72 |嘉庆/JiaQing | 2 | XieTaLa                     | 1             | 2             | 3             | 1    | 2      | 0    | 0      |
|    |          |                |                                 | NiuHuRu                   | 2             | 1             | 3    | 1      | 1    | 0      |
|    |          |                |                                 | DongJia                   | 0             | 1             | 1    | 0      | 0    | 0      |
|    |          |                |                                 | NiuHuRu                   | 1             | 2             | 3    | 1      | 0    | 2      |
| 73 |道光/DaoGuang | 2 | Yehe Nara                   | 1             | 0             | 1             | 1    | 0      | 0    | 0      |
|    |          |                |                                 | NiuHuRu                   | 0             | 0             | 0    | -      | -    | -      |
| 74 |咸丰/XianFeng | 2 | Yehe Nara                   | 0             | 0             | 0             | -    | -      | -    | -      |
|    |          |                |                                 | NiuHuRu                   | 0             | 0             | 0    | -      | -    | -      |
| 75 |同治/TongZhi | 1 | ALuTe                       | 0             | 0             | 0             | -    | -      | -    | -      |
| 76 |光绪/GuangXu | 1 | Yehe Nara                   | 0             | 0             | 0             | -    | -      | -    | -      |
| Total |         |                |                                 |                            | 107           | 68            | 175  | 40     | 44   | 32     |

Behavioral Ecology and Sociobiology (2022) 76: 116
better maternal social status may greatly influence SRB. Thus, we conclude that the imperial SRBs are significantly male-biased, and the empresses have significantly larger MSRB than the concubines. That clarifies that the maternal condition plays a crucial role in influencing the SRB (Trivers and Willard 1973; Clark 1978; Simpson and Simpson 1982; Symington 1987; Hiraiwa-Hasegawa 1993; Brown and Silk 2002).

**Condition for a higher MSRB**

As indicated in the “Materials and methods”, the early stage of a new dynasty was always the period recovering from warfare and other disasters. Its middle stage was generally regarded as the most prosperous period, followed by an ending stage replaced by another dynasty (Zhang 1974; Zhao 1977; Sima and Zhang 1982). During the heyday, resources were the most abundant, and the economy was booming. The result that imperial SRB in the heyday was not significantly higher than during low point periods (Table 1) implies that the abundance of resources may not be the leading cause influencing SRB.

Empresses and concubines were the emperor’s mates and lived in the same harem, the former had a higher social rank than the latter. However, they both were supplied with enough resources, much better than ordinary people (Zhang 2009). The results found in this study indicate that only the SRB\textsuperscript{empress} is significantly higher than the ordinary people (0.61 vs 0.514, \(N = 175\), \(Z = 2.58, p = 0.006\)), but not the SRB\textsuperscript{concubine} (0.53 vs 0.514, \(N = 909\), \(Z = 1.04, p = 0.155\)). Thus, we propose that the key factor determining SRB is tightly associated with social status instead of the guaranteed resources; maternal social status plays an essential role in sexual selection.

An empress had the highest social status among the females in the nation. Such advantages have been reported to psychologically promote her hormone release and other reactions benefitting reproduction, but the SRB\textsuperscript{empress} was significantly male-biased just after the coronation; this is consistent with the glucose hypothesis and hormone hypothesis (James 1980b, 1996, 2012; Cameron 2004; Cameron and Linklater 2007), implying that such an advantage around the conception period plays a pivotal role in deciding the SRB ratio. In other words, a temporal boundary must be taken into account in assessing SRB, such the good condition that the key factor was set in TWH appeared temporally. Thus, we proposed the instant social condition (ISC) to replace the current condition in SRB study that is ambiguous: ISC appears in the conception period and plays a vital role in sexual selection. In other words, a female with advanced instant social privileges may intend to generate an MSRB. Thus, we propose the sexual selection in humans is primarily decided by the maternal ISC.

