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The Trivers–Willard hypothesis of parental investment No effect in the contemporary United States

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Abstract

The Trivers–Willard hypothesis (TWH) predicts that parents will bias their sex ratio toward sons when in good condition and toward daughters when in poor condition. Many human studies have tested the related hypothesis that parents' bias allocation of resources to existing sons and daughters according to the same principle. The present study used time diary and self-report data from the parents of 3200 children in the US to test the hypothesis that as status increases, parents will allocate more resources to sons vs. daughters. It finds no evidence that higher-status parents invest more in sons or that lower status parents invest more in daughters. This finding illustrates the specificity of situations in which the TWH effects should be expected. Only certain types of parental investment — such as protection and a bias in the sex ratio — may have been selected to vary according to parental condition. Optimal allocation of resources after the child is born, however, is achieved not by the simple bias predicted by the TWH, but by allocating resources among offspring in ways that yield the largest marginal inclusive fitness gains. © 2001 Elsevier Science Inc. All rights reserved.

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1. Introduction

In 1973, Trivers and Willard suggested that an ability to adjust the sex ratio of offspring should be favored by natural selection. The logic of their hypothesis was that (a) if there is a positive correlation between condition of the mother when pregnant and the condition of her offspring at the time of its reproduction and (b) if being in "good" condition increases male reproductive success (RS) more than female RS, then (c) mothers who bias their sex ratio toward sons when in good condition, and toward daughters when in poor condition, will have a fitness advantage (Trivers & Willard, 1973). The theory is now known as the Trivers–Willard hypothesis (TWH). The classic example is Clutton-Brock, Albon, and Guinness's (1984) research on red deer. Red deer offspring tend to inherit the rank of their mother and rank is more important to the RS of males than females. Consistent with the TWH, high ranking red deer mothers give birth to more sons while mothers of low rank give birth to fewer sons.

Trivers and Willard went on to say that sex ratio biasing is but one prediction of a more general principle. "If the model is correct, natural selection favors deviations away from 50/50 investment in the sexes, rather than deviations in sex ratios per se" (Trivers & Willard, 1973, p. 91). Thus, parents can invest more in one sex either by having more offspring of that sex or by allocating more parental effort towards individuals of that sex, or some combination therein. We make this distinction explicit by designating the manipulation of the sex ratio depending upon maternal condition, both in utero and through infanticide after birth, *sex ratio biasing* (SRB). Allocating more resources to offspring of one sex after birth depending upon condition we term *resource allocation biasing* (RAB). Although these two types of behavior are usually distinct, there is some gray area between them, such as when drastically lowering resource investment increases the risk of offspring death.

In the nonhuman animal literature, the TW effect generally refers to SRB — the RAB version of the TWH is mainly invoked among those studying humans. Among nonhuman animals, we found 62 studies investigating SRB but only 8 investigating RAB. Most published studies on SRB do show the theoretically predicted sex ratio bias — mothers in good condition tend to give birth to more sons, and vice versa for mothers in poor condition. Some studies, however, show no effect or show the opposite pattern in the sex ratio. It is difficult to draw firm conclusions for at least two reasons. First, there may be a bias towards publishing positive results in this literature (Festa-Bianchet, 1996; Maynard Smith, 1983). Second, positive results do not necessarily rule out nonadaptive explanations. Findings of a sex ratio bias consistent with the TWH may be due to the fact that sons are constitutionally weaker, and thus are more prone than daughters to die under adverse conditions, either in utero or postnatally (Clutton-Brock, 1991). To further complicate matters, "contradictory" findings are not necessarily contradictory: if maternal status correlates more positively with daughters' than sons' RS, this would reverse the prediction of the TWH.

The eight animal studies of RAB were evenly split between positive and negative results. Favoritism in resource allocation consistent with the TWH was found in wood rats (McClure, 1981), house mice (Wright, Crawford, & Anderson, 1988), hamsters (Labov, Huck, Vaswani, & Lisk, 1986), and Mongolian gerbils (Clark, Bone, & Galef, 1990), but not in cotton rats (Mattingly & McClure, 1985), pronghorn (Byers & Moodie, 1990), wood rats (Sikes, 1995), or grasshopper mice (Sikes, 1996). Even within the same species, findings have been inconsistent. McClure (1981) reported that food deprived female wood rats actively discriminated against their sons, who therefore grew more slowly than daughters. However, attempts to replicate McClure's finding using the same conditions and using either the same species (Sikes, 1995) or a related species (Sikes, 1996) both failed. It should be noted that the biasing of resources in these studies often led to the death of some offspring, highlighting the gray area between SRB and RAB.

