A DEMOGRAPHIC MODEL WITH CULTURAL TRANSMISSION OF SON PREFERENCE

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Abstract

Remarkably high sex ratios at birth (SRBs; Chahnazarian, 1988; Johansson and Nygren, 1991) have been observed recently in Asian populations. A quantitative demographic explanation of this has been given by Li et al. (1997). In brief, fertility decline elevates the sex-selection pressure, and in the presence of strong son preference, the result is sex selection of sons. The purpose of this paper is to analyze what may happen to the SRB if fertility is maintained at a low level. We do this with a model of cultural transmission (Cavalli-Sforza and Feldman, 1973, 1981; Kumm et al., 1995) that links the evolution of a specific cultural trait, son preference, and the SRB in a population. We also discuss possible economic reasons for transmission of an interesting trait that occurs in some rural areas of China, namely, the tendency for parents to live with sons-in-law.

In Li et al. (1997), the *sex-selection situation* occurs when a woman has no son to that point in her life and is able to have only one more child. That a woman is in the sex-selection situation corresponds to a random event Y. The *sex-selection pressure*, y, is defined as the probability of the occurrence of Y. The *son-preference potency*, p, is defined as the probability that a woman has a sex-selected son, given that she is in situation Y. Li et al. developed the relationship between SRB, y, and p, under the assumption that the fertility remains constant for a long time. They showed that the value of y can be calculated from fertility data and can be used as an approximate estimate for a given population. Under the assumption that it is the same for all ages, p can be computed from an observed SRB using the relationship between SRB, y, and p.

A pronounced decline in fertility causes a significant increase in SRB in a population with strong son preference because the fertility decline increases y, which, in turn, causes a significant increase in SRB if p (constant) is large. However, when fertility stops changing, or after the fertility transition, y will be constant, so that change in SRB depends on change in p. Meanwhile, fertility decline not only elevates y but also causes SRB to be sensitive to p. That is, in a low-fertility population, a small change in p brings about a significant change in SRB.

China's SRB in 1989 was 114 (10 percent sampling tabulation from the 1990 population census of the People's Republic of China, edited by the Population Census Office under the State Council and Department of Population Statistics, State Statistics Bureau, People's Republic of China (SSB), 1993), whereas in 1995 the sex ratios for ages 0 to 5 were 117, 121, 121, 119, 115, and 114, respectively (*Population Yearbook of China 1996*, edited by SSB). Because the TFR of China has remained slightly above 2 for about 15 years (since 1980), it seems that the increase in SRB between 1990 and 1995 may not have been entirely due to an increase in y (which is caused only by a decrease in TFR) but may be at least partly due to an increase in p.

Son preference seems to play a key role in determining SRB in low-fertility populations. There are optimistic projections that son preference tends to diminish in response to economic development (Poston et al., 1997; Warren, 1985). However, negative evidence comes from the comparison between China and South Korea. In 1989, the TFRs of China and South Korea were 2.25 and 1.57, respectively (*Demographic Yearbook*, 1987, United Nations, New York), and the values of SRB of South Korea in 1989, 1990, 1991, and 1992 were 112, 117, 113, and 114, respectively (Park et al. 1994). From the slightly lower fertility and SRB of South Korea, its value of p might be slightly lower than China's. In 1989, however, the per capita GNP of China was \$360 and of South Korea \$4,400 (*World Tables, 1991*, published for The World Bank, The Johns Hopkins University Press, Baltimore and London). From such a remarkable economic gap and such a slight difference in SRB, it is difficult to claim that economic development alone is sufficient to diminish the son preference and lead to a normal SRB. Economic development may yield an elevation of adult women's status, but the elevation of adult women's status in a society does not directly increase the value of daughters to families (Das Gupta et al., 1997); it is the difference between the values of a son and a daughter to the family that determines the son preference.

Our goal is to investigate the evolution of son preference, that is, the change in the value of p over time, under conditions where economic development seems to have only indirect effects. The probability of having a sex-selected son for a couple in the sex-selection situation, p, is a measure of son preference, which should be regarded as a cultural trait, π. The decision to have a sex-selected son for a couple in the sex-selection situation is obviously affected directly by their parents, neighbors, and mass media, and economic development may contribute through all three channels. We suggest that the evolution of p can be described naturally in terms of a cultural-transmission model.

In order to discuss the transmission of son preference between generations (and therefore between different age groups) or changes in p and hence its effect on SRB, we should take account of the likelihood that the values of p for different age groups may be different. Thus, instead of a single y for the whole life cycle of a woman, values y_i for each age class should be included. For constant fertility over time, all y_i are constant over time. To investigate how p changes as a function of the population's dynamics, we need at least a female age-specific population model. In this population model, the fertility for both sexes is assumed constant owing to limited resources that constrain couples to have a certain number of children. However, an individual couple may still choose the sex composition of their children by means of sex selection. This choice reflects the distribution of resources according to the couple's cultural values and induces a cultural-trait-dependent female fertility. An important property of the cultural trait π is that it can be measured only for reproductive and older ages. Thus, π does not apply to individuals younger than the earliest childbearing age, because the decision to have a sex-selected son does not make sense for them. Therefore, in the cultural-transmission model we construct below, individuals do not have trait π before they reach the youngest reproductive age.

To prevent SRB reaching its maximum possible value, p must be less than 1. It is important to know under what conditions a value of p less than 1 can be maintained in a population. We derive these conditions with a limiting analysis. The conditions require certain levels of vertical, oblique, and mass-media transmission. We discuss economically based transmission, using a rural area of China as an example.

Population Dynamics

We begin with an assumption for the population model.

ASSUMPTION 1. Fertility and mortality are constant over time and there is no migration. The fertility of women aged 45 and older is ignored.

