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THE IMPACT OF TECHNICAL CHANGE IN AGRICULTURE ON HUMAN FERTILITY: DISTRICT-LEVEL EVIDENCE FROM INDIA

Stephen A. Vosti, Julie Witcover, and Michael Lipton

Environment and Production Technology Division

International Food Policy Research Institute
1200 Seventeenth Street, N.W.
Washington, D.C. 20036-3006 U.S.A.

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ABSTRACT

Green Revolution technologies were developed and promoted to boost food supplies and foster development, both of which were expected to create "breathing space" for achieving demographic transitions in developing countries through lowered human fertility. Little comprehensive research, however, has been done on the effects of those technologies themselves on human fertility -- leaving unanswered the question of whether particular types of agricultural technologies were actually increasing, or decreasing, this demographic "breathing space." This paper uses District-level data from rural India on agricultural change (from 1961 to 1981) and changes in human fertility (from 1971 to 1981) to assess the impact of the former on the latter, with particular emphasis on high yielding (HYV) Green Revolution technologies. Modifying a conceptual framework derived from theory on the determinants of fertility, and estimating a reduced form model that explicitly accounts for endogeneity of real wage growth, we find that, while socio-cultural and demographic factors were the strongest determinants of fertility change: a) Green Revolution and related technologies did have an impact on fertility change; b) that the magnitude and direction of this impact was technology specific; and c) that the impact was only partially due to the effect of the new technologies on changes in real wage growth.

Rapid real wage growth was significantly associated with more rapid subsequent fertility decline. Even controlling for real wage growth effects explained by HYV technologies, HYV-technology-specific impacts on human fertility declines persisted: greater diffusion of both wheat and rice HYV led to faster fertility declines, while greater diffusion of bajra HYV led to smaller fertility declines. The study confirms the overwhelming importance of socio-cultural and demographic variables such as female literacy and marriage rates in determining fertility change, and finds a fertility-promoting role of high initial (1961) levels (not growth) of per capita cereal calorie production -- perhaps an indication of the low nutritional levels prevalent at that time in the sample. Policy implications are drawn, including the need to continue to develop sustainable agricultural technologies appropriate to developing areas, but with more attention paid to their human fertility consequences, so that compensating policies can be implemented, if needed.

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1. INTRODUCTION

AGRICULTURAL TECHNICAL CHANGE AND DEMOGRAPHIC TRANSITION: CONVENTIONAL WISDOM

No direct and comprehensive studies of the impact on human fertility of overall, substantial technical change in agriculture as yet exist. Since the classic analysis by the Ford Foundation (1959) of "India's food crisis and steps to meet it," however, the mission, mandate, and underlying assumptions of the International Agricultural Research Centers (IARCs) in developing countries have been rooted in a particular view of the nexus between population growth and agro-technical change. This Ford-IARC view accepted Malthus's belief that population growth eventually reaches a point of land exhaustion. Beyond that point, food supply per person cannot be maintained by

* Research Fellow, Environment and Production Technology Division, International Food Policy Research Institute, Washington, DC.

** Research Analyst, Environment and Production Technology Division, International Food Policy Research Institute, Washington, DC.

*** School of African and Asian Studies, University of Sussex, England.

expansion of land area, except with prohibitively sharp rises in the marginal cost of bringing land into cultivation. The Ford Foundation's 1959 document argued that this point would be reached in India in the early 1960s, but that technical change in agriculture could be developed and promoted to avoid (not just postpone) Malthusian outcomes. This more recent view has been dubbed "Malthusian optimism" by Sen (1981).

This paper seeks to test one key underlying assumption associated with the belief that, through yield-enhancing progress in the production of food staples, which can substantially and sustainably reduce hunger and poverty, a "breathing space" wherein a society will reduce its human fertility will be created. This assumption is that such progress does not itself increase human fertility. In particular, we examine the relationship between the spread of seed-fertilizer-water-control (hereafter called "HYV-linked") technologies, and subsequent changes in human fertility, across a sample of Districts in rural India.

Early Malthus[1] and the Ford-IARC view diverge sharply on whether higher yields of food staples would help at the point of land exhaustion. Malthus argued that (1) the scope for rapid yield-enhancing responses of food production to population growth was usually small and readily exhausted; more fundamentally, (2) extra food and income would increase fertility and hence population growth, so that the gain in the level of living would be wiped out; indeed, (3) further population growth was liable to meet

[1] Malthus (1798). Later editions, and above all Malthus (1824/1830), recognized that "extreme healthiness" could induce lower, not higher, fertility (and was itself linked to improved income and nutrition) (see Lipton, 1990).

"positive checks," especially from famines. In contrast, the Ford-IARC neo-Malthusian view was that (1) HYV-linked advances in food yields could bring about big, sustainable rises in the rate of growth of food supply; more fundamentally, (2) there would be no "positive checks" because in the long run the HYVs would help to reduce human fertility in a "demographic transition." The neo-Malthusian optimists accepted that poor people, as they enjoyed better income and nutrition, would at first not only lower their mortality but, as Malthus had feared, raise their fertility. However, the neo-Malthusian view is that, in the 10- to 20-year time-horizon, the poor would respond to better life chances (for themselves and their children) by lowering fertility by more than enough to offset reduced mortality.[2] HYVs, in other words, would fit into a context of "demographic transition" and voluntary fertility reduction, both by delayed marriage (of which Malthus approved) and by contraception (which he rejected as vicious).

Thus, on the Ford-IARC model, the HYV-centered transformation of food production would solve the problem of poverty and undernutrition:

- in the short run, by raising yields (despite the virtual ending of land expansion) more and faster than Malthus had deemed feasible and thereby reducing mass poverty;
- in the long run, by providing "breathing space" during which the reduction of mass poverty -- partly due to the HYVs themselves -- would lastingly reduce fertility, natural increase, and hence pressure on food supplies.

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[2] It is beyond the scope of this paper to explore the role of high-yielding varieties and associated technologies in mortality reduction, or the subsequent impact of lower child and infant mortality on fertility.

Both links in this chain of reasoning have been questioned. First, although food output and average income have grown fastest where HYV-linked technologies have advanced furthest (Lipton, 1989), such growth may have initially -- within the first few years until HYV adoption had diffused -- reached mainly the better off, slightly delaying the benefit to many of the poor and undernourished. And, while evidence from one Indian District suggests that, after diffusion had run its course, the poor had proportionally better income gains than other wealth groups (Hazell and Ramasamy, 1991), there may be circumstances under which the poor did not gain relatively more in terms of income. As it is the poor and undernourished whose initial fertility (and mortality) was highest, and whose well-being food constrained, these relative differences in income growth, and even a short time lag for benefits may make a difference for demographic transition. If the poor could not obtain more food and income from (or at least after) HYVs, the Ford-IARC model would not have had a chance to work, let alone to achieve the "breathing space."[3] Second, even if poor people (with high initial fertility and mortality) obtain sharply improved income and nutrition, modern theory and evidence suggest that such improvements may not affect fertility directly at all, instead operating through intervening variables to alter the incentives to have children. If so, the way in which gains in income and nutrition are realized would affect the timing, extent, and perhaps even direction of subsequent changes in fertility. Different mechanisms,

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[3] There is a life-cycle issue here. For the model to work, not only must those with currently high fertility and mortality benefit from HYVs, they must also do so early enough in their life-spans, and respond swiftly enough, for their fertility decisions to be affected (reduced) by the income and health gains from HYVs. There is much research on the effect of yield-enhancing agricultural progress on poverty and income distribution. We know of no research into its effect on their age distribution!

technologies, etc., for achieving income and nutrition gains could affect these intervening variables differently. These intervening variables fall into three main categories: demand, supply, and socio-cultural.

Demand by couples[4] for children is affected by human, emotional, and biological needs -- but also by parents' expectations about the economic costs of bearing and rearing offspring and about their subsequent income benefits from offspring's income. Costs are affected both by the direct expenditure on the child's food and by the foregone opportunities of mothers to work and earn if they are free of child care. Income benefits are affected by the expected earnings of "few but educated" children vis-ą-vis those of "many but unskilled" children -- that is, by the strength of the case for parents to "substitute quality for quantity" in setting family size norms.[5] These cost-income determinants of couples' demand for children, which include the full cost of averting births via contraception, comprise the Chicago-Columbia factor (Becker and Lewis, 1974; Schultz, 1981). This suggests that HYV technologies, in areas more affected by them, will (a) reduce fertility because -- since HYVs increase income, living standards, and the skill content of work -- the costs of child-rearing increase, as do the prospects for the educated, later-marrying children (and educated women); but (b) offsetting this, increase fertility to the extent that HYV technologies raise the demand for unskilled and

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4 This argument implies that the couple is the decision-making unit, either by agreement or by (usually male) dictatorship. Alternatively, theories of intrahousehold bargaining posit that partners may have opposing (or imperfectly congruent) ideal outcomes vis-ą-vis fertility decisions, and adversarial (or partially cooperative) strategies to reach household decisions. Such theories may imply different fertility outcomes from the "couples' demand" model (see, e.g., Rao and Greene, 1991).

5 Note that this case depends on the couple's trade-off between present and future income streams -- and hence on its capacity to defer consumption and/or to borrow (and on the rate of interest). "Unskilled"

young labor; and (c) ambiguously affect fertility as HYV technology raises the demand for women's work -- discouraging frequent pregnancies, but raising the "long-sighted" demand for girl children. In Indian conditions, we hypothesize that effect (a) will predominate (because (b) is diffused over a long period, and (c) works both ways).

children and workers earn less than "educated" ones in the long run; but at age 10-18 they earn more, and usually cost their parents less.

Couples' supply of children is affected by biological fertility, which initially increases as nutrition improves among very poor people, partly for biomedical reasons emphasized by Easterlin (1980). These supply influences comprise the "Pennsylvania factor." For the very poor, more and better food brings earlier menarche, later menopause, and a lower risk of miscarriage or stillbirth. The extreme version of such effects is that, if caloric intake is below some critical level, reproductive capacity shuts down. Above that level, but below a still very low caloric intake -- called the nutritional biomedical "sufficiency" level with regard to reproduction -- additional calories normally increase fertility, perhaps at first with increasing reproductive returns,[6] but over most of the range with a diminishing marginal increment. The Pennsylvania factor would induce higher fertility in areas more affected by HYV-linked technologies, but only as long as income (and other circumstances) induce caloric intakes between the critical level and the sufficiency level. Hence, we hypothesize that -- among the poorer Indian Districts only, that is, those below the sufficiency level -- the spread of HYV-linked technology would prompt short run fertility increases.

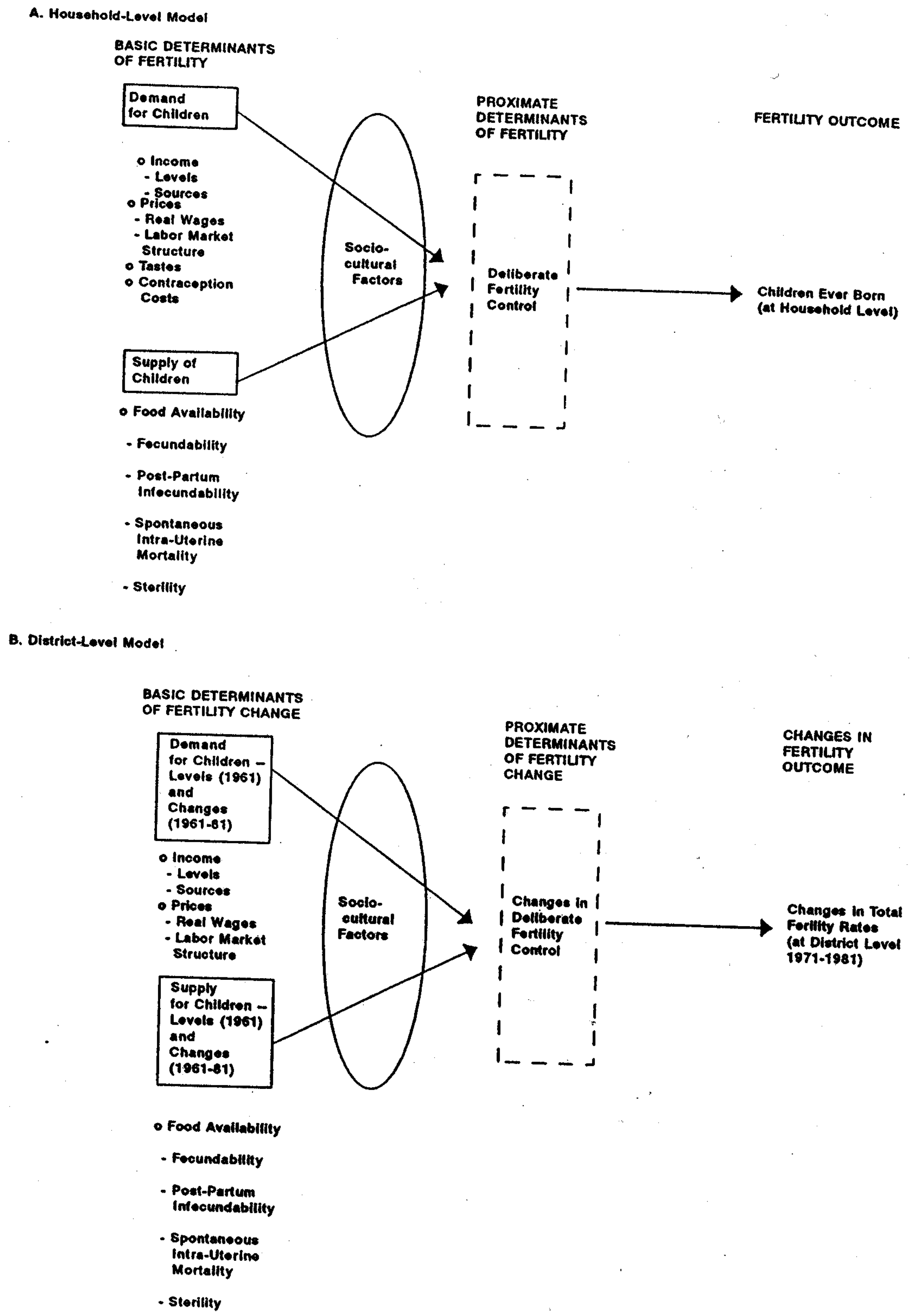
The "Easterlin synthesis" combines the biological and socioeconomic determinants of human fertility, and is largely supported by the findings of the World Fertility Survey (1984); see Easterlin and Crimmins (1985). However, the "institutional

[6] In other words, between the critical calorie cut-off, and the sufficient calorie cut-off, exists a "biological fertility curve," with portions at least shaped like a standard production function for a given input (first increasing, then decreasing returns, but always positive, over the relevant range).

factor" constitutes an important modification to this synthesis (Cain and McNicoll, 1986). For example, Cain (1981) argues that, in the absence of effective institutions to smooth consumption in the face of risk, children have an insurance value that can significantly increase fertility. More broadly, socio-cultural factors -- the religion, family and inheritance pattern, kin structure, caste and class norms regarding marriage and literacy, etc. -- surrounding a couple will affect its "demand for children," by altering the incidence of costs and incomes from them (which is caught in the Easterlin synthesis), but also -- less measurably -- by influencing "family size norms" (and attitudes towards various contraceptive methods) at any given set of costs, prices, and income streams.

