AGRICULTURAL CHANGE AND POPULATION GROWTH: DISTRICT-LEVEL EVIDENCE FROM INDIA

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1. Introduction

In 1959, a Ford Foundation analysis of India's food crisis helped spark international agricultural research that led to the high-yielding varieties (HYVs) of the Green Revolution (Ford Foundation). Underlying the effort lay an assumption that agricultural technical change could help avoid (not just postpone) Malthusian outcomes where burgeoning populations led to famine (Sen). By the early 1970s, HYV adoption was well under way in India, yields were up, and the food crisis averted (Lipton). Many voiced hope that the Green Revolution and economic development more generally would catalyze a fertility transition in developing countries. But population there has continued to grow since, albeit often at ever slower rates. This paper examines how Green Revolution technological change altered rural India's pace of demographic change.

Theory presents myriad pathways via which agricultural change can positively or negatively influence fertility choices, assignable into supply-related, demand-related, and sociocultural categories, Studies confirm that both biological and socioeconomic factors within these categories act as human fertility determinantes (Easterlin and Crimmins; Thomas and Price).

Couples' supply of children is affected by biological fertility, which is in turn affected by nutrition and access to contraception. Agricultural change can prompt nutrition gains, raising fertility among the very poor, partly for biomedical reasons (Easterlin). Agricultural change can lead to greater access to contraception, should it lead to higher incomes or wider availability of health services, or if adoption of agricultural innovations makes innovation in other spheres more likely (Mueller).

Demand by couples for children is influenced in part by parents' expectations about the economic costs of bearing and rearing offspring and about their subsequent income benefits from offspring's income, along with other human, emotional, and biological needs. Costs include direct expenditure on children, foregone work opportunities for women due to childcare, and expense of averting births via contraception (Becker and Lewis; Schultz). Expected earnings of (few but educated or many but unskilled) children, plus (related) ability to care for aging parents, enter on the benefits side. Green Revolution technologies might: a) reduce fertility by raising child-rearing costs and improving income prospects for educated, later-marrying children (Foster and Rosenzweig); but, offsetting this, b) increase fertility should they raise the demand for young, unskilled labor (Islam and Taslim); and c) ambiguously affect fertility if they alter demand for women's work (Mukhopadhyay).

Institutional factors – for example, religion, family and inheritance pattern, kin structure, caste and class norms regarding marriage and literacy – also affect demand for children by altering cost and income potential per child, and influencing family size norms (Bongaarts and Cotts Watkins).

Supply changes might shift outcomes more quickly than demand due to the former's reliance on biology and the latter's on expectations. Throughout the diffusion process, moreover, direct effects on adopters would appear first, and spill over into society at large only as adoption gathered steam. These complex avenues suggest that implementation of HYV-linked technologies could confound priors about HYV-linked fertility effects as regards timing, extent, direction, and level of change. Particular technologies, moreover, phased in at varying times and extents in different places, diffused at different speeds, and had different impacts on the local economy, particularly labor use (Jayasuriya and Shand).

Studies on South Asia examined agricultural technology change and its effects, and fertility decline and its causes. Early adopters of HYV technologies tended to be better off, but the poor eventually benefited (Hazell and Ramasamy). Technology change enhanced investment in and returns to schooling (Foster and Rosenzweig); in turn, education, especially for women, is linked to fertility declines (Murthi *et al.*). In Bangladesh, population pressure led to a less mechanized HYV adoption. Yield increases fell behind population growth, and labor productivity declined (Islam and Taslim).

Other studies focus on how technologies' use of labor shifted demand for children. In West Bengal, the switch to HYVs resulted in fewer women working on-farm and a smaller wage labor pool, promoting fertility increases (Mukhopadhyay). More recent work from West Bengal shows that modern agriculture pursued by more capitalized farmers may make more intensive use of child labor (Majumdar *et al.* 2001a), so that demand for child labor rose along with cropping intensity, capital to labor cost ratios, and gross crop value per acre (Majumdar *et al.* 2001b).

In these studies, where geographical and temporal coverage is best (Foster and Rosenzweig; Islam and Taslim), the focus is technical change. Those that look at fertility levels or spatial heterogeneity in its decline (Population Council; Guilmoto and Rajan) do not consider technical change. Where fertility and technology decisions (at household level) were analyzed jointly (Mukhopadhyay), the temporal and geographical focus was narrower.

This study seeks to partially fill this gap by looking at the effects of a great agricultural transformation on changes in fertility over a broad, diverse geographic area. The data offers variation in a 10-year period of fertility change, 1971-81, following an agricultural transformation from 1965-80, and a prior base period of agricultural activities, 1960-64, for a sample of 131 Indian Districts. Section 2 discusses District-level study data. Section 3 uses multiple regression analysis to trace evidence for direct effects on fertility transition of variables measuring changes linked to biological supply of children, parents' expected economic gains and losses from children, or sociocultural factors. Section 4 controls HYV-related technological change’s impact on real wage growth in order to disentangle how such technologies influenced fertility transition via real wage shifts vs. net of them. Section 5 concludes the paper.