The female population at time t is divided into three age groups: $n_1(t)$ is the number aged 0 to 14, $n_2(t)$ the number aged 15 to 29, and $n_3(t)$ the number aged 30 to 44. The population model can be written as

$$N(t+1) = \begin{vmatrix} f_1(t) & f_2(t) & f_3(t) \\ p_1 & 0 & 0 \\ 0 & p_2 & 0 \end{vmatrix} N(t), \tag{1}$$

where $N(t)' = (n_1(t), n_2(t), n_3(t))$.

Here, p_1 and p_2 are the survival rates from the first to the second age group and from the second to the third age group, respectively. We use n(t) to represent $n_2(t)$, unless there is a chance of ambiguity. From (1), the population equation for n(t) can be written as

$$n(t+1)= f_1(t-1)n(t) + p_1f_2(t-1)n(t-1) + p_1p_2f_3(t-1)n(t-2). \quad (2)$$

In equation (2), the parameters describing female fertility and survival from birth to the first age group, $f_h(t)$, change over time because the constant fertility refers to both sexes, not only female offspring. If, however, the number of sex-selected sons changes over time, the female fertility will also change and so will $f_h(t)$. In order to compute $f_h(t)$, the number of sex-selected sons and hence the degree of son preference in the population is required.

Son preference is regarded as a cultural trait and is measured by its potency p. The trait of no preference, π_0, is measured by the complementary probability, namely, the probability that a mother in the sex-selection situation y does not carry out sex selection:

$$p_N = 1-p. \quad (3)$$

Establishing the cultural-transmission model requires a second assumption.

ASSUMPTION 2. The cultural trait, son preference or no son preference, is formed at the second age group and persists through the third age group.

That is, son preference is absent from the first age group, and the trait in members of the third age group at time t is their trait when they belonged to the second age group at time t−1.

In equation (2), the term $f_1(t-1)n(t)$ describes the number of females who are born in [t−1,t) and survive to the second age group at time (t+1) produced by the women, who were in the first age group at time (t−1) and in the second at time t. These women experienced half of their childbearing in [t−1,t) while in the second age group, and their son preference p(t) is formed at time t. From equation (A17) of Appendix A, we know that s, the SRB of children produced by these women in the second age group, is $(s_0F_2 + p(t)\cdot y_1)/(F_2 - p(t)\cdot y_1)$. Here, s_0 is the normal sex ratio at birth (or sex ratio at birth without sex selection), F_2 is the birth rate for both sexes of second age group, and y_1 is the sex-selection pressure of the second age group, which is given by equation (A14) in Appendix A. Therefore, the birth rate for female children of these women in the second age group is

$$F_2/(1+s) = (F_2 - p(t)\cdot y_1)/\ (1+s_0). \quad (4)$$

Since these women in [t−1,t) experienced half of the childbearing of the second age group,

$$f_1(t-1) = 0.5\cdot l_2(F_2 - y_1)/(1+s_0) + [0.5\cdot\ l_2y_1/(1+s_0)]\ p_N(t), \quad (5)$$

where l_i is the survival rate from birth to the ith age group.

Let

$$c_{11} = 0.5 \cdot l_2(F_2 - y_1)/(1+s_o),\ c_{21} = 0.5 \cdot l_2 y_1/(1+s_o). \tag{6}$$

Then,

$$f_1(t-1) = c_{11} + c_{21}\, p_N(t). \tag{7}$$

Similarly, we have,

$$p_1 f_2(t-1) = c_{12} + c_{22}\, p_N(t-1), \tag{8}$$

with

$$c_{12} = 0.5 \cdot [(l_2 F_2 + l_3 F_3) - (l_2 y_1 + l_3 y_2)]/(1+s_o),\quad c_{22} = 0.5 \cdot (l_2 y_1 + l_3 y_2)/(1+s_o), \tag{9}$$

where F_3 is the birth rate for both sexes of third age group and y_2 is the sex-selection pressure of the third age group, which is given by (A15) in Appendix A. Also,

$$p_1 p_2 f_3(t-1) = c_{13} + c_{23}\, p_N(t-2), \tag{10}$$

where

$$c_{13} = 0.5 \cdot l_3(F_3 - y_2)/(1+s_o),\quad c_{23} = 0.5 \cdot l_3 y_2/(1+s_o). \tag{11}$$

From equations (6)–(11), the population equation (2) becomes

$$n(t+1) = \sum_{h=1}^{3} [c_{1h} + c_{2h} p_N(t-h+1)]\, n(t-h+1). \tag{12}$$

It is clear that the female birth rate of the hth generation is $[c_{1h} + c_{2h} p_N(t-h+1)]/l_2$, which changes over time as p_N changes.

Let

$$c_{0h} = c_{1h} + c_{2h},\qquad h = 1,2,3, \tag{13}$$

namely, the female birth rates with no sex selection. The sex ratio at birth in the time interval $[t-1,t)$, $s(t)$, is

$$s(t) = \frac{(1+s_o) \sum_{h=1}^{3} c_{0h} n(t-h+1)}{\sum_{h=1}^{3} c_{1h} n(t-h+1) + \sum_{h=1}^{3} c_{2h} n(t-h+1)\, p_N(t-h+1)} - 1. \tag{14}$$

It is obvious that when $p_N(t-h+1)=1$ for $h=1,2,3$, we must have $s(t)=s_o$. Otherwise, if

$p_N(t-h+1)<1$, then $s(t)>s_0$. Also if $p_N(t-h+1)=0$, then s(t) reaches its maximum. In a stationary population, $n(t-h+1)=n$. Note that the sex-selection pressure of the life cycle, y, is the sum of the pressures of second and third age group, $(y_1 + y_2)$. Denote by T the expected number of children a woman has during her life, that is, $T=(F_2+F_3)$, and the maximum SRB is $(T s_0+y)/(T-y)$, as shown by Li et al. (1997).