In summary, modern demographic theory (Figure 1, Part A) predicts that anything that changes household food availability, opportunity costs, or income prospects will affect fertility largely via couples' (i) demand for children, and (ii) biological supply of children, both mediated by (iii) socio-cultural factors. Excluding emotional and moral impacts on parents of children, childlessness, or contraception, then, modern theory predicts as follows. From factor (i) -- parents' economic demand for children -- fertility will increase: with rises in the discounted present value of children's expected transfers (to parents) of their future incomes as surviving workers (as children, adolescents, or adults); with rises in the returns to unskilled vis-a-vis educated labor; with falls in the discounted present value of childbearing and rearing, including opportunity cost of, access to, and use of contraception. From factor (ii) -- biological supply of children -- fertility will increase as potential mothers' caloric intake (relative to requirements) increases between the critical and the sufficiency levels; rising household income, as a cause of such increases for the very poor, is mediated largely by maternal health, nutrition, and hygiene. In empirical studies, factors (i) and (ii) typically account for 30-40% of inter-household variance in fertility indicators. The remaining 60-70% of the variance among households is presumably explained by factor (iii): socio-cultural (including individual psychological and emotional) factors affecting attitudes toward fertility, contraception, and the intrinsic worth of larger or smaller families.

Figure 1



Derived from Easterlin and Crimmins, 1985, p. 13. The Fertility Revolution.

HYV TECHNOLOGIES: POTENTIAL AVENUES FOR FERTILITY IMPACT

HYV-linked technologies -- as they change income, income sources, real wages, labor demand patterns, and food availability, can well affect factors (i) through (iii), and consequently alter human fertility. As for factor (i), HYVs can raise overall household income, and also increase real wages to working children and adolescents (and to labor overall). This at first raises incentives to fertility, but also -- by raising opportunity-cost of child care for potentially working women, and, more directly, by increasing the skill levels of production -- leads parents to prefer fewer but better-educated children, on or off the farm (Becker and Lewis, 1974).[7] Still with factor (i), but on the cost side, HYV-based rises in agriculturists' family income, by reducing child mortality, should lower the expected (average) cost of producing a child that survives to adulthood.

[7] HYVs can also influence wage rates and demand for labor indirectly. The elasticity of the employment per hectare, with respect to growth in yields due to HYV-linked technology, had fallen from about 0.4 in the early 1970s to about 0.1 in the mid-1980s, for both rice (Jayasuriya and Shand, 1986) and for wheat (Bhalla, 1987). This is because the manner in which HYVs have spread (not their direct economics) has, via mechanization, tended to reduce the extent to which HYV-linked technology raises the demand for adolescent labor, and to increase the demand for skilled relative to unskilled labor. Both trends are fertility reducing.

As for factor (ii), insofar as HYVs provide extra food to those whose fertility behavior had been food-constrained, they initially remove biological, health-nutrition constraints upon the number of live births, raising the "supply curve" of children and thus total fertility. However, health-nutrition improvements can also lower the "demand curve" for children. As parents come to rely on being able to produce (relative to the number of conceptions) more -- and healthier -- children who survive to adulthood, couples may choose voluntarily to restrict conceptions, therefore lowering total fertility.[8]

Factor (iii) may also be affected. HYVs are likely to be associated with a transition to market-mediated, impersonal transactions, and that transition tends to be accompanied by changes in family and social structure. These changes, in turn, may well affect fertility decisions, generally by reducing family size norms.

These complex effects are far from the earlier, automatic assumptions that HYVs would necessarily accompany, and probably accelerate, transition to lower fertility rates. They suggest that HYVs could exert an initial upward effect on fertility (through a hypothesized rise in demand for labor), especially in extremely poor areas, where undernutrition may have constrained fertility previously. The initial upward effect would be followed by a fertility decline, as reductions in child mortality, rising demand for parental (and for skilled relative to unskilled) labor, and rising "living standards" and

[8] Medically, this is a virtuous circle, because high-order siblings run sharply increased risks of child mortality, so that smaller family size norms induce lower child mortality as well as being induced by it.

therefore child-rearing costs, together altered couples' assessment of the net economic advantages of extra children.

Still, because of the manner in which HYV-linked technologies were implemented, "priors" regarding particularly the timing and extent, but also the direction and level, of an HYV-linked effect on fertility under specific conditions are highly speculative. Particular technologies were phased in at different times and to varying extents in different geographical areas; they therefore, taken separately or together, had different effects on local labor demand, income, and food availability. To isolate such effects requires controlling for the agricultural, and socio-cultural and demographic situations of rural households at the onset of HYV-linked technological change, and also for concurrent agricultural change not explicitly linked to HYV technologies (such as mechanization, area expansion, changes in crop mix, etc.).

In the absence of comprehensive studies of this kind, we can look to a small number of studies of how rural projects, for example, in irrigation or electrification, affect fertility (Stoeckel and Jain, 1986; Oberai, 1992, especially pages 98-131; and to some extent Schutjer and Stokes, 1984) for some hints on what to expect. The results of these studies tend to be in line with the "Easterlin synthesis," and our expectations. Where fertility is measured shortly after a project begins to operate -- within 2-3 years of start-up -- there is a short-run increase in live birth-rates, perhaps because higher incomes bring improved maternal nutrition and thus a lower proportion of miscarriages and stillbirths, and/or because couples see better earnings prospects for children. However, if fertility is measured over a longer run (several years after project start-up), it usually falls below pre-project levels, for two reasons. First, higher family incomes -- and better prospects for children to find more skilled work as the project area develops -- lead couples to spend on fewer but better-educated children. Second, in some cases, project-based development improves mothers' employment prospects (and perhaps even returns to their further training or education), raising the opportunity cost of their time, which again reduces desired fertility. A village-level pilot study (Basu, Raghu, and Nikhil, 1979) lends some support to the Cain-McNicoll hypothesis that community-level factors intervene between these individual preferences and fertility behaviors, thus modifying the "Easterlin" outcomes.

Although the signs of the variables linking project impact to fertility are plausible given the leading hypotheses of modern economic demography, the indicators of the sizes of the effects (betas, R^2s, sometimes t-statistics, etc.) are, on the whole, unconvincing and small, for three reasons. (a) First, a single project, even a substantial irrigation or electrification investment, often provides only a small "prod" to household incentives affecting fertility, as compared with other changing influences on fertility via new options for production, employment, or education-health-nutrition. (b) Second, such project impact is normally in a rather small area, whereas choices affecting fertility (including migration) take place over a wider area. (c) Third, most studies of fertility effect are carried out within five years of project construction and start-up; even that is probably too little time to isolate many fertility effects (because of time-lags in responses), or to observe them (because vital events per year are generally few, even relative to quite large sample sizes).

FILLING RESEARCH GAPS: A DISTRICT-LEVEL MODEL

This study meets points (a)-(c) by looking at: (a) the fertility effects of not a project, but a great agricultural transformation, viz., the seed-water-fertilizer changes associated -- to very different extents in different parts of India -- with the "green revolution"; (b) differences in impact on fertility, not within a small project area, but among well over one hundred Indian rural Districts, typically large areas of 2-3 million people;[9] and (c) a ten-year period of fertility change, 1971-81, covering responses to a fifteen-year period of (regionally specific) agricultural transformation, 1965-80, and a prior four-year base period of agricultural activities, 1960-64. A District-level approach has the additional benefit for policy research of coinciding with administrative boundaries (that is, to some extent, distinct areas for possible policy responses to the research), yet also of having some degree of internal homogeneity. Further, our data reveal that aggregation to a larger administrative level, the State, would "wash out" variations from District to District in characteristics critical to the specification of agricultural growth patterns and their role in subsequent fertility change.

As noted above, Part A of Figure 1 depicts an implicitly cross-sectional, household-level view of fertility determinants. This study, in contrast, focuses on a

[9] The sample contains 14 of 23 Districts in Andhra Pradesh, 16 of 18 Districts in Gujarat, 1 of 8 Districts in Haryana, all 43 Districts in Madhya Pradesh, 25 of 26 Districts in Maharashtra, all 19 Districts in Karnataka, 4 of 12 Districts in the Punjab, and 9 of 13 Districts in Tamil Nadu. The representativeness of the sample is discussed, and the descriptive statistics for variables included in the study presented, in a later section. A list of included Districts is available from the authors.

modified, District-level conceptual model, depicted in Part B of Figure 1 -- that is, the analysis takes place not at the level of the household, but at District level, where District data are (large) aggregates of household (and farm and other) data. Note also that, instead of focusing on fertility and its determinants, this study's modified model focuses on fertility change and its determinants. Part B of Figure 1 reflects our view that the basic determinants of fertility change will be changes in, and levels of, the basic determinants of fertility. For example, a change in demand for children due to a change in income could result in change in fertility behavior -- but that effect may well depend upon starting income level, and/or be mediated by socio-cultural factors.

This District-level approach does have disadvantages: lost is any ability to scrutinize how within-District variation in key variables affects fertility outcomes. We address such concerns as much as possible by incorporating into our model socio-cultural and demographic control variables for characteristics thought relevant to fertility decisions, which, while measured at District level, reflect within-District differences: for example, changes in prevalence of cultivators,[10] in scheduled tribes within the District population, and in female age-specific literacy rates and marriage rates.[11] Data

[10] Our measure of cultivators is based on Indian demographic data that classify households according to whether labor or farm operations is the main income source. Krishnaji (1989) goes into the difficulties of pinpointing prevalence of landlessness using these data, and notes the lack of fertility statistics specific to each labor category. He suggests that the size and structure of landless households indicate that their patterns of mortality, and perhaps fertility, differ from those of cultivators.

[11] Migration, especially of rural females, both within and across Districts, could in principle be significant for fertility rates. However, an examination of migration patterns for 1981, and of the State of Karnataka in particular, revealed that most rural female migration (77%, in Karnataka's case) occurs within Districts, and most of the remainder (a further 16%, in Karnataka's case) occurs within States. Thus the fact that this study does not control for inter-State migration is not seen to be a serious flaw (Lipton and Vosti, 1991). Moreover, most intra-District female migration stems from marriage. To the extent that these patterns (and

unavailability makes within-District variation in the agricultural and technical change characteristics (both those measured, and those not, for example, farm size) under study impossible to gauge.

Using the District-level model in Figure 1 Part B, this study empirically estimates the impact of levels and changes in critical components of District-level demand for children (crop-derived incomes and rural real wages), and one important component of the biological supply of children (District-level caloric production from major staples) variables on District-level fertility change. Subsequently, we assess the impact of HYV-technologies on these demand for and supply of children variables. Finally, we estimate the effects of HYV-technologies on fertility change via these intervening variables, and net of them.[12]

To begin with, Section 2 presents evidence on the substantial, but regionally variable, decline in human fertility in India, and in our sample Districts, between 1971 and 1981. Section 3 briefly reports findings on the speed, nature, and regional variability of agricultural change in India, and in our sample Districts, in 1960/61-1980/81, with special emphasis on real wages, crop-derived income, and caloric production from major

male migration patterns) vary significantly and in a way that affects fertility from District to District, this study cannot account for them.

[12] Our study variables cannot fully capture the demand for and supply of children as described by theory, because (a) no data were available for critical factors such as opportunity cost of time for women, and (b) market imperfections -- in real wages and elsewhere -- may mean that the demand for and supply of children variables used do not fully reflect changes associated with HYV-related technologies. We therefore expect particular HYV-linked technologies, even controlling for our demand for and supply of children variables, to affect fertility change, and test for this.

staples. In both these sections, we review the representativeness of our sample (which had to exclude some States, as well as some Districts for States within the sample, for want of data). Section 4 uses multiple regression analysis to trace any evidence for direct effects on fertility transition, as predicted by theory, of variables measuring changes likely to alter: factor (i), viz., parents' expected economic gains and losses from children; factor (ii), viz., biological supply of children; or factor (iii), viz., socio-cultural factors. Section 5 tests for the role played by HYV-related technological change and mechanization in influencing one major determinant of fertility change -- real wage growth. In addition, Section 5 includes a test for the extent to which HYV-linked technologies influenced fertility transition via change in real wages, as opposed to through other, non-price paths. Section 6 concludes the paper with a discussion of results and their policy implications.

2. CHANGES IN HUMAN FERTILITY IN INDIA—1971-1981

By any measure, aggregate human fertility in India has dropped dramatically since the 1970s (Rele, 1987).[13] Figures 2a and 2b depict the frequency distributions of declines (in absolute and proportional terms, respectively) in total fertility rate (a measure of lifetime female fertility,[14] hereafter called "TFR") for the 131 Districts[15] making up our sample.[16] Note that, on average, sample Districts saw a 20% <u>decline</u> in TFR over the 1971 to 1981 period, but ranging widely, from 1% to 38% (see Figure 2b).

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[13] State-level evidence suggests that fertility began to decline in India in the middle to late 1960s or early 1970s (Rele, 1987), but that there was substantial variation across States in the timing and the swiftness of these declines (Bhat, et al., 1984). Owing to the need to rely on 1971 Census data, we began our coverage of fertility in India in 1970/71. While we may have missed some initial total fertility rate (TFR) declines because of this truncation, we believe we have captured most of them -- certainly those related to the agricultural "green revolution" that occurred between 1965 and 1980.

[14] Average number of children that would be born to a woman if she were to follow the contemporaneous fertility pattern throughout her reproductive span (ages 15-49 years), and live to achieve it. (See Shryock, et al., 1976, Ch. 16.)