In humans, findings on the TWH have also proved inconclusive. Turning first to SRB, the Gypsies of Hungary (Bereczkei & Dunbar, 1997) are a low ranking subpopulation in a regional hierarchy; consistent with the TWH, this population has a female-biased sex ratio at birth. In the contemporary US, Mackey and Coney (1987) reported that women married to men in the prestigious *Who's Who* registry were more likely to give birth to sons than the population in general, but this was not found for women who were members themselves, nor was it found for families in an alternative high-status registry, the *Social Register*. Using the national birth registry of Venezuela (N = 578,000), Chacon-Puignau and Jaffe (1996) documented slight increases in the percentage of sons born to higher-status mothers. However, the effect sizes were extremely small; the difference in the sex ratio between married and single mothers, for instance, was .512 vs. .508, which may be significant in a statistical sense only. Investigations of the Bari Indians of Venezuela (Zaldivar, Lizarralde, & Beckerman, 1991) showed no relationship between status and birth sex ratios or sex ratios at later ages. Finally, among the Gabbra pastoralists of Kenya, Mace (1996) found no relationship between status and the sex ratio among living children, and ostensibly therefore there was no difference between status and the sex ratio at birth.

Findings on SRB after birth are also equivocal. Cronk (1989) found that the sex ratio of Mukogodo children (ages 0–4) was female-biased, which is consistent with the TWH because Mukogodo are at the bottom of a regional hierarchy. Using the birth registry in Tennessee between 1976 and 1983 (N = 350,000), Abernathy and Yip (1990) detected a very small but statistically significant tendency for mortality rates of sons to drop to the level of daughters as parental education rose. However, using more modest sample sizes, no effect of parental status on differential survivorship was observed in 19th century Sweden (Low, 1991), in 19th century West Indies (Brittain, Morrill, & Kurl, 1988), or among the Kipsigis of Kenya (Borgerhoff Mulder, 1998). Perhaps the best-known report on the TWH in humans is Dickemann's (1979) analysis of female infanticide in historically hypergynous societies. She found that female infanticide was widespread among the upper classes of such societies because higher-class daughters had little chance to "marry up." Dickemann's results might be best interpreted as being due to proximate desires of economic improvement and desires to see offspring have an opportunity to marry, in which case the results are consistent with the TWH but probably not due to an adaptive mechanism that leads to extreme neglect or infanticide based on parental condition. Theoretical work suggests that infanticide should rarely be an adaptive strategy (Anderson & Crawford, 1993; Maynard Smith, 1980). Furthermore, the sex bias in infanticide can be the opposite of that predicted by the TWH. For instance, high-status 18th and 19th century Germans in Krummhorn were more likely to commit male infanticide, ostensibly to keep their property from being divided (Voland, Siegelkow, & Engel, 1991). Instead of a specialized TW adaptation that evolved to bias the likelihood of infanticide depending on status, these observations suggest that infanticide may have more to do with a complex set of proximate goals (economic in these cases) that sometimes happen to be consistent with TWH predictions.

Proportionately, there have been many more studies of RAB among humans than among nonhuman animals. Betzig and Turke (1986) reported that high-status Ifaluk parents were more likely to spend time with sons than daughters, and vice versa for low-status parents. Among the Mukogodo of Kenya, Cronk (1989) found that daughters were more likely to be taken in for medical attention, and perhaps were nursed longer, than sons. Similarly, among Hungarian Gypsies, daughters were breastfed longer and were schooled longer than males (Bereczkei & Dunbar, 1997). These two observations are consistent with the TWH because both populations are low ranking populations in regional hierarchies. Among the Kipsigis of Kenya, daughters of poorer families reached a higher class in school than daughters of richer families, but this Sex × Condition interaction was not observed with general treatment or with provisioning of medical services (Borgerhoff Mulder, 1998). Smith, Kish, and Crawford (1983) analyzed the wills of 1000 contemporary Canadians and found that wealthier decedents favored male kin while poorer decedents favored female kin. However, using a similar methodology, Judge and Hrdy (1992) found no evidence for a Sex × Wealth interaction among inheritance records in California between 1890 and 1984.

Of direct comparability to the present study, Gaulin and Robbins (1991) analyzed birth weight, the birth interval, whether the child was breastfed, and duration of breastfeeding as measures of investment in a representative sample of 900 contemporary US women. They used income and whether or not a father figure was present as proxies for status. Of 14 tests, five yielded statistically significant Sex × Status interactions consistent with the TWH. No test was significant in the opposite direction. This was interpreted as evidence that the TWH governs allocation of resources in contemporary US society. More recently, Freese and Powell (1999) came to the opposite conclusion. They used two measures of parental status (education and income) and several measures of parental investment in US eighth-graders (saving for education, involvement in the child's schooling, supervision of the child, knowledge of the child's friends, etc.). Out of 24 possible Sex × Status interactions, only one was statistically significant and consistent with the TWH, while three were statistically significant in the opposite direction. The size of their sample (between 8000 and 21,000 depending on the test) makes Type II errors unlikely. It is difficult to compare these two studies because different measures of parental investment were used, and only one of the two predictors (income) was the same for both. Thus, the possibility exists that the TWH mechanism acts specifically on the class of investments studied by Gaulin and Robbins (1991).