It remains to derive $p_N(t+1)$. If $p_N(t+1)$ is known, $f_h(t-h+1)$, h = 1,2,3 can be obtained from (7), (8), and (10). Then n(t+2) can be calculated using (12). We now develop a cultural-transmission model to complete the dynamic description of the population's evolution.

The Cultural-Transmission Model

To calculate $p_N(t+1)$, we ask how many of n(t+1) would risk having no sons in their life cycle by choosing not to have a sex-selected son. It is obvious that this number is

$$n(t+1)\cdot p_N(t+1).$$

This behavior can only be acquired from older generations (not the same generation, by Assumption 2) by vertical or oblique transmission or from mass media.

It is easier to trace the parents with trait π_0 because the SRB of their offspring is normal. Of the n(t+1), the number of offspring produced by parents with trait π_0 is

$$\sum_{h=1}^{3} c_{0h} n(t-h+1)\, p_N(t-h+1).$$

But the π_0 trait of parents who are not in situation Y is not manifested because they have not decided whether to have a sex-selected son. Thus, their trait might not be transmitted vertically. The number of offspring whose parents have the π_0 trait and were, are, and could be in situation Y is the number of these offspring whose parents have trait π_0 times the probability of these parents being in situation Y in their life cycle (not a particular age group), which is y (not y_i); that is,,

$$y\sum_{h=1}^{3} c_{0h} n(t-h+1)\, p_N(t-h+1).$$

These offspring adopt the π_0 trait at a rate C_V $(0 \le C_V \le 1)$, the coefficient of vertical transmission, after which the resulting number of π_0 individuals is

$$C_v \cdot y\sum_{h=1}^{3} c_{0h} n(t-h+1)\, p_N(t-h+1).$$

The number of the offspring from all other parents is n(t+1) minus the number of offspring produced by parents with trait π_0 and in Y; that is,

$$[n(t+1) - y\sum_{h=1}^{3} c_{0h} n(t-h+1)\, p_N(t-h+1)]$$

$$= [\sum_{h=1}^{3} c_{1h}n(t-h+1) - \sum_{h=1}^{3} c_{3h}n(t-h+1)\, p_N(t-h+1)]$$

$$= \sum_{h=1}^{3} n(t-h+1)\, [c_{1h} - c_{3h}\, p_N(t-h+1)], \tag{15}$$

where

$$c_{3h} = yc_{0h} - c_{2h}, \qquad h = 1,2,3. \tag{16}$$

Let the average trait π_o of the previous generation be measured by $\bar{P}_N(t)$, then

$$\bar{P}_N(t) = \frac{\sum_{h=1}^{3} l_h n(t-h+1)\, p_N(t-h+1)}{\sum_{h=1}^{3} l_h n(t-h+1)}. \tag{17}$$

So that the number of those in (15) who adopt trait π_o by oblique transmission is

$$C_o \sum_{h=1}^{3} n(t-h+1)\, [c_{1h} - c_{3h}\, p_N(t-h+1)]\, \bar{P}_N(t), \qquad 0 \le C_o \le 1.$$

Here, C_o is the coefficient of oblique transmission.

The offspring of all parents except those who are π_o and in situation Y may also acquire π_o from the mass media at a rate M_O (assuming that if the offspring of π_o parents do not become π_o by vertical transmission, they will not acquire it from oblique transmission), after which their number is

$$M_o[1 - C_o\, \bar{P}_N(t)]\{\sum_{h=1}^{3} n(t-h+1)[c_{1h} - c_{3h}\, p_N(t-h+1)]\}, \qquad 0 \le M_o \le 1.$$

The number of individuals in n(t+1) who adopt trait π_o from vertical, oblique, and mass-media transmission should be equal to $n(t+1)p_N(t+1)$. Thus, we have the complete iteration of $p_N(t)$:

$$p_N(t+1) = C_v \frac{y\sum_{h=1}^{3} c_{0h}n(t-h+1)\, p_N(t-h+1)}{n(t+1)}$$

$$+[M_o + C_o(1 - M_o)\, \bar{P}_N(t)] \frac{\sum_{h=1}^{3} n(t-h+1)[c_{1h} - c_{3h}\, p_N(t-h+1)]}{n(t+1)}. \tag{18}$$

This completes the construction of the model.

Limit Analysis

Zero is always a fixed point of the recursion (18) if $M_O=0$. That is, if $M_O=0$ and $p_N(t-h+1)=0$, for h=1,2,3, then $p_N(t+1)=0$. But there might be another limit; let its value be p_N^*,

$$0 < p_N^* \leq 1. \tag{19}$$

Then, according to the Leslie model (1), n(t) will be stable at $p_N(t) \equiv p_N^*$ when

$$n(t+1)=\lambda n(t), \tag{20}$$

at which point the population equation (12) becomes

$$1= G_1(\lambda) + G_2(\lambda)p_N^* , \tag{21}$$

and the recursion (18) at $p_N(t) \equiv p_N^*$ becomes

$$p_N^*= C_v\, yG_0(\lambda)\, p_N^* + [\, M_o+C_o(1-M_o)\, p_N^*][G_1(\lambda) - G_3(\lambda)\, p_N^*] , \tag{22}$$

where

$$G_k(\lambda) = \textstyle\sum_{h=1}^{3} c_{kh}\, \lambda^{-h} , \qquad k = 0,1,2,3. \tag{23}$$