[15] We began with all Districts with the necessary demographic and agricultural information, approximately 180 Districts. Shifts in administrative boundaries over time for some Districts resulted in the incompatibility of the fertility series (based on all years, 1961 District boundaries) and the agricultural series (1981 boundaries). Also, the impossibility of "weeding out" effects and determinants of the boundary shift itself (and the timing of the shift) for the agricultural and fertility questions under scrutiny here, made these Districts unwieldy to study. This reduced the sample to 131 Districts, in Andhra Pradesh, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Punjab, and Tamil Nadu only. (See Table 1 for the distribution of sample Districts across sample States.) We estimated the potential selectivity bias associated with the restriction of analysis to this generally western Indian sample (Vosti and Lipton, 1991, section (V)). Population change was not linked to shifts in District boundaries, but some forms of agricultural change may have been. In the tables throughout this section of the text, we assess the representativeness of the sample for the purposes at hand. In any event, the study results apply to several hundred million individuals in sample Districts, and allow us to explore the extent to and manner in which their fertility patterns were affected by agricultural change.

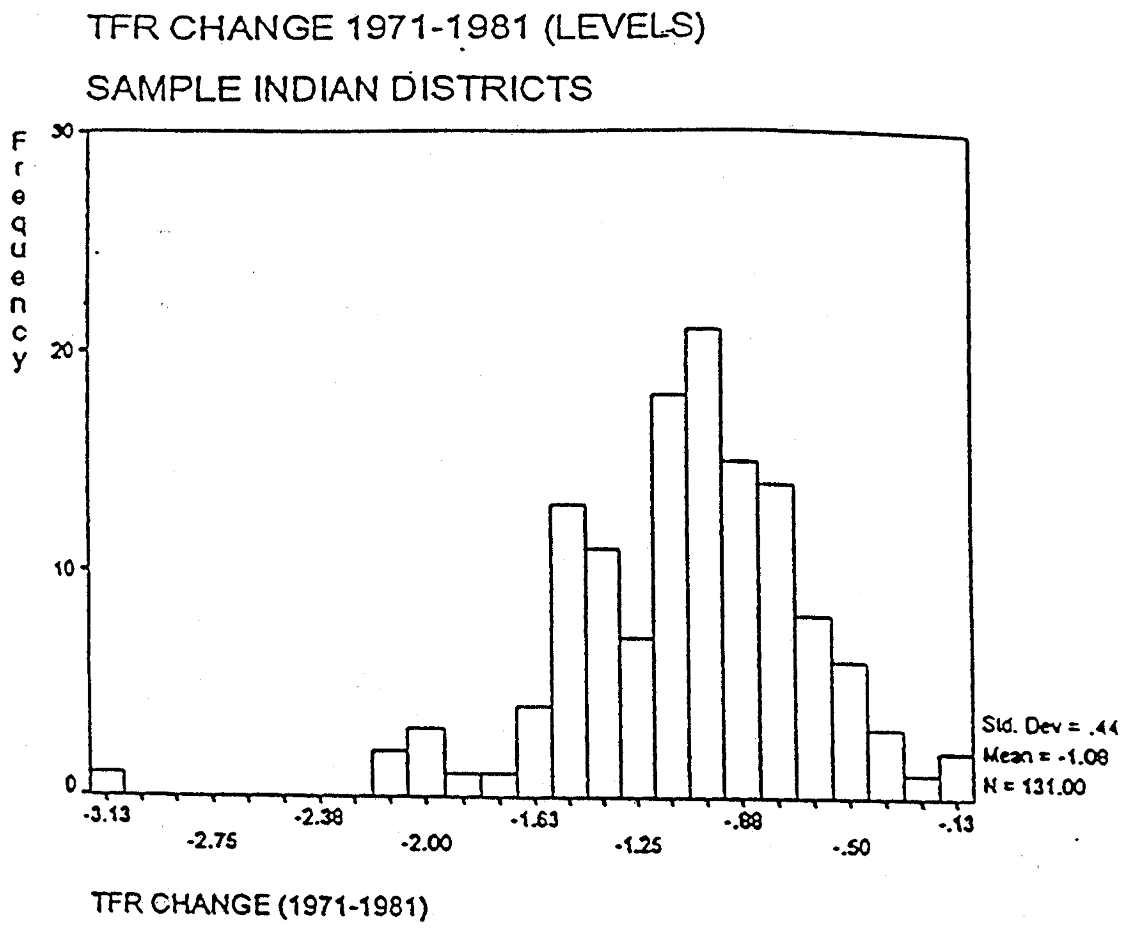
[16] For discussion of the estimation of fertility, see Shryock, et al., 1976. For details of our estimation of District-level TFR, see Vosti and Lipton, 1991. Specifically:

$TFR_t = 5\ \Sigma_5 f_{as} * ({}_5N^o\ (t)/\Sigma(({}_5W_a(t)\ {}_5f_{as}(t) * 5Lo/lo_s) * 5))$;

where ${}_5f_{as}$ are State-level age-specific fertility rates; ${}_5N^o$ is the number of children aged 0-5 years in the District; (t) is 1971 or 1981; ${}_5W_a$ is the number of women per child-bearing (5-year) age group in the District; and $5Lo/lo_s$ is State-level child "survivability," thus incorporating child mortality. Child survival rates were computed in turn from 1981 Census data, and, for 1971, extrapolated from State-level estimates of age 2 child mortality rates from a 1972 Fertility Survey (Bhat, et al., 1984) (U.N. 1983), giving survival probabilities up to age 5 for each State, using the formula:

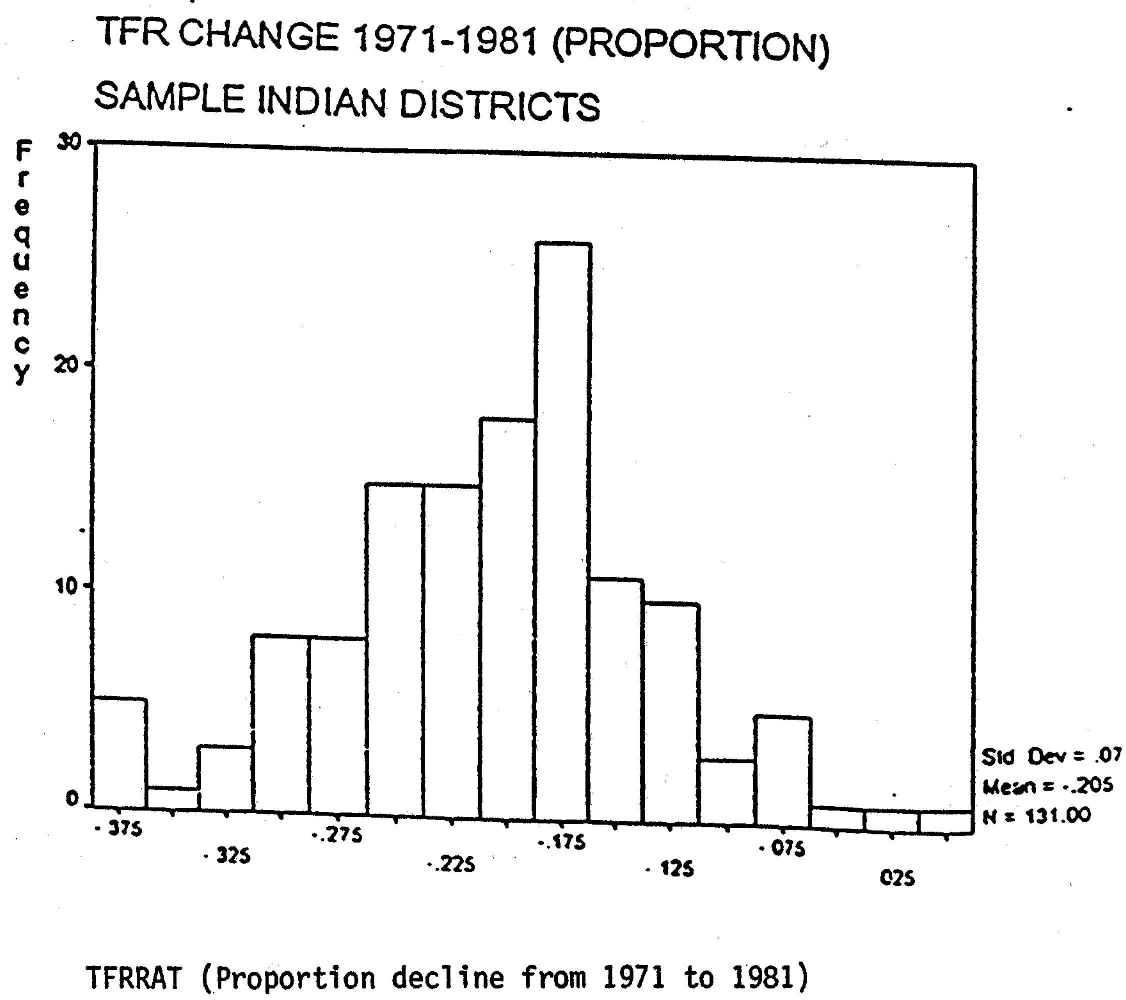
$5Lo/lo_s = 0.2 + 1.3 * p(1) + p(2) + p(3) + p(4) + 0.5 * p(5)$; where p(1) is the State-level probability of surviving to age 1, p(2) to age 2, etc.

Figure 2A



TFR CHANGE 1971-1981 (LEVELS)
SAMPLE INDIAN DISTRICTS
Frequency
30
20
10
0
-3.13
-2.75
-2.38
-2.00
-1.63
-1.25
-.88
-.50
-.13
Std. Dev = .44
Mean = -1.08
N = 131.00
TFR CHANGE (1971-1981)

Figure 2B


TFR CHANGE 1971-1981 (PROPORTION)
SAMPLE INDIAN DISTRICTS
Frequency
30
20
10
0
-.375
-.325
-.275
-.225
-.175
-.125
-.075
025
Std Dev = .07
Mean = -.205
N = 131.00
TFRRAT (Proportion decline from 1971 to 1981)

Estimated TFRs of sample Districts were generally in line with the State-level estimates of TFRs derived from generally more reliable (Sample Registration Survey) data (see Table 1). Perhaps more importantly for this study focusing on change in fertility patterns, the average TFR declines estimated for sample Districts are in line with State-level figures (Table 1, columns 10 and 11).[17]

3. AGRICULTURAL CHANGE AT DISTRICT LEVEL IN INDIA – 1960/61-1980/81

This section reviews trends in agricultural change for sample Districts, as against State and national trends, with special attention paid to HYV-linked technical change and other agricultural change that may affect fertility outcomes.

Virtually every characteristic of agricultural production underwent substantial change between 1960/61 and 1980/81, at all-India, sample State, and sample District

[17] While, at the all-India level, TFR declined (in absolute terms) substantially less (0.6 children) than it did for sample Districts on average (1.1 children), this difference, which could suggest more of a demographic transition in the sample than was occurring country wide, could be misleading: while the all-India figure applies to one geographic area, the all-India "aggregation" averages District-level figures, not compensating for District-level differences in population or geographic area. The mode of calculation for District-level TFR made generation of an aggregate TFR comparable to the all-India figure untenable.

Table 1--Rural total fertility rates (TFRs): Census, 1971, 1981; District sample, 1971, 1981

Area	1971 and 1981 Number of Districts		1971[a]			1981			1971-81 Absolute decline in:		
	In Sample	In Area	Area TFR	Sample TFR District		Area TFR	Sample TFR District		Area TFR	Sample TFR District	
				Mean	Range		Mean	Range		Mean	Range
Andhra Pradesh	14	23	4.8	4.7	4.3-5.4	4.2	3.8	3.4-4.3	0.6	0.9	0.4-1.3
Gujarat	16	18	6.0	5.4	4.8-5.9	4.6	3.8	3.3-4.5	1.4	1.6	0.9-2.2
Haryana	1	8	7.0	6.0		5.3	4.6		1.7	1.4	
Karnataka	19	19	4.5	4.9	4.2-5.4	3.8	4.0	3.2-4.5	0.7	0.9	0.4-1.5
Madhya Pradesh	43	43	6.2	6.0	5.0-8.3	5.5	4.9	3.5-5.8	0.7	1.1	0.1-3.2
Maharashtra	25	26	4.8	5.0	3.8-5.4	4.0	3.9	3.1-4.4	0.8	1.1	0.5-1.5
Punjab	4	12	5.7	5.3	5.0-5.6	4.1	3.9	3.5-4.3	1.6	1.4	1.1-1.6
Tamil Nadu	9	13	4.4	4.4	3.2-4.4	3.7	3.3	2.3-3.8	0.7	0.7	0.5-0.9
All India	131	380	5.4	5.3	3.2-8.3	4.8	4.2	2.3-5.8	0.6	1.1	0.1-3.2

Sources: *Census of India*, 1971, 1981. Registrar General of India, New Delhi.
Sample Registration Bulletin. Registrar General of India, (New Delhi: 1988).
S. A. Vosti and M. Lipton, "Population Change in the Wake of Agricultural Improvement: A District-Level Analysis of India, 1961-81. Final report submitted to the Population Sciences Division of the Rockefeller Foundation (International Food Policy Research Institute, Washington, DC, 1991).
a. State-Level TFRs are based on State-Level Sample Registration System (SRS) Age-Specific Fertility Rates (ASFRS), from 1972; sample TFRs for Districts weight 1972 State-Level ASFRs using 1971 census population data.

levels.[18] Within our sample, moreover, Districts varied greatly in many agro-technical indicators.[19] This section's Tables report levels of and changes in: a) land use, b) crop mix and yields for major crops, c) labor use, and d) technology use for our sample of 131 Districts, the States they fall in, and all-India.[20]

Table 2 highlights some land-use indicators of the agricultural intensification across India in 1960/61-1980/81. Gross cropped area (GCA) per rural inhabitant declined at annual rates of 1.1% for all-India, and roughly 1.3% for sample Districts and sample States. The ratio of net to gross cropped area declined (indicating intensifying land use) at 0.35% per annum for all-India; our sample Districts intensified more gradually, at 0.17%.[21] Irrigated area, however, grew at about 2.4% per annum for sample Districts, sample States, and all-India.

Table 3 presents sample District, sample State, and all-India data for crop mix and yields for major crops. Both wheat and rice were less important to, that is,

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[18] Unless otherwise noted, all point estimates of agricultural change in this section's Tables are three-year averages, centered on the year indicated. This reduces the impact of short-term climatic shocks. See Bhalla and Tyagi, 1989, for a geographically comprehensive review of agricultural change at District level.

[19] As noted above, this section's Tables display sample District statistics aggregated over the entire sample geographic area.

[20] Where possible, the Tables include data for the sample endpoint years, and also for 1950/1 and 1987/8, for sample Districts, sample States, and all-India, to place the sample in geographical and temporal perspective. Representativeness only of relevant characteristics (usually those associated with agricultural change) is discussed.

[21] Sample states intensified at 0.25%, more quickly than sample Districts, but less quickly than all-India.