The basis for studying the TWH in industrialized societies is provided by Trivers and Willard's prediction that "the model can be applied to humans differentiated on a socioeconomic scale, as long as the RS of a male at the upper end of the scale exceeds his sister's, while that of a female at the lower end of the scale exceeds her brother's" (Trivers & Willard, 1973, p. 91). However, these assumptions are probably not met in industrialized societies. Pérusse (1993) found that male RS in Quebec did not increase with status (as measured by a composite of income, education, and occupational prestige), but it did lead to greater sexual access. This lack of connection between RS and status raises the question of whether the TW effect should be applied in industrialized societies; we think it should. It seems unlikely that natural selection would shape a mechanism that was activated only in environments where the status–RS link exists. Based upon studies of contemporary hunter–gatherer societies, it is likely that a reliable association between RS and male status existed among human ancestors (Hill, 1984; Irons, 1993). Given that a consistent link did exist, a mechanism responding to current RS would have been superfluous yet prone to errors (a cost intrinsic to any mechanism that responds to environmental calibration). Furthermore, we know that in other domains, mechanisms seem to respond to past rather than current adaptive landscapes. For instance, women with high access to resources continue to value resources in a mate (Buss, 1989; Townsend, 1989; Wiederman & Allgeier, 1992), despite the fact that these women have sufficient resources to insure their children's survival and eventual reproduction. Also, men in industrialized societies have not lost their desire for status, despite the current dissociation between status and RS. Thus, it seems likely that if status predicted RS among ancestral males, then cues that reflect high status in current environments should trigger the TW mechanism.

A less serious challenge is that TW effects may not be observed in societies that are resource-rich compared to ancestral environments. However, across time and area, the absolute level of resources probably varied considerably between ancestral groups, yet within each group, high-status males had higher RS than low-status males. Because of this, a mechanism tracking absolute inputs (e.g., calories) would be disadvantageous compared to a mechanism that tracked relative inputs (e.g., status). Therefore, it is unlikely that the absolute level of resources has an effect on the putative TW mechanism.

The purpose of this study is to assess whether parents in the contemporary US bias resources (RAB) in the way predicted by Trivers and Willard (1973). Initially, we expected to find results consistent with this hypothesis, and we looked at numerous ways in which the effect might manifest itself. Despite this effort, our results consistently showed that parents do not bias resources differentially to sons and daughters as a function of their own status or the probable status of their children.

2. Method

This study used data from the Panel Study of Income Dynamics (PSID), an ongoing longitudinal US sample survey conducted by the Survey Research Center at the University of Michigan. From March to December 1997, the Child Development Supplement to the PSID contacted 2700 families with children under 13 years of age, from which 2380 families were interviewed, an 88% response rate. The sample is demographically and geographically representative of the US as a whole except that there was an oversampling of lower income families. In all, the parents of 3563 children were interviewed to study how time, income, and parenting/teaching styles are linked to children's cognitive and behavioral development. The maximum number of children studied from one household was capped at two; in larger families these two children were randomly selected. The survey was conducted using face-to-face interviews with the primary caregiver (almost always the mother), time diaries filled out by the caregiver, and interviewer observations of caregiver–child interactions. The interviewers were professionally trained and were blind to the experimental hypotheses. Some phone interviews were necessary when participants could not meet the interviewer in person. Due to nonresponse, entry errors, nonapplicability, etc., not every variable was collected for every participant, so *n* (below) refers to the numbers of valid responses for each variable. To investigate parental investment, the present study dropped the data from 356 children who were not living with either biological parent. Thus, the working data set had information on 3207 children.

3. Predictor variables

3.1. Assays of parental condition

Parental status was operationalized as access to resources using several different measures.

3.1.1. Income

For analysis, family income (sum of both parents' income) was transformed by taking its square root because of the positive skew. A log transformation was not used because it overcorrected due to the number of incomes below US$500 (mean = US$43,606, S.D. = US$37,353, $n = 3207$).

3.1.2. Education

The highest level of education, first grade through doctorate, was highly correlated between mothers and fathers ($r = .64$, $P < .001$), so the educational levels of both parents were averaged (mean = 12.8 years of schooling, S.D. = 2.27, $n = 3173$).

3.1.3. Need for food assistance

Families were asked whether they received public assistance (ADC, AFDC, food stamps, or other public agencies) while the mother was pregnant with the child in question; 12.8% of families had received such assistance ($n = 3025$).

3.1.4. Presence of father

Mothers without a male partner presumably were at a disadvantage in the Pleistocene, so this is a plausible cue for low status and lack of resources. In the interviews, the primary caregivers reported whether the biological father lived with the child. Children living with stepparents were excluded from the analysis. Thus, this variable was used to compare children living with both biological parents vs. those children living only with single mothers. Thirty-two percent of these children lived with single mothers ($n = 2965$).