Now we determine the conditions that allow $0 < p_N^* \leq 1$. We consider two functions λ_1 and λ_2 of the variable $p_N \in [0,1]$. The first is $\lambda_1(p_N)$, which satisfies (24):

$$G_1(\lambda) + p_N\, G_2(\lambda) =1. \tag{24}$$

The second is $\lambda_2(p_N)$, which satisfies (25):

$$p_N = C_v\, y\, p_N\, G_0(\lambda) + [\, M_o+C_o(1-M_o)\, p_N][G_1(\lambda) - G_3(\lambda)p_N]. \tag{25}$$

Then, p_N^* is the root of

$$\lambda_1(p_N) = \lambda_2(p_N). \tag{26}$$

It is obvious that λ_{10}, the value of $\lambda_1(p_N)$ at $p_N = 0$, must make $G_1(\lambda_{10}) = 1$; that is,

$$G_1(\lambda_1(0)) = G_1(\lambda_{10}) = 1. \tag{27}$$

Similarly, let $\lambda_{11} = \lambda_1(1)$. Then, from (13),

$$G_1(\lambda_{11}) + G_2(\lambda_{11}) = G_0(\lambda_{11}) = 1. \tag{28}$$

Comparing (27) and (28) yields $G_1(\lambda_{10}) > G_1(\lambda_{11})$, and from (23) this entails

$$\lambda_{11} > \lambda_{10} > 0. \tag{29}$$

From (24), and noting that $\partial G_h(\lambda)/\partial\lambda < 0$ (h = 0,1,2,3), we have

$$\partial\lambda_1(p_N)/\partial p_N = -G_2(\lambda)/[(\partial G_1(\lambda)/\partial\lambda) + (\partial G_2(\lambda)/\partial\lambda)p_N] > 0. \tag{30}$$

For $M_o > 0$, let $\lambda_2(0) = \lambda_{20}$. Then, from (25),

$$G_1(\lambda_{20}) = 0. \tag{31}$$

Therefore, formally we must set $\lambda_{20} = \infty$, in which case, obviously,

$$\lambda_{10} < \lambda_{20}. \tag{32}$$

Again, define $\lambda_{21} = \lambda_2(1)$. Then, from (25),

$$\{(1-y)[M_o + C_o(1-M_o)] + C_v y\}G_0(\lambda_{21}) = 1. \tag{33}$$

Because

$$(1-y)[M_o + C_o(1-M_o)] + C_v y \le 1, \tag{34}$$

we have

$$\lambda_{21} \le \lambda_{11}. \tag{35}$$

Thus, because $\lambda_1(p_N)$ and $\lambda_2(p_N)$ are continuous functions of $p_N \in [0,1]$ and from (32) at $p_N=0$, λ_1 is less than λ_2; from (35) at $p_N=1$, λ_1 is larger than or equal to λ_2. It follows that $\lambda_1(p_N)$ must cross $\lambda_2(p_N)$ at some $p_N^* \in [0,1]$. This value of p_N at which $\lambda_1(p_N)$ crosses $\lambda_2(p_N)$ is the root of (26). Therefore, (26) must have a root in (0,1].

From (25),

$$\frac{\partial\lambda_2(p_N)}{\partial p_N} = \frac{1-C_o(1-M_o)[G_1(\lambda) - G_3(\lambda)p_N] + [M_o + C_o(1-M_o)p_N]F_3(\lambda)}{C_v y p_N(\partial G_0(\lambda)/\partial\lambda) + [M_o + C_o(1-M_o)p_N][(\partial G_1(\lambda)/\partial\lambda) - (\partial G_3(\lambda)/\partial\lambda)p_N]}. \tag{36}$$

Since

$$1-C_o(1-M_o)[G_1(\lambda) - G_3(\lambda)p_N] + [M_o + C_o(1-M_o)p_N]G_3(\lambda)$$

$$= C_v y G_0(\lambda) + M_o G_1(\lambda)/p_N + C_o(1-M_o)p_N G_3(\lambda) > 0 \tag{37}$$

and

$$C_v y\, p_N(\partial G_0(\lambda)/\partial\lambda) + [M_o + C_o(1-M_o)p_N][(\partial G_1(\lambda)/\partial\lambda) - (\partial G_3(\lambda)/\partial\lambda)p_N]$$

$$\leq C_v y\, p_N\, (\partial G_0(\lambda)/\partial\lambda) + [M_o + C_o(1-M_o)\, p_N]\, [(\partial G_1(\lambda)/\partial\lambda) - (\partial G_3(\lambda)/\partial\lambda)]$$

$$= \{C_v y\, p_N + [M_o + C_o(1-M_o)\, p_N](1-y)\}(\partial G_0(\lambda)/\partial\lambda) < 0, \quad (38)$$

we have

$$\partial\lambda_2(p_N)/\partial p_N < 0. \quad (39)$$

It follows from (30) and (39) that if $M_o > 0$, $\lambda_1(p_N)$ is a monotonically increasing function, whereas $\lambda_2(p_N)$ is a monotonically decreasing function of $p_N \in [0,1]$. Hence, $\lambda_1(p_N)$ must cross $\lambda_2(p_N)$, but only once. In other words, (26) has one and only one root $p_N{}^*$ in (0,1].

Furthermore, $p_N{}^*=1$ if and only if

$$(1-y)[M_o + C_o(1-M_o)] + C_v y = 1. \quad (40)$$

If $M_o = 0$, everything above stands except that (31) becomes

$$C_v y G_0(\lambda_{20}) + C_o G_1(\lambda_{20}) = 1. \quad (41)$$

In this case, (32) is now not a result derived from (31) but a condition, which yields $p_N{}^* > 0$.