Table 2--Land use data[*]: India, sample States, and sample districts 1950-1/1987-8

	1950-1		1960-1			1950-1/1960-1 Compound growth (Percent per Year)		1980-1			1960-1/1980-1 Compound growth (Percent per Year)			1987-8	
	Sample States	India	Sample Districts	Sample States	India	Sample States	India	Sample Districts	Sample States	India	Sample Districts	Sample States	India	Sample States	India
GCA/RURPOP[a] (hectares per person)	0.55	0.44	0.55	0.55	0.43	0	-0.23	0.42	0.42	0.34	-1.3	-1.3	-1.1	-	-
NCA/GCA (%)[b]	92.7	89.4	91.5	90.0	87.0	-0.30	-0.27	88.5	85.6	81.1	-0.17	-0.25	-0.35	84.2	79.1
GIA/GCA (%)[c]	12.8	15.7	12.6	16.7	18.1	2.66	1.42	20.3	27.5	29.0	2.38	2.49	2.36	30.0	32.4

Sources: *Indian Agricultural Statistics*, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi. Various issues.
Area and Production of Principal Crops in India, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi. Various issues.
Census of India 1951, 1961, 1981, Registrar General of India, New Delhi. (1951 figures from *Indian Agriculture in Brief*, 3rd edition; 1961 figures in computer-readable form from Reeve Vanneman.)

[*] Data are 3-year averages centered on year at column head unless otherwise indicated.
[a] GCA is gross cropped area (has.). Rural population is from census years (1951, 1961, 1981) only (not 3-year average).
[b] NCA is net cropped area.
[c] GIA is gross irrigated area.

Table 3--Crop Mix and yield*: India, sample states, and sample districts 1950-1/1970-1

	1950-1		1960-1			1970-1		
	Sample States	India	Sample Districts	Sample States	India	Sample Districts	Sample States	India
GCA (million hectares)	2.8	131.7	72.8	86.9	153.7	76.8	91.6	164.4
Crop Mix								
Percent rice	14.4	22.5	14.6	15.0	22.2	14.6	15.3	22.8
Percent wheat	6.7	7.3	7.4	8.1	8.6	7.9	9.4	11.0
Percent jowar	18.3	11.8	20.6	18.5	11.8	18.3	16.6	10.4
Percent bajra	5.8	6.8	6.5	6.7	7.3	7.1	7.1	7.6
Percent pulses[a]	15.4	15.9	8.2	14.3	15.9	8.0	13.0	13.7
Percent oilseeds[b]	10.1	8.2	9.3	11.8	8.6	9.2	11.7	9.7
	1951-2							
Yield (kilograms per hectare)								
Rice	788.8	707.1	1073.6	1061.5	961.6	1231.4	1359.7	1132.0
Wheat	621.8	682.3	653.6	759.9	816.1	984.2	1373.2	1343.3
Jowar	386.6	385.0	496.0	426.5	457.1	480.9	465.3	463.4
Bajra	291.3	278.2	330.1	334.6	329.2	529.8	634.5	536.8
Pulses[a]	523.2	602.0	425.7	443.5	495.7	449.0	434.0	512.6
Oilseeds[b]	504.9	444.6	663.6	510.0	527.0	724.2	626.0	552.2

Sources: *Indian Agricultural Statistics*, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi. Various issues.
Area and Production of Principal Crops in India, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi. Various issues.

* Data are 3-year averages centered on year at column head unless otherwise indicated.

[a] Sample District figures exclude tur; data for 1950-1 and 1951-2 refer to gram and tur only.

[b] Data refer to 9 main oilseeds, except 1950-1 data, which refer to 5 oilseeds (groundnut, castor, sesamum, rapeseed and mustard, linseed), and Sample District data, which refer to groundnut, rapeseed and mustard, and sesamum only.

(continued)

Table 3 (cont'd)--Crop mix and yield[*]: India, sample States, and sample Districts 1980-1/1987-8

	1980-1			1987-8		Increase 1960/61 to 1980/81 (for Crop Mix, change in % GCA)		
	Sample Districts	Sample States	India	Sample States	India	Sample Districts	Sample States	India
GCA (million hectares)	79.0	94.8	173.1	96.3	176.2	8.5%	9.1%	12.6%
Crop Mix								
Percent rice	15.4	16.7	23.2	16.6	23.0	0.8	1.7	1.0
Percent wheat	8.1	10.3	12.8	10.3	13.3	0.7	2.2	4.2
Percent jowar	18.0	15.5	9.5	14.5	8.9	-2.6	-3.0	-2.3
Percent bajra	5.7	5.8	6.6	5.2	6.1	-0.8	-0.9	-0.7
Percent pulses[a]	12.5	13.5	13.2	13.6	12.8	4.3	-0.8	-2.7
Percent oilseeds[b]	7.8	11.8	10.3	13.9	11.0	-1.5	0	1.7
1951-2								
Yield (kilograms per hectare)								
Rice	1437.6	1584.2	1239.3	1855.1	1541.6	33.9%	49.2%	28.9%
Wheat	1093.7	1728.3	1585.6	2233.1	2053.3	67.3%	127.4%	94.3%
Jowar	722.2	724.7	695.0	702.0	682.2	45.6%	69.9%	52.0%
Bajra	643.2	637.9	433.8	604.8	485.1	94.9%	90.6%	31.8%
Pulses[a]	301.8	390.7	446.9	483.1	536.5	-29.1%	-11.9%	-9.8%
Oilseeds[b]	778.4	652.8	562.8	705.9	689.4	17.3%	28.0%	6.8%

Sources: *Indian Agricultural Statistics*, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi. Various issues.
Area and Production of Principal Crops in India, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi. Various issues.

[*] Data are 3-year averages centered on year at column head unless otherwise indicated.

[a] Sample District figures exclude tur; data for 1950-1 and 1951-2 refer to gram and tur only.

[b] Data refer to 9 main oilseeds, except 1950-1 data, which refer to 5 oilseeds (groundnut, castor, sesamum, rapeseed and mustard, linseed), and Sample District data, which refer to groundnut, rapeseed and mustard, and sesamum only.

and pulses, the changes in crop mix over the study period were fairly uniform at all levels. Wheat increased from 8.6% of GCA in 1960/1 to 12.8% in 1980/81 for all-India, and from 8.1% to 10.3% in sample States, but grew from 7.4% to only 8.1% in sample Districts. Pulses shrank as a percentage of all-India and sample State GCA, while increasing from a relatively small proportion of GCA in sample Districts.

The second half of Table 3 shows average yield figures for six major crops (which benefited from HYV technology to different degrees, and at different times) and percentage change in yields over the study period, revealing large yield gains. Wheat topped the list, with a 94% gain in yield for all-India. Wheat yield gains across sample Districts were more modest, at 67%, but, once again sample Districts were not representative of sample States, where wheat yields jumped 127%. Pulse yields declined over the same period -- nearly 10% at an all-India level and 12% for sample States, as compared with 29% for sample Districts. Sample Districts did not represent the all-India scenario for bajra (millet) yields, either (but were more in line with sample States): sample Districts posted a 95% increase in bajra yield, sample States, 91%, and all-India, only 32%. Finally, the timing of yield changes was crop specific, with increases in wheat and rice occurring during the 1960s and 1970s, and improvements in jowar (sorghum) yields coming somewhat later.

Table 4 reports trends in labor use: composition of the rural labor force, gross cropped area per farm laborer, and real wages for rural agricultural laborers. Cultivators as a proportion of total farm labor declined over time, with the trend among sample Districts similar to that seen in sample States and nationwide.

Table 4--Labor use data[*]: India, sample states, and sample districts 1960-1/1980-1

	1960-1			1980-1			1960-1/1980-1 Compound growth (%yr)		
	Sample Districts	Sample States	India	Sample Districts	Sample States	India	Sample Districts	Sample States	India
Cultivator/ Farm Labor[a]	0.72	0.72	0.76	0.59	0.58	0.63	-1.00	-1.08	-0.94
GCA/Farm Labor (ha/person)[a]	1.34	1.35	1.20	1.25	1.26	1.21	-0.35	-0.35	0.04
Ag Workforce/ Total Workforce[a]	0.81	0.80	0.79	0.82	0.82	0.81	0.06	0.12	0.13
Real Wages[b] (agricultural labor) (1960-1 Rupees/ day)	1.34	1.58	-	1.56	1.58	1.56	0.76	0	-

Sources: *Indian Agricultural Statistics*, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi. Various issues.
Area and Production of Principal Crops in India, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi. Various issues.
Census of India 1961, 1981, Registrar General of India, New Delhi.
Agricultural Wages in India, Directorate of Economics and Statistics, Ministry of Agriculture, New Delhi. Various issues.
India, Ministry of Home Affairs, Department of Labour and Employment. August 1960-August 1969. *Indian Labour Journal*, New Delhi.

[*] Data are 3-year averages centered on year at column head unless otherwise indicated.

[a] Population data based on Census year data (1961-1981) only.

[b] Real wages for Sample States and all India are weighted averages of component States' real wages, with weights being the State's share of the total area's agricultural labor force. For Sample States, 1960-1 data are based on a 2-year average of 1959-60, and 1960-1. For Sample Districts, wage is weighted to reflect seasonal differences in labor use (by State). Where Consumer Price Index (CPI) for Agricultural Labor for some States was missing (1960-1), adjacent States' CPI with similar CPI trends and levels were substituted.

Although population density (per GCA) increased at all levels (as seen in Table 2, above), labor intensity increased only in sample Districts and sample States (where area under plow per farm laborer shrank, while rising slightly in India as a whole). The proportion of the total rural labor force involved in agriculture remained more or less constant, and nearly identical for sample Districts, sample States, and all-India. Finally, real wages paid to agricultural laborers in sample Districts (adjusted for State-level differences in labor use by season) increased at a rate of 0.76% per annum from 1960/61 to 1980/81 (suggesting that rising labor supply was outpaced by demand), while remaining stagnant for sample States (where State-level agricultural real wages were not seasonally adjusted).[22] No real wage data were available for all-India in 1960/1, but sample District wages matched all-India figures at the study's end (1980/1).

That sample Districts saw faster real wage growth than, at least, sample States (and perhaps all-India) has implications for fertility findings, since this parameter is so strongly suggested by theory as affecting fertility change. This non-representativeness does not compromise our ability to statistically estimate the impact of changes in real wage growth on fertility change; however, it may decrease the reliability of elasticities based on these estimates.

Finally, and critically for this study's objective of assessing the impact of HYV-linked technologies on fertility outcomes, Table 5 presents statistics on the adoption

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[22] We don't expect the fact that only District-level wages were seasonally adjusted to affect comparability of sample District and sample State real wage growth rates.

Table 5--Technology[*]: India, sample states, and sample districts 1950-1/1987-8

1950-1	1960-1		1970-1			1980-1			1987-8			variables)		1960-1/1980-1 Compound growth (%/yr) (1970-1/1980 for HYV		
	Sample States	India	Sample Districts	Sample States	India	Sample Districts	Sample States	India	Sample Districts	Sample States	India	Sample States	Sample India	Sample Districts	Sample States	India
NPK (kilogram of nutrient per hectare.)[a]	0.19	0.18	1.3	1.5	1.9	12.8	15.8	13.8	24.8	36.8	32.4	56.42	51.46	14.7	16.0	14.2
4-wheel tractors[b]/ NCA	0.06	0.07	0.13	0.22	0.23	0.52	1.19	1.06	1.87	3.67	3.69	-	-	5.6	14.1	13.9
Percent HYV in GCA[c]	0	0	0	0	0	6.7	12.2	8.6	20.6	24.6	24.8	30.64	32.20	11.2	7.0	10.6
Area[c]																
Rice Percent HYV	0	0	0	0	0	19.3	24.4	13.5	54.1	61.5	44.8	71.3	58.9	10.3	9.2	12.0
Wheat Percent HYV	0	0	0	0	0	19.4	34.1	35.9	54.0	67.0	73.0	77.3	84.0	10.2	6.8	7.1
Jowar Percent HYV	0	0	0	0	0	4.7	9.4	4.0	23.8	23.5	21.3	41.8	37.6	16.2	9.2	16.7
Bajra Percent HYV	0	0	0	0	0	18.1	32.4	13.0	49.5	50.6	32.7	70.9	47.0	10.1	4.5	9.2

Sources: *Indian Agricultural Statistics*, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi. Various issues.

Area and Production of Principal Crops in India, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi. Various issues.

Indian Livestock Census 1951, 1961, 1972, 1982, Directorate of Economics and Statistics, Ministry of Agriculture, New Delhi.

Fertiliser Statistics, Fertiliser Association of India, New Delhi. Various issues.

[*] Data are 3-year averages, centered on year at column head, unless otherwise indicated.

[a] Data in 1950-1 column refer to 1951-2 only; data for 1960-1 are 2-year averages from 1959-60, 1960-1.

[b] Data are from Livestock Census years only: 1951, 1961, 1972, and 1982.

[c] Data for 1970-1 are 2-year averages from 1969-70 and 1970-1.

of "green revolution" technologies in Indian agriculture. Dramatic increases in fertilizer application rates, mechanical traction, and the use of HYV technologies are all evident. Fertilizer application was more intensive at the all-India and sample State than the sample District level in each year shown. Sample Districts lagged behind sample States, but outpaced all-India growth levels of fertilizer application rates. Sample Districts started with fewer tractors per hectare in 1960/1 than India as a whole or sample States, and their number increased at only 6% per annum, compared to sample State and all-India rates of 14%. In both 1970/1 and 1980/1, sample Districts lagged slightly behind India as a whole in proportion of farmed area planted to HYV. The sample Districts' annual growth rate in this proportion outpaced that of both all-India and sample States. In both 1970/1 and 1980/1, all-India and sample States both had higher concentrations of wheat area in HYV than did sample Districts. Both sample Districts and sample States had higher concentrations of bajra area in HYV than did all-India. Crop-specific growth rates in proportion of crop planted to HYV were more similar for sample Districts and all-India, than for sample Districts and sample States.[23]

To summarize, then, agricultural change characteristics where sample Districts differed from sample States and all-India: a) sample Districts intensified land use more gradually than sample States, which in turn intensified more gradually than all-India; b)

[23] Because maize composed such a small percentage of GCA (averaging 2% in sample Districts in 1960/1), it was not included in these tables even though it is included in the final analyses. Of sample Districts, 98% used maize HYV at one level of intensity or another during the sample period, on an average of 21% of maize area in their initial HYV year.

sample Districts had a different pattern in HYV crop mixes and yields -- with wheat less important and jowar more important in terms of share of GCA than all-India, and with smaller wheat yield gains, and larger bajra yield gains than did sample States or all-India; c) labor intensity for sample Districts increased on a par with that for sample States, while all-India levels decreased; and d) agricultural real wages grew faster in sample Districts than in sample States. Finally, in changes in technology use, sample Districts rarely resembled sample States, but often reflected all-India patterns, lagging behind sample States in growth in fertilizer application rates, and surpassing sample States in growth in proportion of GCA planted to HYV. The striking exception to this pattern is that sample Districts had exceptionally low tractor mechanization rates, vis-ą-vis both sample States and all-India.