Although TWH did not propose a condition of generating an MSRB, others have suggested it from different aspects such as income, education level, physique, social rank, occupation, and age (Garenne 2008; Helle et al. 2009; James 2012; Ellis and Bonin 2016; Kolk and Schnettler 2016; Luo et al. 2017; Grech 2019). As for wild animals, such a condition is measured according to social status, physique, habitat, climate, resource occupancy, etc. (Clark 1978; Simpson and Simpson 1982; Clutton-Brock et al. 1985; Brown and Silk 2002; Berkeley and Linklater 2010). The results found in this study can allow us to set up such an objective condition — instant social condition, which is backed by the fact that a female had a significantly higher MSRB after being inaugurated as the empress, and empresses generated significantly greater MSRB than the concubines. Furthermore, although concubines and dynasty’s heydays were guaranteed enough resources and living conditions, they did not produce significantly greater MSRB than the ordinary people, and a greater MSRB did not appear in heydays than during low point periods of the same imperial families. Since a defined condition is indispensable in human biology study (James 1980a, 1986, 2012), the new concept of the condition described in this study would provide a particular reference.

**Conclusion**

With a spatiotemporal imperial genealogical database covering 2142 years of Chinese history, the results found in this study clarify the TWH — parents with higher social status and resources tend to have a male-biased sex ratio at birth (MSRB). Meanwhile, it indicates that the maternal side around the conception period plays a vital role in sexual selection, and most importantly, the condition for having an MSRB is her instant social condition instead of rich resources. Thus, this study provides robust evidence to interpret sexual selection mechanisms and regulations. However, there are still some issues needed to be clarified. Although social status plays a vital role in sexual selection during the conception period, we need to determine how long that advanced period should be before the conception.

**Acknowledgements** We thank Dr. Jacob Kraus and Davide Fornacca for their comments on the manuscript and language editing and the two reviewers and the editors for their constructive comments and invaluable advice in improving the manuscript.

**Funding** This study was partly supported by the National Natural Science Foundation of China (#31860164, #31860168), the Science Research Foundation of Yunnan Education Bureau (2020J0543), and the Yunnan provincial Ten Thousand Talents Plan (YNWR-QNBJ-2019–262).
Data availability  All data generated or analyzed during this study are included in this published article.

Declarations

Competing interests  The authors declare no competing interests.