If

$$C_o = 1,\ C_v > 0, \quad (42)$$

then

$$G_1(\lambda_{10}) = 1 = C_v y G_0(\lambda_{20}) + C_o G_1(\lambda_{20}) > G_1(\lambda_{20}). \quad (43)$$

Therefore, (32) holds. Otherwise, for a given C_o, from (41)

$$\frac{\partial\lambda_{20}}{\partial C_v} = \frac{-\,y\, G_0(\lambda_{20})}{C_v y(\partial G_0(\lambda)/\partial\lambda) + C_o(\partial G_1(\lambda)/\partial\lambda)} > 0. \quad (44)$$

Thus, increasing C_v could produce (32), which guarantees that $p_N{}^*>0$. Let λ_{20} be a function of C_v for a given C_o, $\lambda_{20}(C_v,C_o)$. Then, the minimum value C_{vmin}, which yields $p_N{}^*>0$ for any $C_v > C_{vmin}$, satisfies

$$\lambda_{20}(C_{vmin}, C_o) = \lambda_{10}. \tag{45}$$

However, for some C_o it may be that $C_{vmin} > 1$, which is not feasible. Hence, there is a minimum value of C_o, say C_{omin}, which satisfies

$$\lambda_{20}(1, C_{omin}) = \lambda_{10}. \tag{46}$$

If $C_o < C_{omin}$, then it is impossible to have $p_N^* > 0$, even if $C_v = 1$.

We conclude that in order to ensure that $p_N^* = 1$, it is necessary and sufficient that $C_v = 1$ with $C_o = 1$ or $M_o = 1$. In order to ensure that $p_N^* > 0$, $M_o > 0$ is sufficient; that is, if $M_o > 0$, then $p_N^* > 0$, no matter what C_o and C_v are. However, if $M_o = 0$, then the necessary condition for $p_N^* > 0$ is $C_o > C_{omin}$, and under this condition there is a non-empty and feasible range of C_v $(C_{vmin}, 1]$, which produces $p_N^* > 0$.

The Economic-Transmission Mechanism in a Rural Area of China

In most rural areas of China, there is as yet neither enough wealth to enable people to save for their old age nor a reliable pension system. People must therefore spend their later years either with one of their sons (LS) or one of their daughters (that is, also with a son-in-law, LSL). Thus, from the standpoint of their support, the elderly can be divided into two groups, LS and LSL.

It is natural to seek the reason for the predominance of LS, which leads directly to son preference. In rural China, especially in poor areas, when the male household head grows older, the need for hard physical labor could bring serious hardship, even bankruptcy, to families without a son. This is not sufficient to explain the ubiquity of LS, however, because having a son-in-law or LSL could also solve this problem. It should be remembered that power in the family will inevitably go to the person who makes the most money, whether it is a son or son-in-law. If they are about equally wealthy, then since a son is a blood relative of the family and would normally be regarded as more reliable than a son-in-law who comes from elsewhere, LS is more desirable.

The central question then becomes through what mechanism can LSL appear? In fact, those who have no son and face a limit on their future fertility have a difficult choice: to have a sex-selected son or to become LSL. In earlier times, sex selection was accomplished either through infanticide or abandonment of daughters.

We claim that if a son-in-law makes more money than a son, then the family faces a choice between a better living standard as LSL and a poor but reliable old age as LS. When the economic potential of a son-in-law is sufficiently greater, the family will ultimately sacrifice the reliability of LS and choose the better living standard of LSL.

In fact, for those in the fertile age range who have not yet had a son, the choice is based not on comparing an actual son and an actual son-in-law but on an evaluation of the economic benefit from a potential son or a potential son-in-law. If the son-in-law appears to have higher earning potential, is it great enough to ignore the reliability of the son? If the answer is affirmative, then this family will become a no-preference family.

Making this choice is different for LSL and LS families. For a son-in-law or a child whose parents are LSL, the process of deciding to be LSL might well involve vertical transmission, whereas for individuals from LS families, becoming LSL probably requires oblique transmission.

Thus, one condition for LSL to appear and spread in a population might be that the earning potential of sons-in-law should be significantly greater than the average economic ability of local residents. On the other hand, if LSL is acceptable, what is the benefit to potential sons-in-law from elsewhere to accept their wife's parents? One benefit could result from migrating into an area where there are more natural resources than are available in the son in law's home district.

The prevalence of LSL is a measure of an objective phenomenon, whereas p_N measures an aspect of culture, although the two are obviously related. The current rate of LSL who have no son is the minimum possible value of $y \cdot p_N$ at some earlier time. This is because, if some time ago $y \cdot p_N$ was lower than the current rate of LSL without sons, some of the latter would have had sex-selected sons (by means of earlier infanticide or abandonment of daughters) and become LS. Hence, the expected LSL rate should be lower than what is observed. On the other hand, about half of the p_N individuals have a son by chance, and may then choose to be LS. Therefore, $y \cdot p_N$ some time ago should be larger than the current rate of LSL without sons. In this way, economic considerations involved in deciding between LSL and LS may result in the transmission of p_N.

Lueyang county in Shaanxi province of China, located in the Qin mountains, is rich in natural resources but poor economically. In this county, LSL is popular and is said to have had a long history. In 1992, there were more than 4,700 LSL among the total of 45,100 households; about 10.4 percent. In Jinchiyuan township, where the LSL rate is said to be the highest in this county, there were 135 LSL (of which 19 were two-generation adopted-son households) among the total of 473 households, in 1995. The LSL rate in Jinchiyuan reached 28.9 percent. In Jinchiyuan township or Lueyang county it may be that not having sons is regarded as unimportant because "some time ago" fertility was very high, so the y value at that time was very small. Since the LSL observed now is very high, $y \cdot p_N$ some time ago was very high, and because y was small, p_N must have been large, close to 1, say. That is, p must have been very small. Thus, in these areas, for the SRB to be normal requires only that the value of p be held at about that earlier level by cultural transmission of p_N. From Table 1, this seems to have occurred.