These figures confirm substantial change in Indian agriculture as a whole, and in the sample area. And, while the sample area in the aggregate evinced some differences from Indian and sample State trends, that same sample area, when examined District by District, exhibited wide variation (across sample Districts) in the nature and speed of agricultural change. Thus, the sample touches on situations representing various Indian "realities" -- rapid transitions and slow ones -- even if not in precisely the proportions observed country-wide. For our purposes, therefore, the sample catches the sorts of variation -- in levels and trends -- of agriculture-related variables that might, according to modern theory, affect demand for and supply of children variables, and, therefore, TFR change.

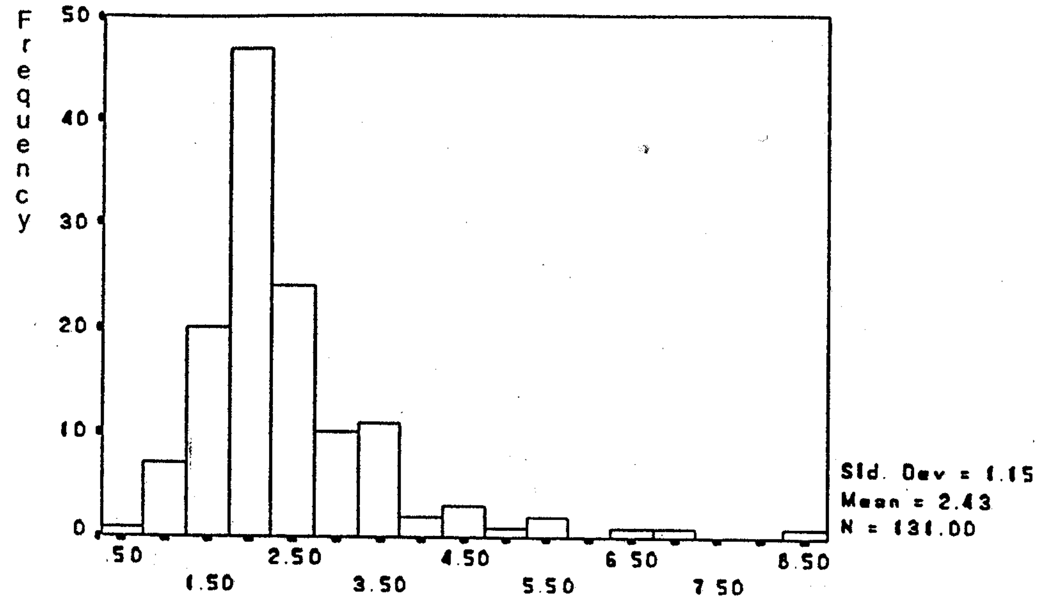
Of equal importance for the analysis, the sample contains wide variation in trends for the main demand for and supply of children variables themselves (see Figure 1, Part B): a) income levels; b) key incentives (the costs and benefits of bearing and raising children); and c) food availability. Figures 3 through 5 present frequency distributions (at two points in time) demonstrating, again, wide variation in sample District levels of proxy variables used to capture demand for and supply of children. Table 6 confirms a variety of trends (positive and negative) in these variables across sample Districts. Table 7 provides a variable list.

Figure 3 depicts the frequency distribution of the value of crop output (VTO) for the 1960/61 and 1980/81 endpoints of our sample. Real, crop-derived income per man-day rose in spite of increasing population pressure. Average rural real wage rates (Figure 4) rose over the sample period;[24] at the District level, rates of change were, on average, positive (Table 6), but some Districts lost ground (annual average changes, in 1960-1 rupees, ranged from -0.03 to +0.16). Finally, Figure 5 depicts the frequency distribution for (daily) District-level cereal calorie production (CCP) per

[24] Growth rates in average rural real wages for agricultural laborers are reported. Unfortunately, the data series cannot be decomposed by age, gender, or other socio-cultural and demographic categories that theory points to as relevant.

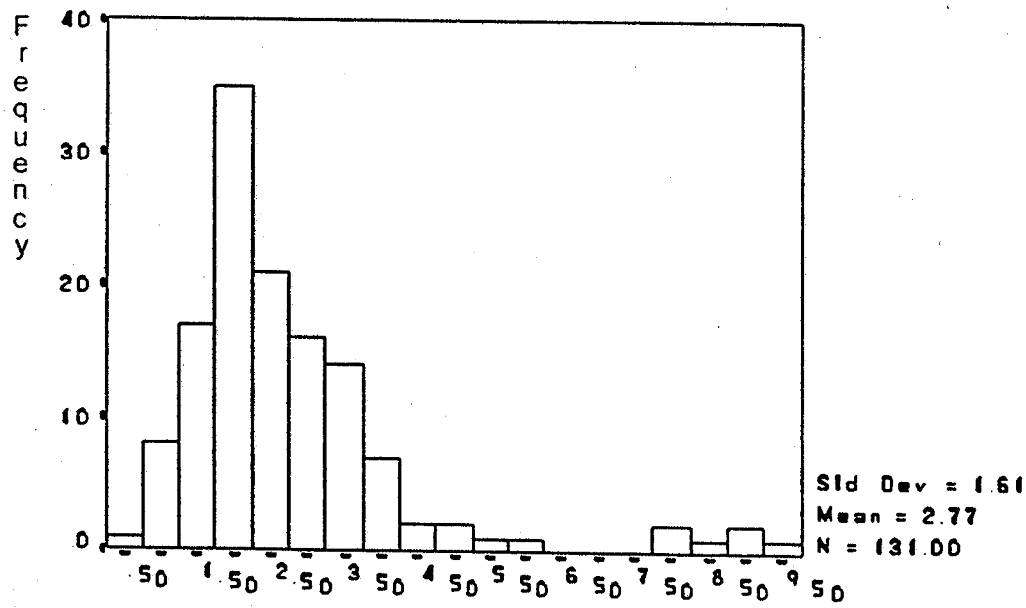
Figure 3

CROP VTO*/DAYS LABOR 1960/1
INDIAN SAMPLE DISTRICTS



CROP VTO*/LABOR (1960/1 Rs/man-day)

CROP VTO*/LABOR DAYS 1980/1
INDIAN SAMPLE DISTRICTS



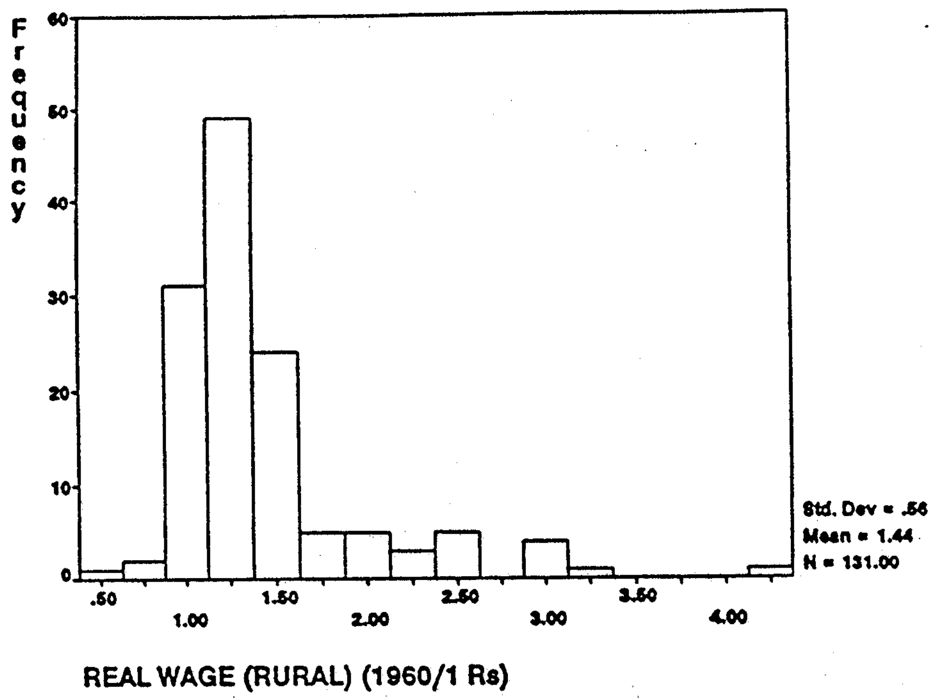
CROP VTO*/LABOR (1960/1 Rs/man-day)

*VTO represents value of total crop production. See Table 7, Variable List, for complete variable descriptions

Figure 4

REAL WAGE (RURAL) 1960/1

INDIAN SAMPLE DISTRICTS



REAL WAGE (RURAL) 1980/1

INDIAN SAMPLE DISTRICTS

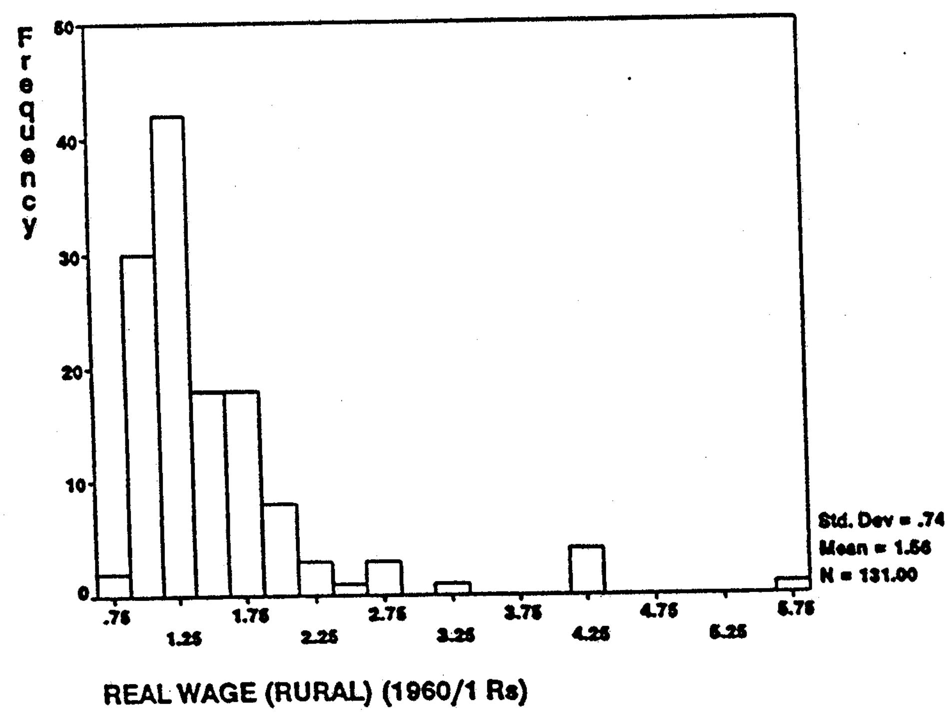


Table 6--Descriptive statistics

Variable		Units	Mean	Std Dev	Minimum	Maximum	N
TFRRAT	1971-81	(prop. change in TFR)	-.20	.07	-.38	-.01	131
Agricultural Production Block							
GCAR[a]	1961-81	(GCA growth --'000 has/yr)	2.41	4.12	-8.49	16.51	131
GCANCAR[a]	1961-81	(GCA/NCA growth -- prp/yr)	.004	.01	-.01	.03	131
CERCALR	1961-81	(cereal calories produced/rural cap./yr -- comp'd growth rate)	.005	.02	-.04	.08	131
CERCAL	1961	(cereal calories produced/rural cap.)	1877.28	738.52	328.70	4268.76	131
Labor Block							
GCALAB	1961	(GCA/labor -- ha/man-day)	2.34	1.10	.80	7.75	131
FRMPRP	1961	(ag labor/total labor growth--prp/yr)	.81	.09	.33	.94	131
RLWAGE	1961	(rural real wage 1960-1 Rs)	1.44	.56	.61	4.22	131
GCALABR[a]	1961	(GCA/labor growth --ha/man-day/yr)	-.03	.03	-.13	.05	131
FRMPRPR[a]	1961-81	(ag labor/total labor/yr)	.000	.003	-.01	.01	131
RLWAGER[a]	1961-81	(rural real wage growth 1960-1 Rs/yr)	.02	.03	-.03	.16	131
Agricultural Income Block							
VTOPOP	1961	(value of crop output 1960-1 Rs)	129.25	45.67	40.27	283.06	131
VTOPOPR[a]	1961-81	(growth in value of crop output 1960-1 Rs/rural person/yr)	1.01	3.42	-10.39	15.17	131
Green Revolution Block							
TRCNCAR[a]	1961-81	(tractors/NCA has/yr)	.15	.29	-.01	2.25	131
NPKGCAR	1961-81	(fertilizer tonnes/GCA/yr -- comp'd growth rate)	.17	.05	.07	.30	131
GIAGCAR[a]	1961-81	(GIA/GCA/yr)	.004	.005	-.01	.02	131
PHYVRCER		(HYV rice area/rice area -- comp'd growth rate)	.21	.10	-.04	.43	131
PHYVWHTR		(HYV wheat area/wheat area -- comp'd growth rate)	.17	.12	.00	.50	131
PHYVJOWR		(HYV jowar area/jowar area -- comp'd growth rate)	.21	.11	-.07	.39	131
PHYVBAJR		(HYV bajra area/bajra area -- comp'd growth rate)	.11	.12	-.05	.35	131
PHYVMAZR		(HYV maize area/maize area -- comp'd growth rate)	.09	.07	-.12	.30	131
Socio-Cultural and Demographic Block							
PRPTRBE	1971	(sched. tribes/total pop.)	.10	.18	.00	.90	131
PRPWIDW	1971	(widows age 40-44/females 40-44)	.15	.04	.06	.26	131
PRPCULR[a]	1961-81	(cultivators/ag Workforce/yr)	-.002	.003	-.01	.01	131
LITFEM1	1971-81	(lit. females age 15-25/females 15-25 -- change in proportion '71-'81)	.06	.05	-.02	.29	131
LITFEM2	1971-81	(lit. females age 25-35/females 25-35 -- change in proportion '71-'81)	.13	.07	.02	.33	131
MARFEM1	1971-81	(married fem.s age 15-19/fem.s. 15-19 -- change in proportion '71-'81)	-.13	.07	-.30	.18	131
MARFEM2	1971-81	(married fem.s age 20-24/fem.s. 20-24 -- change in proportion '71-'81)	-.03	.04	-.19	.06	131
MARFEM3	1971-81	(married fem.s age 25-29/fem.s. 25-29 -- change in proportion '71-'81)	-.003	.02	-.06	.06	131

[a] Estimated growth rate for sample period (a quadratic function form of time tested by District for each variable); where both the linear and quadratic terms were significant (most Districts), the function was evaluated at 1975.