Open Access  This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Ban G (1962) History of the former Han dynasty. Zhong Hua Book Company, Beijing
Berkeley EV, Linklater WL (2010) Annual and seasonal rainfall may influence progeny sex ratio in the black rhinoceros. S Afr J Wild Res 40:53–57. https://doi.org/10.3957/056.040.0102
Bo Y (2011) The lineage of Chinese Emperors, queens, princes and princesses, 1st edn. People’s Literature Press, Beijing
Brown GR (2001) Sex-biased investment in nonhuman primates: can Trivers & Willard’s theory be tested? Anim Behav 61:683–694. https://doi.org/10.1006/anbeh.2000.1659
Brown GR, Silk JB (2002) Reconsidering the null hypothesis: is maternal rank associated with birth sex ratios in primate groups? P Natl Acad Sci USA 99:11252–11255. https://doi.org/10.1073/pnas.162360599
Cameron EZ (2004) Facultative adjustment of mammalian sex ratios in support of the Trivers-Willard hypothesis: evidence for a mechanism. Proc R Soc Lond B 271:1723–1728. https://doi.org/10.1098/rspb.2004.2773
Cameron EZ, Linklater WL (2007) Extreme sex ratio variation in relation to change in condition around conception. Biol Lett 3:395–397. https://doi.org/10.1098/rsbl.2007.0089
Cameron EZ, Lemons PR, Bateman PW, Bennett NC (2007) Experimental alteration of litter sex ratios in a mammal. Proc R Soc Lond B 275:323–327. https://doi.org/10.1098/rspb.2007.1401
Catalano RA (2003) Sex ratios in the two Germans: a test of the economic stress hypothesis. Hum Reprod 18:1972–1975. https://doi.org/10.1093/humrep/deg370
Clark AB (1978) Sex ratio and local resource competition in a prosimian primate. Science 201:163–165. https://doi.org/10.1126/science.201.4351.163
Clutton-Brock TH, Albon SD, Guinness FE (1985) Parental investment and sex differences in juvenile mortality in birds and mammals. Nature 313:131–133. https://doi.org/10.1038/313131a0
Darwin C (1859) On the origin of species by means of natural selection, or the preservation of favoured races in the struggle for life. Murray, London
DeLamater J, Friedrich WN (2002) Human sexual development. J Sex Res 39:10–14. https://doi.org/10.1080/00224490209552113
Diamond M (1976) Human sexual development: biological foundations for social development. In: Beach FA (ed) Human Sexuality in Four Perspectives. The John Hopkins Press, New York, pp 22–61
Dittus WP (1998) Birth sex ratios in toque macaques and other mammals: integrating the effects of maternal condition and competition. Behav Ecol Sociobiol 44:149–160. https://doi.org/10.1007/s002650050527
Douhard M (2017) Offspring sex ratio in mammals and the Trivers-Willard hypothesis: in pursuit of unambiguous evidence. BioEssays 39:1700043. https://doi.org/10.1002/bies.201700043
Ellis L, Bonin S (2016) War and the secondary sex ratio: are they related? Soc Sci Inf 43:115–122. https://doi.org/10.1177/05391545145404708
Fan Y (1965) History of the Later Han Dynasty. Zhonghua Book Company, Beijing
Fisher RA (1930a) Genetics, mathematics, and natural selection. Nature 126:805–806. https://doi.org/10.1038/126805a0
Fisher RA (1930b) The genetical theory of natural selection. Oxford University Press, Oxford
Gardner A, Hardy ICW, Taylor PD, West SA (2007) Spiteful soldiers and sex ratio conflict in polyembryonic parasitoid wasps. Am Nat 169:519–533. https://doi.org/10.1086/512107
Garenne M (2008) Heterogeneity in the sex ratio at birth in European populations. Genus 64:99–108. https://doi.org/10.2307/41430853
Gomendio M, Clutton-Brock TH, Albon SD, Guinness FE, Simpson MJ (1990) Mammalian sex ratios and variation in costs of rearing sons and daughters. Nature 343:261–263. https://doi.org/10.1038/343261a0
Goswami BN, Venugopal V, Sengupta D, Madhusoodanan MS, Xavier PK (2006) Increasing trend of extreme rain events over India in a warming environment. Science 314:1442–1445. https://doi.org/10.1126/science.1132027
Grech V (2019) Maternal educational attainment and sex ratio at birth by race in the United States, 2007–2015. J Biosoc Sci 45:457–462. https://doi.org/10.1017/s0021932819000123
Hamilton WD (1967) Extraordinary sex ratios. Science 156:477–488. https://doi.org/10.1126/science.156.3774.477