TABLE 1. Recent SRB of Lueyang County

Year	1991	1992	1993	1994	1995
SRB	1.043	1.033	1.094	1.039	0.992

In Lueyang county, per capita income has been lower than in surrounding areas, although it possesses more natural resources than these neighboring areas. In Jinchiyuan township, for example, in 1995, the per capita areas of cultivated land, forest, and river were 0.132, 5.132, 0.137 hectares, and the per capita income was 472 yuan. While at the same time the average cultivated land, forest, river, and income of the agricultural population of Shaanxi province were 0.124, 0.307, 0.015 hectares and 963 yuan (*Statistical Yearbook of Shaanxi, 1996,* edited by SSB of Shaanxi province, 1996). Thus, it is rich in resources and poor in earnings, and the high rate of LSL and normal SRB can be understood in terms of our analysis above.

Can LSL be maintained if some of above conditions disappear? Recently, sons-in-law coming from other provinces have reported that the young men from their home districts (mainly Sichuan province) have been more interested in going to eastern areas of China than to Lueyang because they see greater earning potential in industry than from natural resources. The result is a recent trend for the sons-in-law to be local. However, we found this trend to be very weak. From statistical information available for Jinchiyuan in 1996, 59 percent of the sons-in-laws came from inside the county, 17 percent from other counties but inside Shaanxi province, and 24 percent from other provinces. These percentages for sons-in-law older than 30 were 58 percent, 17 percent, and 25 percent, respectively. Will this trend become stronger and cause the perceived economic advantage of LSL to be reduced? If so, could the reliability of sons become a predominant factor again? Of course, this is related to how the transmission mechanism evolves, an issue yet to be studied empirically.

The above discussion invoked economics as the underlying cause of transmission. An important and interesting fact is that being rich in resources and poor in income may not be necessary to maintain LSL. For example, LSL is also popular in Songzi county, Hubei province, where, in Babao township, the fraction of couples living with the wife's family was about 20 percent (Yan, 1995), yet this county seems to be neither rich in resources nor poor in income.

Appendix A

In Li et al. (1997), sex selection was discussed in the context of a woman's complete reproductive age span. Here the analysis will be carried out keeping track of each age group.

Age group $[\alpha, k)$

Denote by a the age of a woman, K the event $\{a \in [\alpha,k)\}$; C, R, and D(i) the number of children, the order of a child, and the number of daughters in the first i children for a woman in an age group specified by K. Supposing there is no mortality in the reproductive ages and fertility remains constant for a long time, then the probability that a woman has her ith child up to or before she reaches age k is

$$
\begin{aligned}
T_i(k) &= \textstyle\sum_{j=\alpha}^{k} F_j(i) \\
&= \Pr\{R=i \mid a=\alpha\} \\
&\quad + \Pr\{R\neq i \mid a=\alpha\} \Pr\{R=i \mid a=\alpha+1) \mid (R\neq i \mid a=\alpha)\} \\
&\quad + \dots \\
&\quad + \Pr\{R\neq i \mid a=k-1\} \Pr\{(R=i \mid a=k) \mid (R\neq i \mid a=k-1)\} \\
&= \Pr\{R=i \mid K\}. \qquad \text{(A1)}
\end{aligned}
$$

Here, $F_j(i)$ is the birth rates of children of order i to women aged j. Furthermore,

$$\Pr\{(R=i+1 \mid K) \mid (R=i \mid K)\} = \frac{\Pr\{(R=i+1 \mid K) \cap (R=i \mid K)\}}{\Pr\{R=i \mid K\}}. \qquad \text{(A2)}$$

Since

$$(R=i+1 \mid K) \subset (R=i \mid K), \qquad \text{(A3)}$$

we have

$$\Pr\{(R=i+1 \mid K) \mid (R=i \mid K)\} = \frac{\Pr\{R=i+1 \mid K\}}{\Pr\{R=i \mid K\}} = \frac{T_{i+1}(k)}{T_i(k)} = p_i(k), \qquad \text{(A4)}$$

Note that (A3) is not true for $K = \{a \in [x,k)\}$ where $x > \alpha$, because an ith child may be born to women of ages less than x. This is the reason for our focus here on the special age group $[\alpha, k)$.

To deal with the effect of son preference, we need an assumption.

ASSUMPTION 1. The preference for having next a child is a life-cycle character that is independent of age k.

With this assumption we have

$$\Pr\{(R=i+1 \mid K) \mid (D(i)= i \mid K)\}= a_i p_i(k), \quad \text{(A5)}$$

where a_i is independent of k. In the case of son preference, women without a son should be more likely to have a next child than other women, so $a_i \geq 1$. The conditions $\Pr\{R=i+1 \mid D(i)= i\} \leq 1$ and $\Pr\{R=i+1 \mid D(i)< i\} \geq 0$ for given $\Pr\{R=i+1 \mid R= i\}$ produce the upper limit of a_i. Because there is no sex selection if D(i)=i, we have

$$\Pr\{D(i)=i \mid K\}= \Pr\{D(i-1)=i-1 \mid K\}\Pr\{(R=i \cap \text{ith child is a daughter}) \mid (D(i-1)=i-1 \mid K)\}$$

$$=[1/(1+s_o)] \Pr\{(R=i \mid (D(i-1)=i-1 \mid K)\} \Pr\{D(i-1)=i-1 \mid K\}$$

$$= [a_{i-1}p_{i-1}(k)/(1+s_o)] \ \Pr\{D(i-1)=i-1 \mid K\}=\ldots$$

$$= (\textstyle\prod_{j=0}^{i-1} a_j)T_i(k)/ (1+s_o)^i . \quad \text{(A6)}$$

In order to analyze the sex-selection situation, denoted here by Y(k), we ignore the possibility that having no son in K and being able or permitted to have only one more child could result in the child being born after k. This is because if k is large and the son preference is sufficiently strong that having this child is an urgent matter, then the possibility of having this child later than age k is small. Therefore, we make a second assumption.