Table 7 -- Variable list

Variable	Description
CERCALR[b]	Compound rate of growth (based on endpoints consisting of three-year averages centered around the sample endyears) in cereal calories per rural population produced annually in District.
FRMPRP	Proportion of total District laborers involved in agricultural labor at the beginning of the sample period (taken from the 1961 Indian Census).
FRMPRPR[a]	Estimated growth rate (proportion/yr) in proportion of total District laborers involved in agricultural labor (as a quadratic function of time *t*), evaluated at *t*=1975.
GCALAB	Land-to-labor ratio (has. gross cropped area/man-day) at the beginning of the sample period (a three-year average centered on the year 1961).
GCALABR[a]	Estimated growth rate (ha./man-day/yr) for gross cropped area to labor (as a quadratic function of time *t*), evaluated at *t*=1975.
GCANCAR[a]	Estimated growth rate (proportion/yr) for gross cropped area to net cropped area (as a quadratic function of time *t*), evaluated at *t*=1975.
GCAR[a]	Estimated growth rate (has/yr) for gross cropped area (as a quadratic function of time *t*), evaluated at *t*=1975.
GIAGCAR[a]	Estimated growth rate (proportion/yr) for gross irrigated area to gross cropped area (as a quadratic function of time *t*), evaluated at *t*=1975.
LITFEM1	Change (from 1971 to 1981) in proportion of rural females age 15-25 who are literate.
LITFEM2	Change (from 1971 to 1981) in proportion of rural females age 25-35 who are literate.
MARFEM1	Change (from 1971 to 1981) in proportion of rural females age 15-19 who are married.
MARFEM2	Change (from 1971 to 1981) in proportion of rural females age 20-24 who are married.
MARFEM3	Change (from 1971 to 1981) in proportion of rural females age 25-29 who are married.
NPKGCAR[b]	Estimated compound rate of growth of tonnes of nitrogen, phosphorus, and potassium fertilizer applied per hectare annually in District.
PHYV{BAJ, JOW, MAZ, RCE, WHT}R[b]	Compound rate of growth (based on endpoints consisting of three-year averages centered around the sample endyears of proportion of crop specified planted to HYV annually in District.

cont'd.

Table 7 -- Variable list (continued)

Variable	Description
PRPCULR[a]	Estimated growth rate (proportion/yr) in proportion of rural District population composed of cultivators (as a quadratic function of time *t*), evaluated at *t*=1975 (trend based on annual population figures extrapolated (assuming compound growth) from 1961, 1971, and 1981 Indian Censuses.
PRPTRBE	Proportion of rural District population composed of scheduled tribes, based on 1971 Indian Census.
PRPWIDW	Proportion of rural District females age 40-44 who were widows, based on 1971 Indian Census.
RLWAGE	Rural real wage (expressed in 1960-1 Rs) at the beginning of the sample period (a three-year average centered on the year 1961).
RLWAGER[a]	Estimated growth rate (1960-1 Rs/yr) in real wage (District-level wages were deflated using State-level CPI for agricultural laborers) (as a quadratic function of time *t*), evaluated at *t*=1975.
TFRRAT	Proportional change, from 1971 to 1981, in District-level Total Fertility Rate estimates (a negative number connotes a drop in TFR).
TRCNCAR[a]	Estimated growth rate (tractors/ha/yr) for tractors per net cropped area (as a quadratic function of time *t*), evaluated at *t*=1975.
VTOPOP	Value of total output (VTO) (expressed in 1960-1 Rs) per capita (rural) for available (top fifteen in terms of area) crops at the beginning of the sample period (a three-year average centered on the year 1961).
VTOPOPR[a]	Estimated growth rate (1960-1 Rs/yr) in crop VTO per rural capita (District-level VTO is based on District-level output and farm harvest prices deflated using State-level CPI for agricultural laborers) (as a quadratic function of time *t*), evaluated at *t*=1975.

[a] Growth rates were estimated through regressions of annual data (in the case of population numbers taken from the Census, annual population in inter-censal years was interpolated assuming a compound rate of growth), using time, $time^2$, and a constant as right-hand side variables. For those Districts for which both independent variables had estimated coefficients significantly different from zero, the first derivative of the estimated equation (the growth rate) was evaluated at time *t*=1975, at the middle of the decade for which demographic transition is being examined.

[b] In the case of NPKGCAR, an exponential function fit the annual data the best, for most Districts; in the case of PHYV___R, and CERCALR, compound growth rate was determined for each District using three-year averages surrounding the sample endpoints (for the HYV variables, the initial endpoint consists of the first non-zero year for use of HYV).

rural population.[25] This calorie-weighted measure reflects our belief that cereal prices alone may not capture relative calorie availability. While CCP is not a complete measure of food availability, especially given inter-District trade, we expect that, particularly for the earlier years under study (early 1960s), and for this relatively poor set of Districts, CCP provides an acceptable, if less than perfect, indication of relative food availability. The rate of growth in CCP is more problematic as a measure of chance in food availability, given the growing trade "wedge" separating locally produced and consumed food (due to infrastructural improvements, and probably not unrelated to the HYV-driven yield and income gains) over the study.[26] Impressive average growth is evident in caloric production, once again despite rapid population growth.

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[25] District-level growth rates in production of daily cereal calorie equivalents per capita were computed as compound growth rates, with the endpoints being (*t* denoting 1960/1 and 1980/1, and *i* noting main cereal crops wheat, rice, bajra, jowar, and maize; all variables computed at District level):
$(\Sigma\ AVCRPOUT_{i,t}*CALORIE_i)/RURPOP_t/DAYS$; where

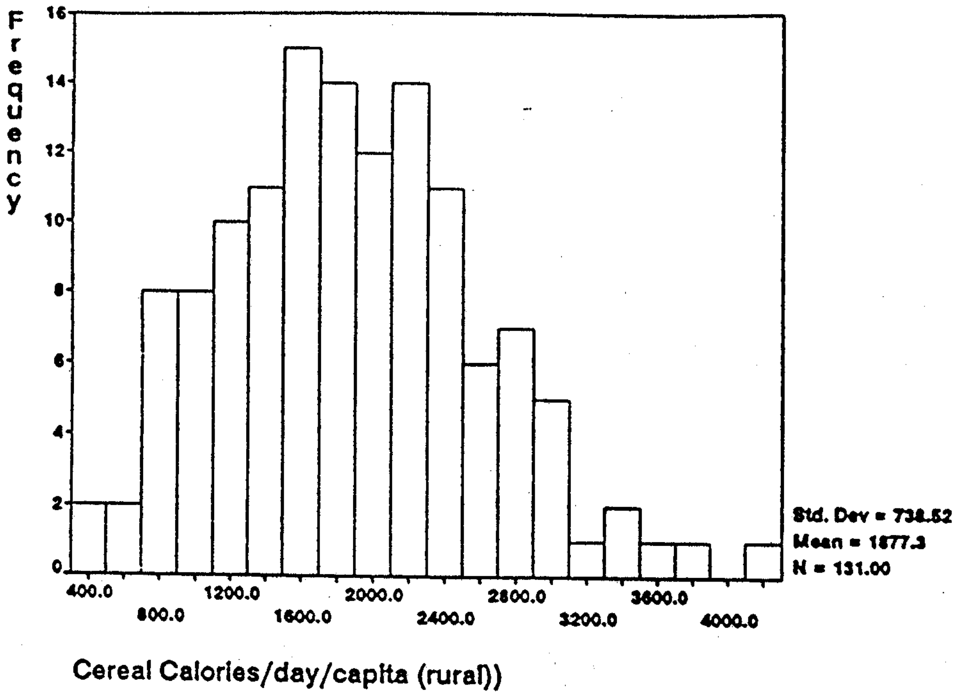
AVCRPOUT = average annual crop output for crop *i* in three years centered on year *t*;
CALORIE = edible calories per harvestable unit of crop *i* (Gopalan, et al., 1981);
RURPOP = rural population from Census in year *t*; and
DAYS = number of days for which crop output required, i.e., 365.

[26] Note that CCP, constructed using cereal production only, and used to capture trends and variation in food availability, differs from the price-weighted value of total crop output (VTO), constructed using a wider array of agricultural products than cereals, and used to capture trends and variations in income.

Figure 5

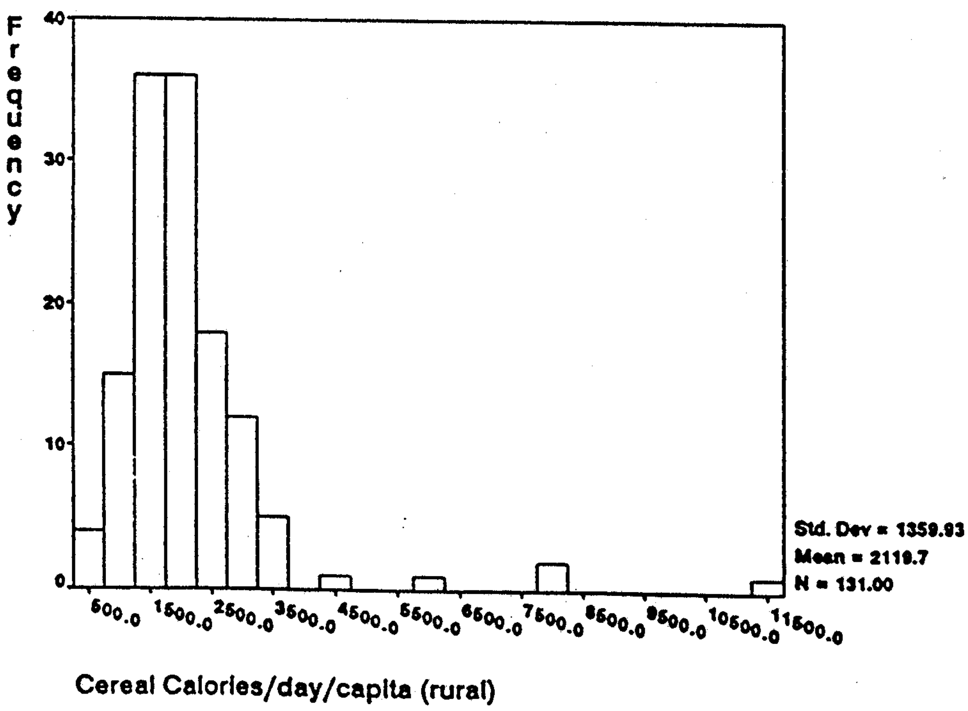
CEREAL PROD. CALORIES/RUR. POP. 1960/1

INDIAN SAMPLE DISTRICTS



CEREAL PROD. CALORIES/RUR. POP. 1980/1

INDIAN SAMPLE DISTRICTS



4. FACTORS AFFECTING DEMAND FOR AND SUPPLY OF CHILDREN

EVIDENCE OF LINKS TO CHANGES IN HUMAN FERTILITY

HYV-linked agricultural change is hypothesized to affect human fertility change through modifications to the factors affecting the demand for and supply of children,[27] namely, changes in real wages, income, and food availability. While, as noted above, *a priori*, theory leads to an expectation of initially rising, then falling TFR in response to such change, it does not: a) explicitly incorporate the timing of agricultural change vis-ą-vis hypothesized TFR change; b) explicitly examine the paths through, extents to, and directions in which each HYV-linked technology (and other agricultural variables) can be hypothesized to affect demand for and supply of children -- nor, therefore, the net effects of such technologies taken singly or together; or c) (aside from consideration of extremely poor areas, where malnutrition constrains fertility) consider the extent to which the net effects described in b) may be conditional on key "starting" or "baseline" agricultural or socio-cultural and demographic conditions. The implications for theory of results from this section will be referred to in the Discussion section.

To identify the impact of levels and changes in real wage, income, and food availability on fertility <u>change</u> at District level, measures of these were regressed on TFR change. Socio-cultural and demographic factors were controlled for.

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[27] As noted above, costs of contraception are not included in this analysis.

Table 8, Equation 1, presents the results for this OLS equation, regressing TFRRAT (proportional change in District-level TFR from 1971-81) on intervening variables[28] that seem plausible determinants of: a) demand for children -- 1961 rural real wage rates, estimated[29] (annual) rural real wage growth rates over the study period (1961-81), an income measure (value of crop output per rural capita) for 1961, and estimated rate of change for this income measure over the period (1961-81);[30] b) supply of children -- annual production of cereal calories per rural population in 1961, and rate of change in this cereal production measure over the study period; and c) an array of socio-cultural (see Easterlin and Crimmins, 1985) -- including the proportion of population belonging to scheduled tribes in 1971, change in age-specific female literacy and marriage rates during the fertility decline (1971-1981), and growth rate of cultivators

[28] All independent variables are at District level.

[29] For all estimated growth rates, District-level predictions were estimated as a quadratic function of time, except in those cases where a linear equation fits the annual data better (i.e., results in a higher adjusted R^2).

[30] Unfortunately, more comprehensive measures of rural income, e.g., including off-farm and livestock sources, were not available at District level. Nor were data on District-level cost of crop production available. Finally, this income measure, based on value of crop output, does not capture extent of commercialization of that output within the sample.

as a proportion of the rural workforce over the entire study period[31] and demographic (widowhood prevalence among women aged 40-44 in 1971) factors.

[31] Measuring demand and supply starting in 1961, and monitoring fertility only from 1971 assumes these changes will affect fertility decisions with some time-lag.