3.2. Assays of offspring condition

These variables, which may be related to the parents' perception of their children's future status, were used in a supplementary analysis (see Results).

3.2.1. Perceived popularity

Principal components analysis (PCA) was used to assess the underlying relationship among five questions parents answered about the child's quality of friendships, number of friends, and esteem among peers. The effects of status, number of siblings, and age of the child were controlled (using residuals in regression) before they were entered into the PCA. The KMO measure (an index of the adequacy of using PCA that measures how interrelated the variables are) was .654, which is "adequate" for PCA analysis (Kaiser, 1974). We used PCA to extract a single factor, explaining 43% of the variance. This factor represented an optimal weighting of the five variables (e.g., those variables correlating less with the other variables were given less weight in creating the factor). This new factor was termed "perceived popularity" and reflected the parents' appraisal of the child's popularity (mean = 0, S.D. = 1, n = 2480).

3.2.2. Test performance

Seventy-one percent of eligible children (ages 6–12) took a standardized test composed of four sections: passage comprehension, letter–word, calculation, and applied problems (mean = 100, S.D. = 15, n = 1262).

4. Dependent variables

4.1. Assays of parental investment

4.1.1. Hours per week parents participated with child

Primary caregivers completed a time diary that recorded the child's activities for one weekday and one weekend day in the same week. Much research has established the validity and reliability of data collected in this way (Juster & Stafford, 1991). These data were later coded for the amount of time during which each parent actively engaged in activities with the child. Parents were not aware that these diaries would be coded to check the amount of time they committed to their child. On average, parents spent 26 hours (sum of both parents) actively engaged with their children per week (S.D. = 17.5, n = 2619).

4.1.2. Self-reported warmth

Although affection (love, nurturance, concern) is not a material resource, it may reflect a willingness to invest more tangible resources. Parents of children aged 6 through 12 answered three questions on how often they had shown various forms of affection over the past week toward their child (praised him/her, hugged him/her, and told something positive about him/her to someone else). Because the questions were open-ended, they probably were more valid than scaled questions that could have induced a ceiling effect. We used PCA to extract one factor explaining 56% of the variance. This common denominator between the three questions we interpreted as reflecting parental feelings of warmth and affection to the child (mean = 0, S.D. = 1, n = 1727, KMO = .61).

4.1.3. Interviewer-observed warmth

Interviewers coded how the parent treated the child during the session on six variables relevant to parental warmth. Three assessments were interviewer-observed frequencies: hugs, conveying positive emotion about the child, and affection. The other three were interviewer assessments: warmth, pride in the child, and tone of voice when talking to child. These six questions were reduced to one using PCA, which explained 66% of the variance (mean = 0, S.D. = 1, $n = 2324$, KMO = .89). The correlation between interviewer-observed warmth and self-reported warmth was low but highly significant, $r = .27$, $P < .001$.

4.1.4. Likelihood that child was breastfed

Fifty-four percent of mothers indicated that they breastfed their child for at least some period of time. We analyzed this dichotomous variable using logistical regression ($n = 3189$).

4.1.5. Months breastfed

Of those mothers who breastfed, the average age at which breastfeeding stopped was 6.4 months (S.D. = 6.4 months, $n = 1418$).

4.1.6. Birth weight

In a supplementary analysis performed to replicate Gaulin & Robbins (1991), the child's birth weight was used as a measure of parental investment (mean = 7.3 lb, S.D. = 1.4 lb, $n = 3107$).

5. Control variables

The *age of the child*, *age of the mother*, and *number of siblings* had consistent effects on parental investment (all $n = 3207$). We controlled for these by entering these terms into multiple regression equations of the TWH. When nonlinearity was present, we entered squared terms (*squared age of child*, *squared age of mother*, *squared number of siblings*).

6. Analysis

The number of predictors (six) and dependent measures (six) leads to at least 36 possible different regression equations. One approach to decrease this number to six equations would be to enter every predictor, along with the child's sex, the Sex × Status interactions, and the control variables into a single regression equation for each dependent measure. For our purpose, this approach has serious problems due to the multicollinearity between the status variables. The effects (β's and *t* values) for each variable would be interpreted as the unique contribution of each predictor, and the effect of the variance that is shared between them would be invisible. It is the effect of this shared variance between the status variables that is our primary interest. To circumvent this problem and for simplicity of presentation, we have used principal components regression (Belseley, 1991) to combine the four highly correlated measures of parental status (income, education, need for food assistance, and presence of father) into one composite measure, Status, that explained 56% of the variance (mean = 0, S.D. = 1, n = 2829, KMO = .68). Status was the primary predictor in our analyses. In a supplementary analysis, these four variables were also analyzed separately to ensure that no effects were missed.