2. District-Level Human Fertility Decline and Agricultural Change in India

Tables 1 through 4 report the vast demographic, agricultural, and economic changes that occurred during the study period throughout India, selected States, and the 131 sample Districts. Table 1 shows rural total fertility rates (TFRs) dropping between 1971 and 1981 country-wide, at State level, and within sample Districts.[1] Sample Districts averaged a 20% decline in TFR over the period, with wide variation (1% to 38%). Table 2 documents substantial change in Indian agricultural production between 1960/1 and 1980/1.[2] Population pressure on cropped area increased, accompanied by more intensive land use, and more widespread use of irrigation and tractors. As HYV crops diffused during the 1970s, so did fertilizer application. Sample Districts were not among the earliest adopters of HYV crops, but expanded them at a relatively fast clip vis-à-vis the rest of India during the study period. This expansion was accompanied by substantially less tractor use than elsewhere in India – perhaps signaling less available capital in these areas during the adoption process. Table 3 reports that, concurrent with this agricultural transformation, labor intensity increased in sample Districts (and sample States) while falling countrywide. Growth in labor demand outpaced supply growth, driving real wages upward. Table 4 lists descriptive statistics for measures of factors hypothesized to affect demand for and supply of children, loosely grouped in blocks corresponding to type of determinant of TFR decline. Sociocultural factors (that work through either demand or supply) are listed separately.

3. From Agricultural Technology to Human Fertility

Measures (from Table 4) of levels and changes in real wage, income, and food availability on fertility change at District level were included as independent variables in an Ordinary Least Squares (OLS) equation for proportional TFR change, controlling for sociocultural and demographic factors. Estimation results appear in Table 5, Equation 1. Demand-for-children variables accounted for 4% of the variation in proportional TFR decline (column 4, Table 5). Higher crop value before the HYV-

[1] Vosti and Lipton detail the estimation of District-level TFR.
[2] Bhalla and Tyagi present a geographically comprehensive review of District agricultural change.

linked changes and faster growth in agricultural real wage rates over the period were both associated with faster proportional TFR declines. Column 3 of Table 5 reports elasticities for these effects (a negative number connotes the percentage increase in proportional TFR decline due to a 1% increase in the regressor). Of child supply variables, more available cereal calories prior to HYV adoption were associated with less of a proportional TFR decline in the 1970s.

Sociocultural and demographic factors explained 39% of the variation in proportional TFR decline. Literacy and marriage effects on fertility varied by age group. A commonly found association between fertility decline and faster advances in female literacy existed only among the older cohort (women aged 25-35); an opposite (weaker) effect appeared among the younger cohort (women aged 15-25). Marriage deferment had an expected association with larger fertility decline, with the stronger effect for the younger cohort. Districts with a higher prevalence of older widows (age 40-44) had lower proportional TFR declines. Greater landlessness or movement out of the farm sector altogether (as measured by decline in proportion of cultivator households) hastened proportional TFR declines.

Of the three statistically significant child demand and supply variables, only the real wage rate growth could be affected by HYV-linked agricultural change starting in the mid-1960s (since the level variables were measured prior to this). So it's an open question how much of that real wage growth linked to TFR declines can be attributed to HYV-related agricultural change and mechanization.

4. HYV-Associated Agricultural Change: Links to Real Wage Growth and Fertility Changes

Equation 1 demonstrated that real wage growth significantly influenced proportional fertility decline. Two additional OLS regressions with real wage growth as the dependent variable shed light on the role of agricultural technology transformation in fertility declines working through and net of real wage growth. Results for the first (Equation 3, Table 5, final column) isolated a significant effect of technological change on real wage growth (accounting for 27% of its inter-District variation) by controlling for labor supply variables indicated by theory to have direct influence on real wage growth.

To tease out the extent to which agricultural transformation's influence on real wage growth drives the real wage – fertility link (an indirect technology – fertility link), and if the agricultural technology had its own, direct impact on fertility decline, a second equation explaining real wage growth rates was estimated leaving out the labor supply regressors and using only the agricultural transformation technology variables on the right-hand side. The resulting predicted real wage growth rates represent that portion of real wage growth explained by technological agricultural transformation variables. These predicted values replaced actual real wage growth rates (as used in Equation 1) in another equation (Equation 2, Table 5).