ASSUMPTION 2. In the situation of no son in K and being able to have only one more child, this last child will also occur in K.

Therefore,

$$Y(k) = [(C=1 \mid K) \cap (D(0)= 0 \mid K)] \cup [(C=2 \mid K) \cap (D(1)= 1 \mid K)] \cup \ldots. \quad \text{(A7)}$$

From (1) of Appendix B,

$$[(C=i+1 \mid K) \cap (D(i)= i \mid K)] \cap [(C=j+1 \mid K) \cap (D(j)= j \mid K)] = \Phi, \ i \neq j, \quad \text{(A8)}$$

where Φ is the empty set. Therefore, the sex-selection pressure y(k) is

$$y(k) = \textstyle\sum_{i=0}^{\infty} \Pr\{(C=i+1 \mid K) \cap (D(i)= i \mid K)\}. \quad \text{(A9)}$$

Using (A25) of Appendix B,

$$y(k) = \sum_{i=0}^{\infty} [\prod_{j=0}^{i} a_j / (1+s_o)^i][T_{i+1}(k) - T_{i+2}(k) (a_{i+1} + s_o b_{i+1}) / (1+s_o)]. \quad \text{(A10)}$$

Sex selection for other age groups

Consider three age groups: $K_1 = \{a\in[\alpha, k_1)\}$, $K_2 = \{a\in[k_1, k_2)\}$, $K_3 = \{a\in[k_2, \beta)\}$, $\alpha \le k_1 < k_2 \le \beta$, and denote the sex-selection pressure in these age groups by $y(\alpha, k_1)$, $y(k_1,k_2)$, and $y(k_2,\beta)$. In equation (A10) we calculated $y(\alpha, k_1)$, that is, $y(k_1)$. Now

$$p\cdot y = \Pr\{\text{sex selection}\cap Y\}$$

$$= \sum_{h=1}^{3} \Pr\{ K_h\}\Pr\{(\text{sex selection}\cap Y) \mid K_h\}$$

$$= \sum_{h=1}^{3} \Pr\{\text{sex selection}\cap Y\cap K_h\}$$

$$= \sum_{h=1}^{3} \Pr\{Y \cap K_h\}\Pr\{\text{sex selection} \mid (Y\cap K_h)\}, \quad \text{(A11)}$$

and $\Pr\{\text{sex-selection} \mid (Y\cap K_h)\}$ is p (namely, the preference potency) by the definition of p, provided $\{Y\cap K_h\}$ is not empty set. That is,

$$p\cdot y = p\sum_{h=1}^{3} \Pr\{Y\cap K_h\}= p\sum_{i=1}^{3} y_h$$

$$= p\sum_{h=1}^{3} \Pr\{K_h\}\Pr\{Y \mid K_h\}$$

$$= p[(k_1-\alpha) \Pr\{Y \mid K_1\}+(k_2- k_1) \Pr\{Y \mid K_2\}+(\beta -k_2) \Pr\{Y \mid K_3\}]/(\beta-\alpha)$$

$$= p[(k_2-\alpha) \Pr\{Y \mid (K_1 \cup K_2)\}+(\beta -k_2) \Pr\{Y \mid K_3\}]/(\beta-\alpha). \quad \text{(A12)}$$

Also, because $\Pr\{Y \mid (K_1 \cup K_2)\}= y(k_2)$, we have

$$y_3= \Pr\{Y\cap K_3\}= (\beta -k_2)\Pr\{Y \mid K_3\}/(\beta-\alpha)= y-(k_2-\alpha)y(k_2)/(\beta-\alpha), \quad \text{(A13)}$$

and because $\Pr\{Y \mid K_1\}= y(k_1)$, we have

$$y_1= \Pr\{Y\cap K_1\}= (k_1-\alpha)y(k_1)/(\beta-\alpha). \quad \text{(A14)}$$

Finally,

$$y_2 = \Pr\{Y \cap K_2\} = \Pr\{Y \cap (K_2 \cup K_1)\} - \Pr\{Y \cap K_1\}$$

$$= [(k_2-\alpha)y(k_2)-(k_1-\alpha)y(k_1)]/(\beta-\alpha). \quad \text{(A15)}$$

The expected number of children born to n women in K_h is

$$n \cdot F_{h+1} = n \cdot \sum_{j \in K_h} \sum_{i=1}^{\infty} F_i(j) \quad \text{(A16)}$$

where F_{h+1} is the birth rate of the hth age group. Of these children, $n \cdot p \cdot y_h$ are the sex-selected sons. That is, in K_h the number of sons is

$$n(s_o F_{h+1} + p \cdot y_h)/(1+ s_o),$$

where s_o is the normal SRB, and the number of daughters is

$$n(F_{h+1} - p \cdot y_h)/(1+ s_o).$$

Therefore, the sex ratio at birth, SRB, is

$$s = (s_o F_{h+1} + p \cdot y_h)/ (F_{h+1} - p \cdot y_h). \quad \text{(A17)}$$

Appendix B

From ASSUMPTION 2 of Appendix A, {K} can be regarded as the total space of outcomes with respect to having the next child. Hence, it is ignored below.