The TWH predicts a bias in investment toward daughters when parental status is low and toward sons when parental status is high, but this Sex × Status interaction need not "cross-over." We used multiple linear regressions when the dependent variable was continuous and logistical regression for *likelihood that child was breastfed*. Condition and status variables were coded (when necessary) so that they always increased with better condition, and the child's sex was coded as -0.5 for males and 0.5 for females. All predictors were centered around zero to reduce collinearity between the interactions and main effects (Cronbach, 1987), and these centered variables were then multiplied to create the interaction terms. The control variables were also centered to reduce collinearity with their squared terms. In every regression equation performed below, the variance inflation factor (VIF) was less than 2, while multicollinearity problems are usually indicated by a VIF >10 (Neter, Kutner, Nachtsehim, & Wasserman, 1996). Partial plots were used to check assumptions. An α level of .05 (two-tailed) was used for all statistical tests.

7. Results

This analysis was designed to allow any possible TW effects, however minor, to reveal themselves. Despite this, we found very little evidence consistent with the TWH. Table 1 presents regression equations for five measures of parental investment. The standardized betas (β) indicate the change in the dependent measure in standard deviation units when the predictor is increased by one standard deviation. Negative Sex × Status β coefficients indicate a bias in investment toward sons when condition is high and toward daughters when condition is low, and thus are consistent with the TWH. Contrary to TWH predictions, there were no significant Sex × Status interactions. Indeed, only two of the five interactions were in the direction consistent with the TWH. In contrast, status had consistent and relatively large positive effects on all measures of investment except for months of breastfeeding. Interestingly, the main effects of the child's sex were small and never significant. Thus, it appears that the child's sex has little effect on the degree to which parents invest in their children, at least for these measures of investment.

It is possible that the principal components regression approach may have missed relationships that existed for some specific predictors. To address this, we analyzed the four status variables separately for each measure of investment. Table 2 shows the results of the Sex × Status interactions for these 20 different regression equations. Three of the 20 Sex × Status β coefficients were statistically significant, two in the direction predicted by the TWH and one in the opposite direction. Bonferroni corrections would have eliminated the statistical significance of all interaction effects. These results give no indication of TW effects.

Table 1
Summary of simultaneous regression analyses for predictors of various measures of parental investment

Investment measure: hours per week parents participated with child ($n = 2326$)			
Predictors	*B*	S.E. *B*	β
Parent's status	3.953	0.267	.30***
Child's sex[a]	0.531	0.475	.02
Sex × Status	**0.003**	**0.242**	**.00**
Mother's age	− 0.076	0.038	− .05*
Child's age	− 1.246	0.076	− .35***
Child's age squared	0.131	0.021	.11***
$N_{siblings}$	− 0.100	0.221	− .01

Investment measure: self-report warmth for children aged 6–12 ($n = 1466$)			
Predictors	*B*	S.E. *B*	β
Parent's status	0.159	0.029	.16***
Child's sex[a]	0.028	0.051	.01
Sex × Status	**− 0.044**	**0.026**	**− .04**
Mother's age	0.007	0.004	.06
Child's age	− 0.032	0.008	− .12***
Child's age squared	− 0.009	0.002	− .10***
$N_{siblings}$	− 0.039	0.024	− .04

Investment measure: interviewer-observed warmth ($n = 2062$)			
Predictors	*B*	S.E. *B*	β
Parent's status	0.331	0.022	.33***
Child's sex[a]	− 0.003	0.040	.00
Sex × Status	**0.037**	**0.020**	**.04**
Mother's age	0.001	0.003	.01
Child's age	− 0.044	0.006	− .16***
Child's age squared	0.004	0.002	.04*
$N_{siblings}$	− 0.049	0.023	− .06*
$N_{siblings}^2$	0.017	0.008	.06*

Investment measure: months breastfed if breastfed ($n = 1262$)			
Predictors	*B*	S.E. *B*	β
Parent's status	0.115	0.199	.02
Child's sex[a]	0.043	0.358	.00
Sex × Status	**− 0.045**	**0.182**	**− .01**
Mother's age	0.117	0.026	.14***
Child's age	0.061	0.057	.03
$N_{siblings}$	0.299	0.166	.05

Investment measure: likelihood that child was breastfed[b] ($n = 2829$)			
Predictors	*B*	S.E. *B*	Odds ratio
Parent's status	0.704	0.048	2.02***
Child's sex[a]	0.065	0.081	1.07

(continued on next page)

Table 1 (*continued*)

Predictors	*B*	S.E. *B*	Odds ratio
Sex × Status	**0.038**	**0.044**	**1.04**
Mother's age	0.012	0.007	1.01
Child's age	0.121	0.039	1.13***
N_{siblings}	− 0.075	0.013	0.93***

β = standardized beta. Negative Sex × Status **β**'s and odds ratios less than 1 are consistent with the TWH. All predictors were centered to reduce collinearity with higher order terms. Squared terms were removed if not significant.