Helle S, Helama S, Lertola K (2009) Evolutionary ecology of human birth sex ratio under the compound influence of climate change, famine, economic crises and wars. J Anim Ecol 78:1226–1233. https://doi.org/10.1111/j.1365-2656.2009.01598.x
Hiraiwa-Hasegawa M (1993) Skewed birth sex ratios in primates: should high-ranking mothers have daughters or sons? Trends Ecol Evol 8:395–400. https://doi.org/10.1016/0169-5347(93)90040-V
Huang M, Zeng Y (2016) Chun Qiu Gong Yang Zhan. Zhong Hua Book Company, Beijing
IMF (2015) Gross domestic product and components selected indicators. IMF. http://data.imf.org/regular.aspx?key=61545852. Accessed 16 Mar 2021
James WH (1980a) Time of fertilisation and sex of infants. Lancet 315:1124–1126. https://doi.org/10.1016/S0140-6736(80)91565-2
James WH (1980b) Gonadotrophin and the human secondary sex ratio. Brit Med J 281:711–712. https://doi.org/10.1136/bmj.281.6242.711
James WH (1986) Hormonal control of sex ratio. J Theor Biol 120:427–441. https://doi.org/10.1016/S0022-5193(86)80163-1
James WH (1996) Evidence that mammalian sex ratios at birth are partially controlled by parental hormone levels at the time of conception. J Theor Biol 180:271–286. https://doi.org/10.1006/jtbi.1996.0102
James WH (2012) Hypotheses on the stability and variation of human sex ratios at birth. J Theor Biol 310:183–186. https://doi.org/10.1016/j.jtbi.2012.06.038
Kolk M, Schnettler S (2016) Socioeconomic status and sex ratios at birth in Sweden: No evidence for a Trivers-Willard effect for a
wide range of status indicators. Am J Hum Biol 28:67–73. https://doi.org/10.1002/ajhb.22756
Leimar O (1996) Life-history analysis of the Trivers and Willard sex-ratio problem. Behav Ecol 7:316–325. https://doi.org/10.1093/beheco/7.3.316
Liker A, Frecelton RP, Székely T (2013) The evolution of sex roles in birds is related to adult sex ratio. Nat Commun 4:1587. https://doi.org/10.1038/ncomms2600
Liu Y (2010) The history officer system and culture in ancient China. MSc thesis. YanTai University, Yantai
Luo L, Ding R, Gao X, Sun J, Zhao W (2017) Socioeconomic status influences sex ratios in a Chinese rural population. PeerJ 5:e3546. https://doi.org/10.7717/peerj.3546
Miao LL (2017) On the construction of official system in ancient China based on emperor’s XiaoWen reform of this imperial harem. TangDu J 33:78–82
Morita M, Go T, Hirabayashi K, Heike T (2017) Parental condition and infant sex at birth in the Japan environment and children’s study: a test of the Trivers-Willard Hypothesis. Lett Evolut Behav Sci 2:40–44. https://doi.org/10.5178/lebs.2017.6.3
Müller W, Eising CM, Dijkstra C, Groothuis TGG (2002) Sex differences in yolk hormones depend on maternal social status in Leghorn chickens (Gallus gallus domesticus). Proc R Soc Lond B 1506:2249–2255. https://doi.org/10.1098/rspb.2002.2159
Nie J (1999) The problem of coerced abortion in China and related ethical issues. Camb Q Health Ethic 8:463–475. https://doi.org/10.1017/S0963180199004077
Osipina-Alvarez N, Pfiffer F (2008) Temperature-dependent sex determination in fish revisited: prevalence, a single sex ratio response pattern, and possible effects of climate change. PLoS ONE 3:e2837. https://doi.org/10.1371/journal.pone.0002837
Palmer AR (2000) Quasi-replication and the contract of error: lessons from sex ratios, heritabilities and fluctuating asymmetry. Annu Rev Ecol Syst 31:441–480. https://doi.org/10.1146/annurev.ecolsys.31.1.441
Petersen JJ (1972) Factor affecting sex ratios of a mermithid parasite of mosquitoes. J Nematol 4:83–87
Polasek O, Kolcic I, Kolaric B, Rudan I (2005) Sex ratio at birth and offspring sex ratio problem. Behav Ecol 7:316–325. https://doi.org/10.1093/beheco/7.3.316
Reece SE, Shuker DM, Pen I, Duncan AB, Choudhary A, Batchelor CM, West SA (2004) Kin discrimination and sex ratios in a parasitoid wasp. J Evol Biol 17:208–216. https://doi.org/10.1046/j.1420-9101.2003.00640.x
Rosenfeld CS, Roberts RM (2004) Maternal diet and other factors affecting offspring sex ratio: a review. Biol Reprod 4:1063–1070. https://doi.org/10.1095/biolreprod.104.030890
Sheldon BC, West SA (2004) Maternal dominance, maternal condition, and offspring sex ratio in ungulate mammals. Am Nat 163:40–45. https://doi.org/10.1086/381003