The statistically significant estimated coefficient on the predicted real wage growth variable indicates that agricultural transformation technology did work through real wage growth to affect fertility. Evidence suggests that HYV- and mechanization-linked real wage changes were actually the driving force behind the impact of real wage growth on fertility decline: in an equation specified similarly to Equation 2, but including the residual rather than the predicted values for real wage growth, the residual – the component of real wage growth not explained by HYV technological change and mechanization – had no significant influence on fertility change.

The fertility effects of real wage growth induced by agricultural transformation technology do not, however, tell the whole story. Controlling for these effects, the HYV-related agricultural change variables and mechanization in Equation 2 (purged of their effect on real wage growth) still as a block influenced human fertility change (at the 9% significance level, with F-statistic=1.82, explaining 3% of inter-District variation in proportional fertility decline). Yet mechanization, irrigation intensity, and growth in fertilizer use all affected fertility decline solely via their effects via real wage growth. The direct impact of agricultural transformation technologies on fertility decline was attributable to adoption rate of certain crop-specific HYV technologies. Faster growth rates in HYV wheat and rice as a proportion of GCA was significantly related to larger proportional declines in TFR. Similar increases in diffusion of bajra HYV instead retarded fertility decline. Results for other child demand and supply variables remained generally robust from Equation 1 to Equation 2, but the younger female cohort results regarding literacy and marriage deferment disappear – suggesting that these effects were related to real wage growth rates.

5. Discussion

High-yielding varieties of staple crops and associated technologies developed to stave off mass starvation in Asia and provide breathing space for demographic transition did influence human fertility rate changes at District level. The study confirmed that sociocultural and demographic factors, some amenable to policy, affected fertility change at this level, exerting a stronger influence than (and largely independent of) changing technology.

That said, better-off Districts at the onset of agricultural transformation experienced larger subsequent TFR declines, supporting the notion that the pace of demographic transition is sensitive to initial income (with fertility declines more readily achieved at higher income levels in this sample). Rural wage level was not significantly linked to subsequent TFR decline, but real wage growth was. As demand for labor outstripped its availability despite a growing population (driving wages upward), the higher opportunity cost of having children won out over countervailing effects, leading to larger drops in fertility. Agricultural transformation technologies were behind some of the real wage growth in the sample. Increasing irrigation density was associated with higher wage growth, while expanding use of fertilizers and tractors were associated with lower wage growth. Greater growth in the proportion of wheat planted to HYV was also associated with slower real wage growth, perhaps indicating HYV wheat's adoption in this sample involved labor-displacing mechanization other than tractors such as threshers and reaper-binders. That these change variables explained real wage growth better than a general measure of labor supply shifts points up that labor demand associated with particular technologies (skill level and timing) mattered to wage trends.

To assess the impact of HYV-linked and mechanization technologies on TFR change via and net of their effect on real wage growth, a second regression for TFR change included estimated values of real wage growth (as predicted by technology variables) as an independent variable. Results show that mechanization, growth in fertilizer use, and growth in irrigated area only affected fertility declines indirectly, via real wages, indicating economy-wide consequences of technology adoption. HYV-specific technology adoption rates, in contrast, had some impact net of real wage effects, so on fertility behavior of HYV adopters without general equilibrium implications. Larger increases in proportions of HYV in wheat and rice gross cropped area led to steeper proportional fertility declines, while those in bajra slowed fertility decline.

Governments and the international community must help sustainably raise yields through appropriate technologies (Rosegrant *et al.* 2001). With yield goals entwined with population projections, policymakers must keep an eye on possible human fertility impacts of new technological packages. This study reemphasizes non-agricultural social investments such as female education (especially for the cohort in their twenties) as effective policy targets to influence fertility rate change, and points to intergenerational influences (presence of older widowed women) on fertility outcomes.

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Table 1-- Rural Total Fertility Rates (TFRs)

State	1971 and 1981 Number of Districts		1971			1981			1971-81 Absolute decline in:		
	In Sample	In State	State TFR	Sample TFR District		State TFR	Sample TFR District		State 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	B	5.3	4.6	B	1.7	1.4	B
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, Sample Registration Bulletin, various issues. For details see Vosti and Lipton.

Table 2 -- Technical Change in Agriculture: Sample Districts and States 1960/1-1980/1