Table 8--Regression analysis

Variable	Unit	Equation 1 - TFRRAT (prop. change in TFR 1971-81) Labor Supply, HYV-Related Institutional Factors Estimated Coefficient	t-ratio (absolute value)	Elasticity[c]	$\bar{R}^2$
Demand for Children Variables					0.04
RLWAGER 1961-81[a]	(rural real wage growth 1960-1 Rs/yr)	-0.43**	2.14	0.04	
VTOPOPR 1961-81[a]	(growth in value of crop output 1960-1 Rs/rural person/yr)	2.93ε-4	0.18		
RLWAGE 1961	(rural real wage 1960-1 Rs)	0.01	1.13		
VTOPOP 1961	(value of crop output 1960-1 Rs)	-4.73ε-4***	3.55	0.31	
Supply of Children Variables					0.06
CERCALR 1961-1981	(cereal calories produced /rural cap./yr--comp'd growth rate)	0.11	0.35		
CERCAL 1961	(cereal calories produced /rural cap.)	1.80ε-5**	2.10	-0.17	
Socio-Cultural Factor and Demographic Variables					0.39
PRPTRBE 1971	(sched. tribes/total pop.)	-0.11***	3.01	0.06	
PRPWIDW 1971	(widows age 40-44/females 40-44)	0.42***	2.87	-0.31	
PRPCULR 1961-81[a]	(cultivators/ag workforce/yr)	4.45***	2.69	0.04	
LITFEM1 1971-81	(lit. females age 15-25/females 15-25 --change in proportion '71-'81)	0.28**	2.03	-0.08	
LITFEM2 1971-81	(lit. females age 25-35/females 25-35 --change in proportion '71-'81)	-0.36***	3.66	0.23	
MARFEM1 1971-81	(married fem.s age 15-19/fem.s 15-19 --change in proportion '71-'81)	0.15**	2.04	0.10	
MARFEM2 1971-81	(married fem.s age 20-24/fem.s 20-24 --change in proportion '71-'81)	0.32*	1.86	0.05	
MARFEM3 1971-81	(married fem.s age 25-29/fem.s 25-29 --change in proportion '71-'81)	-0.45	1.15		
Labor Supply Variables					
GCALABR 1961-81[a]	(GCA/labor growth--ha/man-day/yr)	--	--		
FRMPRPR 1961-81[a]	(ag labor/total labor growth--prp/yr)	--	--		
GCALAB 1961	(GCA/labor--ha/man-day)	--	--		
FRMPRP 1961	(ag labor/total labor)	--	--		
Constant		-0.17***	4.34		
$\bar{R}^2$		0.49			
N		131			

*, **, *** denote significance at the 10%, 5%, and 1% levels, respectively.

[a] Estimated growth rate for sample period (a quadratic functional form of time tested by District for each variable); where both the linear and quadratic terms were significant (most Districts), the function was evaluated at 1975.

[b] The coefficient is estimated (and elasticity given) not for RLWAGER, but for the predicted value of RLWAGER resulting from an equation including HYV-related variables, mechanization, and combinations of these variables. In other words, the component of real wage growth explained by HYV-linked technological change and mechanization.

[c] Evaluated at dependent and independent variable means.

[d] $\bar{R}^2$ column lists the contribution of each "block" of variables to the equation's overall $\bar{R}^2$ (that is, the equation's $\bar{R}^2$ is the sum of $\bar{R}^2$ s of all the equation's blocks).

The results point up significant demand, supply, and socio-cultural and demographic variables' effects on fertility change at District level for the study period (with nearly half of the inter-District variation explained).[32] Of the "demand-for-children" variables, higher levels of value of crop output per capita in 1961 (before the HYV-linked changes studied here began) and faster growth in agricultural real wage rates over the period (regardless of initial real wage rate) were both associated with larger proportional fertility declines in the decade 1971-81. A 1% increase in value of crop output led to a 0.31% greater proportional TFR decline; a 1% increase in real wage growth, however, translated into only 0.04% greater proportional TFR decline. This "block" of variables accounted for 4% of the variation in proportional TFR decline.

Of the "child supply" variables, higher 1961 levels of cereal calories produced per rural head were associated with lower proportional TFR declines in the 1971-81 decade, with an elasticity of -0.17 (that is, a 1% increase in calorie per capita production meant 0.17% less of a proportional TFR decline). Recalling the discussion of a "biological fertility curve" (in the Introduction), and keeping in mind the caveats associated with using cereal calorie production as a measure of food availability), this suggests that around 1961 a preponderance of sample Districts lay clustered between the critical calorie cut-off, and the calorie sufficiency cut-off, poised to have additional calories yield

[32] These results regarding TFR change do not bear on these measures as determinants of TFR levels. Regarding the equation's form, note that non-linearities of the demand-for- and supply-of-children variables were tested and found not significant, and that their rates of growth were tested and found not to be endogenous using the Hausman-Wu test. Results of these tests are available from the authors.

increasing returns to reproductive capacity -- the fertility-enhancing effect seen here. While rate of change in District-level cereal production over the study period registered no effect on TFR declines, the serious shortcomings associated with this variable as a cross-sectional measurement of changes in food availability makes this finding far less conclusive. This "block" of variables accounted for slightly more, 6%, of the variation in proportional TFR decline.

Socio-cultural and demographic factors were also significant (though one of them only 10%), explaining 39% of the variation in proportional TFR decline. First, Districts with relatively 1971 values of some variables normally associated with low fertility, tended to show significantly above-average declines in total fertility rates in 1971-81; such variables included higher proportion of tribal population, and lower proportion of widows among women aged 40-44 (suggesting that more women were still potentially child-bearing close to the end of their reproductive cycle). Their elasticities were respective responses of 0.06% and -0.31% in TFR proportional decline to a 1% increase in the independent variable.

Second, a District in which the proportion of cultivator households fell 1% faster than the average for all Districts in our sample during 1961-81 -- signalling a relative increase in landlessness and/or in non-farm involvement -- would typically have a 0.04% above-average decline in the total fertility rate (in proportional terms).

Third, as for literacy, the direction of fertility effects varied surprisingly by age group. A District with above-average literacy improvement among women aged 15-25 from 1971-81 tended to show proportional declines in TFR below the average for all the

Districts; among women aged 25-35, it had the opposite effect (fertility dampening). However, the latter, more familiar impact of female literacy in decreasing fertility (for example, by increasing opportunity cost of women's time), was much stronger (that is, an elasticity of 0.23, as opposed to -0.08 for the younger age group).

Fourth, in line with expectations, Districts with above-average rates of decline in marriage among women aged 15-19 and 20-24, during 1971-81, experienced faster-than-average proportional TFR declines over the same period. However, the elasticity for the older cohort was larger: a 1% decline among the younger cohort was associated with a 0.10% further proportional decline in TFR, whereas a 1% decline in marriage rates among the older cohort, with only a 0.5% further proportional decline in TFR.

Of the significant child demand and supply variables, only one -- 1961-1981 real wage growth rates -- could be affected by HYV-linked agricultural change that started in the mid-1960s, since the income and cereal production level variables were measured in 1961, prior to the beginning of the HYV-related changes examined here. We saw above that faster real wage growth was linked to faster TFR declines. How did HYV-linked agricultural change affect real wage growth -- to what extent was the former responsible for the latter's impact in speeding up the TFR decline?

5. HYV-ASSOCIATED AGRICULTURAL CHANGE: LINKS TO REAL WAGE GROWTH AND CHANGES IN HUMAN FERTILITY

Thus far, our results point to one factor influencing the change in demand for children -- real wage growth over a two-decade period -- as one significant determinant of changes in human fertility at District level. To what degree was HYV-related agricultural change responsible for the real wage changes that influenced fertility?

Equation 2, Table 9 shows the results of an OLS regression examining the links between District-level real wage growth rates and HYV-related agricultural change, controlling for labor supply variables.[33] Also included as an independent variable is growth in tractor mechanization (number of tractors per net cropped area (NCA) of land), which, while not strictly part of the HYV technology "package," often accompanied its adoption.

The adjusted R^2 of the equation was 0.32, with the HYV-related technology variables accounting for 20% of total inter-District variation in real wage growth rates (the block added significantly to the explanatory power of the equation, with an F-statistic of 7.35), the labor supply "block" accounting for 7%, and tractorization

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[33] Labor supply variables are combinations of demographic and agricultural variables that can influence growth rates in real wages, above and beyond the impact of HYV-linked technical change. They are controlled for here to isolate estimated coefficients on HYV-linked technologies' influence on real wage growth.

explaining an additional 4%. These results illustrate the imperfect labor mobility among Districts, unless real wage rates were converging over the period.

Table 9--Regression analysis

Variable	Unit	Equation 2 - RLWAGER[a] (real wage growth rate 1961-81) Full Model — Estimated Coefficient	t-ratio (absolute value)	Elasticity	$\overline{R}^2$	Equation 3 - TFRRAT (prop. change in TFR 1971-81) Basic Determinants and Technology, Mechanization — Estimated Coefficient	t-ratio (absolute value)	Elasticity[c]	$\overline{R}^2$
Demand for Children Variables									
RLWAGER 1961-81[a]	(rural real wage growth 1960-1 Rs/yr)		--	--			-1.79**[b]	2.26	0.20
VTOPOPR 1961-81[a]	(growth in value of crop output 1960-1 Rs/rural person/yr)	--	--			-0.001	0.63		
RLWAGE 1961	(rural real wage 1960-1 Rs)	--	--			0.004	0.38	0.01	
VTOPOP 1961	(value of crop output 1960-1 Rs)	--	--			-4.64ε-4***	2.98	0.30	
Supply of Children Variables									0.10
CERCALR 1961-1981	(cereal calories produced /rural cap./yr--comp'd growth rate)	--	--			-0.004	0.01		
CERCAL 1961	(cereal calories produced/rural cap.)	--	--			2.14ε-5**	2.02	-0.20	
Institutional Factor (Sociodemographic) Variables									0.32
PRPTRBE 1971	(sched. tribes/total pop.)	--	--			-0.12***	3.04	0.06	
PRPWIDW 1971	(widows age 40-44/females 40-44)	--	--			0.34**	2.03	-0.25	
PRPCULR 1961-81[a]	(cultivators/ag workforce/yr)	--	--			4.82**	2.40	0.05	
LITFEM1 1971-81	(lit. females age 15-25/females 15-25 --change in proportion '71-'81)	--	--			0.22	1.49		
LITFEM2 1971-81	(lit. females age 25-35/females 25-35 --change in proportion '71-'81)	--	--			-0.26**	2.51	0.17	
MARFEM1 1971-81	(married fem.s age 15-19/fem.s 15-19 --change in proportion '71-'81)	--	--			0.13	1.31		
MARFEM2 1971-81	(married fem.s age 20-24/fem.s 20-24 --change in proportion '71-'81)	--	--			0.39*	1.94	0.06	
MARFEM3 1971-81	(married fem.s age 25-29/fem.s 25-29 --change in proportion '71-'81)	--	--			-0.55	1.27		
Labor Supply Variables					0.07				0.02
GCALABR 1961-81[a]	(GCA/labor growth--ha/man-day/yr)	0.12	1.17		0.04	0.15			
FRMPRPR 1961-81[a]	(ag labor/total labor growth--prp/yr)	1.35	1.36			3.69	1.62		
GCALAB 1961	(GCA/labor--ha/man-day)	0.01***	4.00	1.26		-0.001	0.18		
FRMPRP 1961	(ag labor/total labor)	0.02	0.47			0.16*	1.74	-0.64	

cont'd.

Table 9 (cont'd)--Regression analysis

Variable	Unit	Equation 2 - RLWAGER[a] (real wage growth rate 1961-81) Full Model: Estimated Coefficient	t-ratio (absolute value)	Elasticity	$\overline{R}^2$	Equation 3 - TFRRAT (prop. change in TFR 1971-81) Basic Determinants and Technology, Mechanization: Estimated Coefficient	t-ratio (absolute value)	Elasticity[c]	$\overline{R}^2$
HYV-Related Technology Variables					0.20				0.03
PHYVMZR	(HYV maize area/maize area--comp'd growth rate)	0.04	1.32			-0.10	1.34		
PHYVJWR	(HYV jowar area/jowar area--comp'd growth rate)	0.02	0.91			-0.01	0.11		
PHYVBJR	(HYV bajra area/bajra area--comp'd growth rate)	0.03	1.06			0.12*	1.92	-0.07	
PHYVWHR	(HYV wheat area/wheat area--comp'd growth rate)	-0.10***	3.77	-0.75		-0.18*	1.91	0.15	
PHYVRCR	(HYV rice area/rice area--comp'd growth rate)	-0.02	0.79			-0.12*	1.91	0.13	
GIAGCAR[a]1961-81	(GIA/GCA/yr)	1.85***	3.06	0.32		2.57	1.32		
NPKGCAR 1961-81	(fertilizer tonnes/GCA/yr--comp'd growth rate)	-0.14**	2.42	-1.04		0.04	0.30		
Mechanization					0.04				
TRCNCAR[a]1961-81	(tractors/NCA has/yr)	-0.03***	2.91	-0.20		-5.70ε-4	0.02		
Agricultural Change									
GCAR[a] 1961-81	(GCA growth--'000has/yr)	--	--			0.001	0.66		
GCANCAR[a]1961-81	(GCA/NCA growth--prp/yr)	--	--			-0.61	0.45		
Constant		0.02	0.59			-0.22**	2.32		
$\overline{R}^2$		0.32				0.49			
N		131				131		131	

*, **, *** denote significance at the 10%, 5%, and 1% levels, respectively.

[a] Estimated growth rate for sample period (a quadratic functional form of time tested by District for each variable); where both the linear and quadratic terms were significant (most Districts), the function was evaluated at 1975.

[b] The coefficient is estimated (and elasticity given) not for RLWAGER, but for the predicted value of RLWAGER resulting from an equation including HYV-related variables, mechanization, and combinations of these variables. In other words, the component of real wage growth explained by HYV-linked technological change and mechanization.

[c] Evaluated at dependent and independent variable means.

[d] $\overline{R}^2$ column lists the contribution of each "block" of variables to the equation's overall $\overline{R}^2$ (that is, the equation's $\overline{R}^2$ is the sum of $\overline{R}^2$s of all the equation's "blocks.").

Within the HYV-related block, three variables had significant associations with real wage growth. First, increases in gross irrigated area as a proportion of GCA was positively tied to real wage growth, with a 1% increase in this proportion resulting in a .32% higher real wage growth rate. Second, surprisingly, growth in fertilizer use per gross cropped hectare dampened real wage growth, all else held constant. Moreover, the elasticity was high -- a 1% increase in fertilizer application growth rate resulting in a 1.04% decrease in real wage growth rate. Third, only one crop-specific variable revealed a significant link to real wage change: a 1% rise in growth of HYV wheat prevalence leading to a 0.75% decline in real wage growth rate, possibly because HYV wheat was associated with other forms of mechanization, some of it labor displacing -- for example, threshers and reaper-binders -- not captured in the tractorization variable.[34]

We have demonstrated the link between real wage growth and fertility, and subsequently measured the impact of HYV-linked technologies, plus mechanization, on real wage growth. Several questions remain. First, how much do HYV-linked technologies drive real wage growth's effect on fertility change? A second question involves interpretation of our results. Given that imperfect markets and data mean our measure of real wage growth may not capture completely the impact of HYV-linked

[34] Two other variables were significantly associated with real wage growth throughout the study period, and in the expected directions: a 1% above-average increase in a labor supply variable, viz., the land/labor (GCA per man-day) ratio in 1961, would be associated with a 1.26% above-average increase in the annual real wage growth rate; a 1% increase in tractorization rates, on the other hand, would be associated with a 0.2% below-average real wage growth rate.

technical change or mechanization on fertility change, is there evidence that these phenomena influence fertility decisions apart from the real wage growth path measured here? Our average annual wage data would not capture, for example, a fertility effect of altered seasonal labor demand patterns brought on by the introduction of HYV-linked technology. Two additional equations are estimated to further clarify the influence of HYV-linked technologies on fertility change *via* real wage growth (to the extent that this is captured in the variables of this study), and apart from such growth.