[a] Son = − 0.5, daughter = 0.5.

[b] Dichotomous variable; logistical regression was used.

* $P < .05$, two-tailed.

*** $P < .001$, two-tailed.

We also performed regression equations separately on children living with both biological parents vs. those not living with both biological parents (including those living with stepparents). *Resident male* was confounded with this partition and thus could not be analyzed. The Sex × Status interactions from both subsets were essentially equivalent to those shown in Table 2 and thus are not displayed. Another analysis (also not shown) included income and education together, thereby removing the effects of education from income and vice versa. Neither the Sex × Income interaction, the Sex × Education interaction, nor the three-way interaction was significant for any of the six measures of investment. Another analysis (not shown) repeated the 20 regression equations in Table 2 but controlled for differences in investment between families by choosing only families that had a son and a daughter ($n = 302$ families). Within each family, we subtracted the investment in the

Table 2
Summary of Status × Sex interactions consistent (yes) or not (no) with the TWH

DVs:	IVs: Measures of parental status			
Investment	Income	Education	Resident male	Food assistance
Hours per week with child	no (β = .01)	no (β = .02)	no (β = − .01)	no (β = .02)
Self-report warmth	no (β = − .04)	no (β = − .01)	yes (β = − .06)*	yes (β = − .06)*
Observed warmth	no (β = .04)	no (β = .01)	no (β = .02)	no (β = .01)
Months breastfed	no (β = .04)	no (β = .01)	no (β = .02)	no (β = − .03)
Likelihood breastfed[a]	no (OR = 1.00)	no (OR = 1.06)	no (OR = 1.04)*	no (OR = .94)

Yes = consistent (negative β or OR below 1.00, $P < .05$) with TW predictions; no = opposite of TW predictions (positive β or OR above 1.00, $P < .05$) or null findings ($P > .05$); β = standardized beta of the Status × Sex interaction from 20 separate equations regressing each status measure on each investment measure; OR = odds ratio. Terms in each regression equation were: the status measure, child sex, Sex × Status interaction (results shown), presence of stepparents, mother's age, mother's age squared, child's age, child's age squared, number of siblings, and number of siblings squared.

[a] Dichotomous variable; logistical regression was used.

* $P < .05$, two-tailed.

son from the investment in the daughter after controlling for the child's age. None of the 20 regressions were significant in a direction that supported the TWH.

In a final analysis, we considered the possibility that parents base differential investment not on their own status, but on some assessment of their children's traits that predict status. If parental status has lacked the heritability that Trivers and Willard were originally thinking of, then offspring traits may be the best cue parents have available to gauge the likely status of their offspring (L. Cronk, personal communication, April 2001). We attempted a rough test of this possibility by using two traits of the children that may correlate with child's future status: perceived popularity and test performance. The TW prediction is that sons who are perceived as popular, or who are academically gifted, would receive more investment than popular or gifted daughters (and vice versa for low scoring sons). Table 3 shows the β coefficients from six regression equations testing this possibility. The four additional possible tests predicting the two types of breastfeeding behavior were not conducted because these investment decisions were made before parents could assess the children's traits analyzed here. Once again, there was no evidence for a TW effect.

The null findings of this report are consistent with the results of Freese and Powell (1999) but contradict the positive findings reported by Gaulin and Robbins (1991). The Freese and Powell study shared only one predictor (income) and no dependent variables with the Gaulin and Robbins study. Our study examined both predictors used by Gaulin and Robbins and had in common three of the four dependent variables they used. Nonetheless, we found almost no evidence supporting the TWH. However, there were difference between the samples and analyses. Gaulin and Robbins eliminated mothers with only one child and split their sample into youngest and next-to-youngest children in order to assess the birth interval between siblings. They performed analyses on the youngest and next-to-youngest children separately (using ANOVA) even for those dependent variables that could have been analyzed using all children. They also dichotomized yearly income into "over US$60,000" and "under US$10,000" in order to "... make the effects of income maximally apparent ..." (Gaulin & Robbins, 1991, p. 64), which reduced their sample from 906 to 172 on tests using income.

Table 4 shows our attempt to replicate their analysis with our sample. We performed 10 ANOVAs after adjusting our sample as closely as possible to the ways described above.

Table 3

Summary of Sex × Offspring Trait interactions consistent (yes) or not (no) with the TWH

	IVs: Measures of offspring condition	
DVs: Investment	Perceived popularity	Test performance
Hours per week with child	no ($\beta = .01$)	no ($\beta = .04$)
Self-report warmth	no ($\beta = .01$)	no ($\beta = -.01$)
Observed warmth	no ($\beta = .01$)	no ($\beta = -.03$)

Yes = consistent (negative β, $P < .05$) with TW predictions; no = null findings (negative or positive β, $P > .05$); β = standardized beta of the Status × Sex interaction from six separate equations regressing each status measure on each investment measure. Terms in each regression equation were: the condition measure, child's sex, Sex × Condition interaction (β's shown), presence of stepparents, mother's age, mother's age squared, child's age, child's age squared, number of siblings, and number of siblings squared.