(A) For any i,

$(R \neq i) \subset (R \neq i+1)$,

so that for $j > i$,

$$(C=i+1 \cap D(i)=i) \cap (C=j+1 \cap D(j)=j)$$
$$= (R \neq i+2 \cap R=i+1 \cap D(i)=i) \cap (R \neq j+2 \cap R=j+1 \cap D(j)=j)$$
$$\leq (R \neq j+1 \cap R=j+1) \cap (R=i+1 \cap D(i)=i \cap R \neq j+2 \cap D(j)=j) = \Phi. \quad \text{(A18)}$$

(B)

$$\Pr\{C=i+1 \cap D(i)=i\} = \Pr\{R \neq i+2 \cap R=i+1 \cap D(i)=i\}$$
$$= \Pr\{R=i+1 \cap D(i)=i\} \Pr\{R \neq i+2 \mid (R=i+1 \cap D(i)=i)\}$$
$$= \Pr\{R=i+1 \cap D(i)=i\}(1 - \Pr\{R=i+2 \mid (R=i+1 \cap D(i)=i)\})$$
$$= \Pr\{R=i+1 \cap D(i)=i\} - \Pr\{R=i+2 \cap D(i)=i\}$$
$$= \Pr\{D(i)=i\}(\Pr\{R=i+1 \mid D(i)=i\} - \Pr\{R=i+2 \mid D(i)=i\})$$
$$= \{T_i[1/(1+ s_o)]^i \Pi_{j=0}^{i-1} a_j\}(a_i\, p_i - \Pr\{R=i+2 \mid D(i)=i\}). \quad \text{(A19)}$$

(C)

Because

$$(D(i)=i)=(R=i+1 \mid D(i)=i)+ (R \neq i+1 \mid D(i)=i), \quad \text{(A20)}$$

therefore

$$\Pr\{R=i+2 \mid D(i)=i\} = \Pr\{R=i+1 \mid D(i)=i\} \Pr\{R=i+2 \mid (R=i+1 \mid D(i)=i)\}$$

$$= a_i\, p_i \Pr\{R=i+2 \mid (R=i+1 \mid D(i)=i)\}. \qquad \text{(A21)}$$

Because

$$(R=i+1 \mid D(i)=i) = (D(i+1)=i+1 \mid D(i)=i) + (D(i+1)=i \mid D(i)=i), \qquad \text{(A22)}$$

therefore

$$\Pr\{R=i+2 \mid (R=i+1 \mid D(i)=i)\}$$

$$= \Pr\{D(i+1)=i+1 \mid D(i)=i)\}\Pr\{R=i+2 \mid (D(i+1)=i+1 \mid D(i)=i)\}$$

$$+ \Pr\{D(i+1)=i \mid D(i)=i)\} \Pr\{R=i+2 \mid (D(i+1)=i \mid D(i)=i)\}$$

$$= [1/(1+s_o)]\Pr\{R=i+2 \mid (D(i+1)=i+1 \mid D(i)=i)\}$$

$$+[s_o/(1+s_o)]\Pr\{R=i+2 \mid (D(i+1)=i \mid D(i)=i)\}$$

$$= [1/(1+s_o)]\Pr\{R=i+2 \mid D(i+1)=i+1\}$$

$$+ [s_o/(1+s_o)]\Pr\{R=i+2 \mid D(i+1)<i+1\}$$

$$= [1/(1+s_o)]\, a_{i+1}p_{i+1} + [s_o/(1+s_o)]\, b_{i+1}p_{i+1}. \qquad \text{(A23)}$$

Hence,

$$\Pr\{R=i+2 \mid D(i)=i\} = a_i\, [a_{i+1} + s_o b_{i+1}]\, p_i p_{i+1}/(1+s_o). \qquad \text{(A24)}$$

(D)

From B and C,

$$\Pr\{C=i+1 \cap D(i)=i\} = (\Pi_{j=0}^{i} a_j)[T_{i+1} - (a_{i+1} + s_o b_{i+1})\, T_{i+2}/(1+s_o)]/(1+s_o)^i. \qquad \text{(A25)}$$

References

Cavalli-Sforza, L. L., and M. W. Feldman. 1981. *Cultural Transmission and Evolution.* Princeton University Press, Princeton, N.J.

Chahnazarian, A. 1988. Determinants of the sex ratio at birth: Review of recent literature. *Social Biology* 35: 214–235.

Das Gupta, M., et al. 1997. Family systems, economic factors and son preference in China, South Korea and India. Paper presented at the Annual Meeting of the Population Association of America, 1997, Washington, D.C.

Feldman, M. W., and L. L. Cavalli-Sforza. 1976. Cultural and biological evolutionary processes: Selection for a trait under complex transmission. *Theoretical Population Biology* 9: 238–259.

Johansson, S., and O. Nygren. 1991. The missing girls of China. *Population and Development Review* 17(1): 35–52.

Kumm J., K. N. Laland, and M. W. Feldman. 1994. Gene-culture coevolution and sex ratios: The effects of infanticide, sex-selective abortion, sex selection, and sex-biased parental investment on the evolution of sex ratios. *Theoretical Population Biology* 46: 249–278.

Li, N., M. W. Feldman, and S. Tuljapurkar. In press. Sex ratio at birth and son preference. *Mathematical Population Studies.*

Park, C. B., and N. H. Cho. 1995. Consequences of son preference in a low-fertility society: Imbalance of the sex ratio at birth in Korea. *Population and Development Review* 21: 59–84.

Poston, D. L., B. Gu, P. P. Liu, and T. McDaniel. 1997. Son preference and the sex ratio at birth in China: A provincial level analysis. *Social Biology* 44(1–2): 55-76.

Warren, M. A. 1985. *Gendercide.* Roman & Allanheld, New Jersey.

Yan, M. 1995. An empirical study about the effect of the marriage pattern on sex (of children) preference of women. *Population Science of China* 50: 11–16 [in Chinese].