Shun ZQ, Shun TY (2010) Historical time map of China. Jilin literature and history press, Changchun
Silk JB (1983) Local resource competition and facultative adjustment of sex ratios in relation to competitive abilities. Am Nat 121:56–66. https://doi.org/10.1086/284039
Sima Q, Zhang S (1982) Historical records, vol 30. Zhong Hua Book Company, Beijing
Simpson M, Simpson AE (1982) Birth sex ratios and social rank in rhesus monkey mothers. Nature 300:440–441. https://doi.org/10.1038/300440a
Song Q, OuYang X, Fan Z, Lv XQ (1975) New history of the tang Dynasty. Zhonghua Book Company, Beijing
Stevens SS (1955) On the averaging of data. Science 121:113–116. https://doi.org/10.1126/science.121.3135.113
Symington MM (1987) Sex ratio and maternal rank in wild spider monkeys: when daughters disperse. Behav Ecol Sociobiol 20:421–425. https://doi.org/10.1007/BF00302985
Tanvez A, Pariset M, Chastel O, Leboucher G (2008) Does maternal social hierarchy affect yolk testosterone deposition in domesticated canaries? Anim Behav 75:929–934. https://doi.org/10.1016/j.anbehav.2007.08.006
Touger S (2008) The eunuch in Byzantine history and society. Taylor & Francis Group, New York
Trivers RL, Hare H (1976) Haplodiploidy and the evolution of the social insects: the unusual traits of the social insects are uniquely explained by Hamilton’s kinship theory. Science 191:249–263. https://doi.org/10.1126/science.1108197
Trivers RL, Willard DE (1973) Natural selection of parental ability to vary the sex ratio of offspring. Science 179:90–92. https://doi.org/10.1126/science.179.4068.90
Tuo T, ALaTu A (1974) History of Song dynasty. ZhongHua Book Company, Beijing
van Schaik CP, Netto WJ, van Amerongen AJJ, Westland H (1989) Social rank and sex ratio of captive long-tailed macaque females (Macaca fascicularis). Am J Primatol 19:147–161. https://doi.org/10.1002/ajp.13501900303
Wan J (2004) On the establishment of the system of emperors and concubines in ancient China. J ChengDu Univ 03:38–40
Wang C (2012) History of the Chinese family planning program: 1970–2010. Contraception 85:563–569. https://doi.org/10.1016/j.contraception.2011.10.013
Wang J (2008) The characteristics of the phased evolution of the historiographer’s institute system of the Qing Dynasty. J Historiography 130:46–54 (in Chinese)
West SA, Sheldon BC (2002) Constraints in the evolution of sex ratio adjustment. Science 295:1685–1688. https://doi.org/10.1126/science.1069043
Wilson JD, Roehrborn C (1999) Long-term consequences of castration in men: lessons from the Skoptzy and the Eunuchs of the Chinese and Ottoman courts. J Clin Endocrinol Met 84:4324–4331. https://doi.org/10.1210/jcem.84.12.6206
Zhang TY (1974) History of Ming dynasty. Zhonghua Book Company, Beijing
Zhang S (2006) On Tang Dynasty’s domination and promotion of historiography based on system of historiographers’ institute. J Shangluo Univ 20:62–65
Zhang M (2009) Research on the Harem system in Qing dynasty. MSc thesis. Guizhou University, Guiyang
Zhang TY (1977) History of the Qing dynasty. Zhonghua Book Company, Beijing
Zhu ZY (1998) Research on the system of Imperial Harem. Huadong Normal University Press, ShangHai
Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.
Authors and Affiliations

Yan-Peng Li1,2,3 · Wei Ding4 · Zhi-Pang Huang1 · Ru-Liang Pan2,5 · Na Li1 · Guo-Peng Ren1 · Liang-Wei Cui3,6 · Qing-hua Cai3,7 · Wen Xiao1,2,3

1 Institute of Eastern-Himalaya Biodiversity Research, Dali University, Dali 671003, Yunnan, China
2 International Center of Biodiversity and Primate Conservation, Dali University, Dali 671003, Yunnan, China
3 Collaborative Innovation Center for the Biodiversity in the Three Parallel Rivers of China, Dali University, Dali 671003, Yunnan, China
4 Qujing Normal University, Qujing 655011, Yunnan, China
5 School of Anatomy, Physiology, School of Anatomy, Physiology and Human Biology, The University of Western Australia, Perth, Western Australia 6009, Australia
6 Southwest Forestry University, Kunming 650224, Yunnan, China
7 Institute of Hydrobiology, Chinese Academy of Science, Wuhan 430072, Hubei, China