Table 4
Replication of Gaulin and Robbins (1991) and summary of Status × Sex interactions consistent (yes) or not (no) with the TWH

		IVs: Measures of parental status	
DVs: Investment	Child	Income (above US$60,000 vs. below US$10,000)	Resident male (yes−no)
Present study			
Months breastfed[a]	older	no, $F(1,200)=0.39$, ns	no, $F(1,457)=0.19$, ns
Likelihood breastfed	older	no, $F(1,399)=1.82$, ns	no, $F(1,961)=2.63$, ns
	younger	no, $F(1,403)=0.29$, ns	no, $F(1,986)=0.00$, ns
Birth weight	older	no, $F(1,395)=0.49$, ns	no, $F(1,942)=0.12$, ns
	younger	no, $F(1,391)=3.08$, ns	no, $F(1,957)=0.53$, ns
Gaulin and Robbins (1991)			
Months breastfed[a]	next-to-youngest	no, ns	yes, P=.02
Likelihood breastfed	next-to-youngest	yes, P=.01	yes, P=.02
	youngest	no, ns	no, ns
Birth weight	next-to-youngest	no, ns	no, ns
	youngest	no, ns	no, ns
Birth interval	next-to-youngest	no, ns	no, ns
	youngest	yes, P=.03	yes, P=.00

Yes = ANOVA interaction consistent ($P<.05$) with TW predictions; no = null findings ($P>.05$). Gaulin and Robbins (1991) split their data into youngest and next-to-youngest child and reported only P values, so their F values are not available. The present data were split into older vs. younger child because birth order information was unavailable. *Birth interval* could consequently not be analyzed in the present study.

[a] *Months breastfed* was not analyzed for the younger/youngest child because many were still being breastfed.

Among the 10 tests we could replicate, they observed three significant interactions in the predicted direction while we observed none. Due to our larger sample sizes and inability to replicate Gaulin and Robbins (1991) using a wide range of analytical approaches, we think that it is likely that their positive findings arose from factors unique to their sample.

Our null findings were not the result of low statistical power. Due to the large sample size, the mean power of the five tests in Table 1 for an effect size $\rho=\pm.10$ (roughly a β of .10) was .985, meaning that the average test on the interaction had only a 1.5% chance of missing a relationship in the population that explained a mere 1% of the variance in investment. The power of the tests in Tables 2 and 3 were roughly equivalent. Increasing the likely effect would of course increase the chance of its detection. In essence, if a signal existed in our data, even a very small one, it would have been detected. We conclude that the chance that the pattern of these findings was due to Type II errors is vanishingly small.

8. Discussion

These findings suggest that the TW effect does not predict parental investment in all human groups. There are three possible classes of explanations for this: (a) TW effects on parental investment are present in the US but were not found because of problems with methods, or (b) TW effects on parental investment are present among some human groups but not found in evolutionarily novel environments like the US, or (c) the TWH cannot make definitive predictions for the allocation of resources to existing offspring. We will take these in order.

One obvious interpretation of our null results is that parents' bias investments other than those that we measured, although it is unclear theoretically exactly what class of investments these should be. It is also conceivable that effects would have been found if status had been operationalized differently. Perhaps within-group status is a more ecologically valid criterion of status in humans. For instance, poor inner-city residents may not compare their income to society at large in order to judge their status. Freese and Powell (1999) compared incomes within the same schools in an attempt to address this possibility; they found no evidence for the predicted TW interactions. However, it is also possible that people of lower income simply do not use income as a status criterion whatsoever. If criteria of status differ within a society, it may be difficult to test the TWH across groups within that society.

It is also possible that TW effects are present among some humans but not found in novel evolutionarily environments like the US. One suggestion is that TW effects could have been masked in US society because our culture's egalitarian values inhibited their being reported (R. D. Alexander, personal communication, April 20, 2000). However, all of our investment measures, except possibly the warmth measures, probably had low demand characteristics. It is also possible that null results were observed because conditions in US society do not engage the mechanisms governing TW biases. In the Introduction, we tried to dispel the notion that the TW effect, if it exists, should not be observed in the US because it is too resource-rich compared to the conditions under which humans evolved. Similarly, we argued that the effect should occur even in societies where male status and RS are currently unlinked. We note that this parallels an enduring debate about whether past or present adaptive landscapes are the relevant criteria for predicting behavior (e.g., Symons, 1989; Turke, 1990). Determining whether TW effects are seen only in societies where status is associated with RS must depend upon further research. While the evidence is inconclusive, the RAB manifestations of the TW effect does seem more pronounced among nonindustrialized than among industrialized societies. With such a small sample of studies and the probability of unreported negative findings, this generalization is tenuous. Future research should compare a range of cultures using similar measures to those already collected, so that the degree to which status affects male RS within each culture can be correlated with the degree to which the TW bias is present within each culture. If these two variables are related, it could be evidenced that the TW mechanism is sensitive to cues that predict current RS.