The first equation, not reported here,[35] estimates the component of real wage growth explained by HYV-linked technological change and tractor mechanization using OLS (that is, real wage growth was the dependent variable, and HYV-linked technological change and tractor mechanization variables, separately and interactively, were the independent variables): HYV-linked technology plus mechanization accounted for 27% of the variation observed in real wage growth (adjusted R^2=0.27).

[35] Results available from authors.

In order to test whether real wage growth due to HYV-linked technology and mechanization influenced fertility change, the next step was to include predicted real wage growth from the above equation as an independent variable in place of real wage growth in an OLS equation with TFR proportional change as the dependent variable, regressed on a more fully specified array of variables than was the case in Equation 1. As in Equation 1, an independent variable with a negative coefficient can be interpreted as hastening the proportional fertility decline. In addition to the Equation 1 variables, viz., those affecting (a) demand for children (including the predicted growth rate of real wages, as noted above), (b) the biological supply of children, and (c) the socio-cultural and demographic variables, we also include (d) labor-supply control variables, (e) variables relating to HYV-linked technology, (f) a tractorization indicator, and (g) other variables indicating the pace of agricultural change. HYV-linked technology and tractorization variables were included to test for the significance of non-real-wage-growth fertility effects of this agricultural transition (since their real wage growth effects are controlled for).[36]

[36] As was the case for Equation 1, Hausman-Wu endogeneity tests were performed and rejected for predicted real wage growth, crop-derived income growth, and cereal calorie production growth vis-ą-vis the TFR change dependent variable; in addition, endogeneity of land/labor growth and agricultural labor/total labor growth was also rejected.

Results appear in Table 9, Equation 3.[37]

The estimated coefficient for the predicted real wage growth variable is negative, statistically significant at 5%, and has an elasticity of 0.20, suggesting that above-average growth in real wages at District level caused by HYV technologies and tractorization spurred on above-average proportional declines in TFR. Moreover, evidence suggests that HYV- and mechanization-linked real wage changes not only affected TFR change, but were the driving force behind the impact of real wage growth on fertility decline: in an equation specified similarly to Equation 3, but including the residual rather than the predicted values for real wage growth, the residual -- the component of real wage growth <u>not</u> explained by HYV technological change and mechanization -- had no significant influence on fertility change.[38]

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[37] If any of these HYV and/or mechanization variables ha been chiefly responsible for real wage growth's effect on fertility change: a) their coefficients would have been expected to turn up as significantly linked to fertility change <u>once</u> their effect on real wage growth was purged; and b) the coefficient on the real wage growth variable, and/or its significance level, would have been likely to change from one version of Equation 3 to the other.

[38] "Not explained," that is, in a statistical sense; we do not mean to imply that household decisionmakers calculate such a decomposition of effects.

However, the fertility effects of real wage growth induced by HYV technology do not wholly capture HYV impacts on fertility change. Controlling for these effects, the HYV-related agricultural change variables and mechanization, tested as a block, are still linked to human fertility change (though only at the 9% significance level, with F-statistic=1.82). This suggests that Districts experiencing faster-than-average change in technologies linked to HYVs, also enjoyed faster-than-average declines in total fertility rates for reasons <u>other than</u> the already-established effect via our measure of real wage growth. These variables, as a block (and purged of real wage effects), are associated with 3% of subsequent inter-District variation in proportional fertility decline.

More specifically, Districts with above-average rates of growth in proportion of wheat and rice gross cropped area planted to HYV, starting in the mid-1960s and continuing until 1981, tended to experience significantly (at 10%) above-average proportionate declines in TFR from 1971-81 at the 10% level, with similar elasticities (0.15 and 0.13, respectively). Growth rate in proportion of bajra (millet) gross cropped area planted to HYV had the opposite effect (also significant at the 10% level), but with a smaller elasticity: with a 1% increase in proportion of a District's bajra cropping area planted with HYV seeds, 0.07% less of a TFR proportional decline would be experienced. Our HYV wheat and rice variables may be capturing the presence of accompanying labor-displacing innovations other than the tractorization that we control for, for example, threshers, reapers, and weedicides, that are not fully reflected in the predicted real wage growth variable. Wheat and rice HYV diffusion would therefore be associated with decelerating increases in demand for labor -- a situation enhancing the fertility transition. Bajra HYV diffusion, on the other hand, might also have labor demand effects unexplained by our prediction of measured real wage growth, perhaps to due its frequent association with less unequal operated holdings, and thus with owner- or tenant-farming (that is, less hired labor). Then, an above-average rate of increase in the prevalence of high-yielding varieties in the bajra crop -- as compared with a similar increase in rice or wheat -- could well be associated with rising family labor demand, which, especially as it encompasses child and adolescent labor, would be expected to slow the fertility transition.

Of the child demand, child supply, and socio-cultural and demographic factors tested as statistically significant determinants of fertility change in Equation 1, all but two (changes in the literacy rates for women aged 15-25, and changes in the marriage rates for women aged 15-19) remained significant after controlling for HYV-related technology, labor supply, mechanization rate, and expansion of gross cropped area and GCA/NCA ratio.[39] With the exception of the new real wage growth variable, elasticities for statistically significant relationships remained relatively unchanged from those described in Equation 1. With the changes from Equation 1 to 3, relative contribution of blocks to overall explanatory power shifted somewhat: with the predicted real wage growth, the child demand block in Equation 3 explains only 1% of total variation in TFRRAT; the child supply block explains 10%; and the socio-cultural and demographic block accounts for 32%.

The labor supply variables included in Equation 3 (but not in Equation 1) explained 2% of total variation in the dependent variable, with a 1961 labor force composition variable the only one significant (at the 10% level). A district with a 1% above-average proportion of agricultural laborers in the rural workforce in 1961 tended to

[39] As noted above, predicted values of real wage growth were used in Equation 3, differentiating the child demand variables from those used in Equation 1. The predicted real wage growth effect held up in Equation 3 as negative and significantly tied to TFR change at the 5% level; when tested in place of predicted real wage growth (but not reported here), actual real wage growth was also significantly, negatively linked to TFR change, but only at the 10% significance level.

experience a 0.64% below-average proportional fertility decline between 1971 and 1981.[40]

6. DISCUSSION

High-yielding varieties of staple crops were developed to stave off mass starvation in Asia, and to provide "breathing space" during which demographic transitions would occur in developing countries. This research assesses the impact of HYV-linked technologies on one essential component of demographic transition -- human fertility. Economic theory and recent demographic evidence highlight likely avenues through which HYV-linked technical change in agriculture might affect household fertility decisions: changes in real wages, improved incomes, improved access to food, and changes in traditional institutions and norms.

Data from 131 Indian Districts demonstrate dramatic and highly variable (inter-District) agricultural change from 1961-1981, as well as across-the-board -- but again

[40] The coefficient on the estimated rate of change of agricultural labor/total labor, not significant in the reported version of Equation 3, was significant at the 10% level and positive when real wage growth was fully controlled for (i.e., not just that component explained by technological change).

variable -- decreases in fertility over the 1971-1981 period.[41] We initially focused on the relationship of 1961 levels and subsequent growth rates in real wages, income, and food availability to subsequent fertility declines.[42]

A strong negative association between real wage growth and changes in total fertility rates (TFRs) was identified, that is, Districts with above-average growth in real wages in rural areas experienced above-average proportional declines in TFRs. According to theory, growth in rural real wages could have this effect through dampened child demand if it captured: a) increased opportunity cost of child-rearing; b) rising demand for more highly skilled labor (which could prompt the decision to invest in educating a few children (rather than rearing many); or c) increased old-age security for parents with fewer children (given higher expected real income).

Initial (that is, 1961) differences among Districts in the rural real-wage rate had no bearing on their speed of TFR decline over the 1971-81 period. Growth in income derived from annual cropping (per capita) had no influence on TFR change either, but starting levels of crop-derived income per person did: Districts with higher 1961 levels experienced swifter subsequent declines in TFRs. This result can be explained by theory

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[41] Lack of data (i.e, lack of panel data for both demographic and agricultural data series) prevented our testing alternative time-lag structures for the effects of agriculture-related change on fertility declines.

[42] Given that, as stated previously, theory does not allow us to hypothesize *a priori* about the size and direction of fertility change determinants, discussion of results in this section focuses on proposing plausible scenarios given the theory, not definitive ones.

if such Districts were "primed" to replace investments in child quality for those in child quantity.

Finally, above-average 1961 levels of cereal calorie production per rural capita led to slower proportional decreases in TFR, because (we believe): a) cereal calorie production in 1961 provided a relative measure of District-level food availability; and b) sample Districts clustered around levels of caloric intake below biomedical "sufficiency" levels at levels such that more calories yielded increasing returns to fertility. If, in these instances, greater food availability removed biological constraints to fertility, subsequent fertility declines may have been dampened. Growth rates of cereal availability did not affect TFR change.

In Equations 1-3, we demonstrated the impact of real wage growth on TFR change. Next, the impact of HYV-linked technologies on such growth was assessed, controlling for labor supply effects (previous analyses having failed to link growth in either income or cereal availability to declining TFR). Overall, in wheat and rice, Districts with above-average growth in the proportion of area planted to HYV tended to have below-average growth in real wages, as did those Districts with faster tractor mechanization (in some Districts, real wages actually declined). Fertilizer use had the same retarding effect on real wage growth, a surprising finding. HYV-linked technical change in irrigation led to increased growth in real wages.

Given data (and labor-market) imperfections, and consequent (expected) impacts on the ability of price-related variables (especially the rural real wage) to fully capture the impact of HYV-linked technologies on TFR change, a final set of analyses was performed to assess the impact of these technologies on TFR change: a) via their effect on real wage growth; and b) net of their effect on real wage growth. Results show that: a) HYV-linked technological change and tractorization did affect rural real wage growth, and were responsible for some of its fertility-dampening effect; and b) controlling for the effect on TFR change of HYV-linked technical changes via our measure of real wage growth, HYV-linked technical changes still influenced TFR change, and did so, depending on the crop in question, in different directions, due to differences in the labor-displacing or labor-using nature of the production process, given real wages. Higher proportions of HYV in wheat and rice led to steeper proportional fertility declines, while those in bajra led to smaller proportional fertility declines.

The study confirms that socio-cultural and demographic factors, some amenable to policy, affect fertility change at District level. Districts with faster decreasing proportions of cultivator households in the population experienced faster fertility declines, perhaps due to the removal of the fertility incentive provided by child and adolescent family labor on farm. Having a workforce that is more diversified out of agriculture before technological change begins enhances fertility decline (perhaps capturing differences in norms, information, and services that can characterize a diversified versus a largely agricultural workforce); and larger increases in prevalence of female literacy for females aged 25-35 also translate into larger fertility declines (with schooling delaying marriage, and education perhaps increasing opportunity cost of child-rearing). This array of socio-cultural and demographic factors exerted a much stronger influence on fertility than did technological change.[43]

The fact that some technology packages, as in the case of HYV bajra, wheat, and rice, do have fertility effects should not prompt policymakers to discard otherwise promising technologies on the grounds of those effects -- whether they retard or enhance fertility. Governments and the international community must continue to seek biotechnological and other answers to particular agroecological problems of underdeveloped areas, to improve crop robustness in the face of biotic and moisture stresses, to raise yield potential in main food staples, and to promote adoption of appropriate technologies through regional outreach. However, it is critical that policymakers know what the human fertility impact of the technological packages is, so that whenever theory and/or empirical evidence suggest that such technology packages will affect, directly or indirectly, the population side of the food-per-head equation, policy can seek to compensate for such effects. Likewise, evidence of technology-induced fertility decline should not lead governments to reduce investments in other key areas. This study (and many others) point to policy-relevant community factors such as non-agricultural social infrastructure, particularly female education, as effective ways to counter the potential pro-natalist effects of some HYV-linked technologies.

[43] This study did not delve into the extent to which technological change works via socio-cultural and demographic determinants to affect TFR declines (or how the primary "three general fertility determinants" explicitly interact with these variables vis-ą-vis fertility), but correlations among these variables suggest that such an indirect link is possible.

This study suffers from three principal drawbacks. First, India's fertility and agricultural transitions are far from over, and this paper captures just a part (an important part, albeit) of each. More time, more longitudinally comprehensive data series (especially the 1991 census results in full), and more comprehensive information (for example, incomes, wages disaggregated by labor type, and nutritional status vis-ą-vis biological fertility thresholds) would be required to more thoroughly pinpoint pathways through which technological change affects fertility, and explore how quickly such effects take place (for example, the time lag structure left unspecified in theoretical diagrams such as Figure 1).

Second, there are important gaps in our data. Regionally, they preclude the inclusion of some of the poorest areas of India, which have experienced the least "green revolution" and often the lowest TFR declines. These data gaps can and should be rectified. Primary data often exist, but much time and many resources will need to be invested to collect, prepare, and analyze these data. It is especially unfortunate that disaggregated District-level results, especially TFRs from the Sample Registration Survey, are not available; they would give a much more reliable and time-specific (yearly) picture of fertility changes -- and permit much better tracking of local time-lags from, and effects of, HYV progress -- than was possible with our purely Census-based population data.

Finally, much of the impact of technical change in agriculture is likely to be felt below the District level. We should recall that many Indian Districts have larger populations than several African and Asian countries -- and at least as much diversity.

Different socioeconomic and ethnic groups -- especially the least mobile -- are probably affected by localized changes in area under plow, in crop-specific yield increases, and in crop mix. Within a District, different implications for household fertility decisions may co-exist given the same District-level trends in food production and agricultural change. Data of sufficient geographic and longitudinal scope for undertaking the current study at a more disaggregated level are not currently available; major investments would be required to generate such data.

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