A third type of explanation for our results is that the TWH does not, in fact, predict RAB to existing offspring. Consider the case of a sick offspring with lower fitness value to its parents than its healthy sibling. Despite the fact that the healthy offspring is more valuable to its parents, the parents should invest more resources in the sick offspring if the marginal fitness gains for doing so outweigh larger investments in its healthy sibling. In contrast, for other types of investments (for instance, which of two offspring to rescue), parents should prefer the healthier offspring because of its higher reproductive value. Applying this to the TWH, RAB should be biased toward the offspring that most improves the parents' fitness per unit invested. However, this bias has no necessary link to the fitness *value* of the offspring. Rather, it is predicted by cues related to the marginal gains of allocating each particular resource to the sex in question. The assumptions of the TWH (a higher correlation between condition and RS among males than females, and a correlation between the parent's and offspring's conditions) are unrelated to these marginal benefits, but they *are* related to the fitness value of offspring. The TWH should therefore be limited to predicting those parental investments (e.g., SRB, protection) related to fitness value.

As a simple example, consider two mothers in equally poor condition, one that has a son and one a daughter. Given the TWH assumptions, the mother with the daughter should have a fitness advantage over the mother with the son due to the different fitness values of the offspring; this is why selection favors a female-biased sex ratio for mothers in poor condition. However, the low-condition mother with the son should invest *more* in the son than the low-condition mother does in the daughter if the marginal benefit of investing additional resources is greater for sons. The bias for SRB in this case is in the opposite direction from the RAB bias.

It is worth noting that a Sex $\times$ Condition interaction in RAB may arise in certain species from factors unrelated to the assumptions of the TWH. If sons' RS benefits more from increasing allocation, and the benefits of devoting greater investment to a son outweigh other types of parental investment (such as producing additional offspring), then those able to afford the marginal costs of increasing investment (high-condition parents) should devote disproportionately more resources to sons than low-condition parents. Notice that these assumptions differ from the assumptions of the TWH. By explicitly differentiating the two hypotheses, it is clear that unlike the SRB interaction, this interaction might never exhibit crossover; low-condition parents might still invest more resources in sons than daughters. Moreover, the reason that the interaction exists is different between the two types of investments. For SRB, the interaction exists because of the fitness value differences between the sexes. For RAB, all parents might be selected to invest increasingly in sons, but only high-condition parents have the available resources to make the bias apparent.

Such reasoning implies that in species in which sons' RS is aided more by investment (such that both low- and high-status parents invest more in sons), male offspring will receive more investment than females across the population. This contradicts Fisher (1958), who predicted that there should always be equal investment between the sexes. However, Charnov (1979) demonstrated that an implicit assumption of Fisher's argument is that the investment returns between the sexes are linear. When the returns are nonlinear and differ between the sexes (i.e., when the marginal returns on investment differ between the sexes) equal allocation is not expected. Critically, differing marginal returns are a necessary consequence of the TWH assumptions, and thus it is logically inconsistent to attempt to apply Fisher's prediction at the same time as the TW effect (interested readers are directed to an excellent synthesis by Frank, 1990). It is true that frequency dependence will still be an integral part of sex allocation — just not in the 1:1 way Fisher envisioned. In polygynous species where males may be disproportionately aided by increasing investment, this bias will generally be towards greater investment in males (Maynard Smith, 1980).

We are not the first to emphasize the distinction between RAB and SRB and its implication for predictions based on the TWH. Anderson and Crawford (1993) developed a model in order to address the question: "Under what conditions do the parental behaviors that maximize numbers of grandchildren resemble the Trivers–Willard rules of thumb?" (p. 151). For the SRB, they found that optimal sex ratios are strongly influenced by existing offspring of different ages and sexes in ways not predicted by the TWH. For RAB, Anderson and Crawford concluded that the simple rules provided by the TWH were unlikely to maximize parental fitness. Their RAB model did not, however, test the interaction between condition and offspring sex; it tested whether sons should receive an overall bias in investment due to greater marginal returns. Thus, their RAB model is not directly relevant to most TW empirical tests.

In summary, we conducted a strong test that showed no evidence that parents in the US differentially invest in sons vs. daughters as a function of parental status or the child's future status. While it is possible that this finding is accounted for by some special aspect of modern Western society, we think it is more likely that the TWH does not, in fact, predict differential allocation of resources to sons vs. daughters as a function of status.

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