	1960/1			1970/1			1980/1			1960/1-1980/1 Compound Growth (%/yr) (1970/1-1980 for HYV Variables)		
Modern Input Use	Sample Districts	Sample States	India	Sample Districts	Sample States	India	Sample Districts	Sample States	India	Sample Districts	Sample States	India
NPK (kg of nutrient/ha)[a]	1.3	1.5	1.9	12.8	15.8	13.8	24.8	36.8	32.4	14.7	16.0	14.2
4-wheel tractors/NCA[b]	.1	.2	.2	0.5	1.2	1.1	1.9	3.7	3.7	5.6	14.1	13.9
% HYV in GCA[c]	0	0	0	6.7	12.2	8.6	20.6	24.6	24.8	11.2	7.0	10.6
Area in HYV (%)												
Rice	0	0	0	19.3	24.4	13.5	54.1	61.5	44.8	10.3	9.2	12.0
Wheat	0	0	0	19.4	34.1	35.9	54.0	67.0	73.0	10.2	6.8	7.1
Jowar	0	0	0	4.7	9.4	4.0	23.8	23.5	21.3	16.2	9.2	16.7
Bajra	0	0	0	18.1	32.4	13.0	49.5	50.6	49.5	10.1	4.5	9.2

Sources: Indian Agricultural Statistics, Area and Production of Principal Crops in India, Indian Livestock Census and Fertiliser Statistics, Various issues. See Vosti and Lipton for details.

[a] Data for 1960/1 are two-year averages from 1959/60, 1960/1.

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

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

Table 3 - Agricultural Labor Use Data*

	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, Area and Production of Principal Crops in India, Census of India, Agricultural Wages in India, and Indian Labour Journal, various issues. See Vosti and Lipton for details.

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

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

Table 4 - Descriptive Statistics

Variable	Mean	Std Dev	Description
TFRRAT	-.20	.07	Proportional change from 1971 to 1981 in District-level Total Fertility Rate
Demand for Children			
RLWAGER	.02	.03	Estimated growth rate* (1960-1 Rs/yr) in real wage
VTOPOPR	1.01	3.42	Estimated growth rate* (1960-1 Rs/yr) in crop VTO per rural capita
RLWAGE	1.44	.56	Rural real wage (expressed in 1960-1 Rs) at the start of the sample period
VTOPOP	129.25	45.67	Value of total output (expressed in 1960-1 Rs) per capita (rural) for available from top fifteen crops at the start of the sample period
Supply of Children			
CERCALR	.005	.02	Compound rate of growth over sample period in cereal calories per rural population produced annually
CERCAL	1877.28	738.52	Daily cereal calorie equivalents per capita = (average annual crop output)*(calories per harvestable unit [Gopalan et al. 1981])/(rural population)/365. (See footnote 13.)
Sociocultural and Demographic Variables			
PRPTRBE	.10	.18	Proportion of rural District population composed of scheduled tribes, 1971 Census
PRPWIDW	.15	.04	Proportion of rural District females age 40-44 who were widows, 1971 Census
PRPCULR	-.002	.003	Estimated growth rate* (proportion/yr) in proportion of rural District population composed of cultivators
LITFEM1	.06	.05	Change from 1971 to 1981 in proportion literate of rural females age 15-25
LITFEM2	.13	.07	Change from 1971 to 1981 in proportion literate of rural females age 25-35
MARFEM1	-.13	.07	Change from 1971 to 1981 in proportion married of rural females age 15-19
MARFEM2	-.03	.04	Change from 1971 to 1981 in proportion married of rural females age 20-24
MARFEM3	-.003	.02	Change from 1971 to 1981 in proportion married of rural females age 25-29
Labor Supply Block			
GCALABR	-.03	.03	Estimated growth rate* (ha/man-day/yr) for gross cropped area to labor
FRMPRPR	.000	.003	Estimated growth rate* (proportion/yr) in proportion of total District laborers involved in agricultural labor
GCALAB	2.34	1.10	Land-to-labor ratio (has. gross cropped area/man-day) in 1961
FRMPRP	.81	.09	Proportion of total District laborers involved in agricultural labor in 1961
HYV-Related Technology Block			
PHYVMZR	.09	.07	Compound rate of growth of proportion of crop specified planted to HYV annually in District
PHYVJWR	.21	.11	Compound rate of growth of proportion of crop specified planted to HYV annually in District
PHYVBJR	.11	.12	Compound rate of growth of proportion of crop specified planted to HYV annually in District
PHYVWHR	.17	.12	Compound rate of growth of proportion of crop specified planted to HYV annually in District
PHYVRCR	.21	.10	Compound rate of growth of proportion of crop specified planted to HYV annually in District
GIAGCAR	.004	.005	Estimated growth rate* (proportion/yr) for gross irrigated area to gross cropped area
NPKGCAR	.17	.05	Estimated compound rate of growth of tonnes of nitrogen, phosphorus, and potassium fertilizer applied per ha annually in District
Mechanization			
TRCNCAR	.15	.29	Estimated growth rate* (tractors/ha/yr) for tractors per net cropped area
Agricultural Area Block			
GCAR	2.41	4.12	Estimated growth rate* (has/yr) for gross cropped area
GCANCAR	.004	.01	Estimated growth rate* (proportion/yr) for gross cropped area to net cropped area

* Estimated as a quadratic function of time *t*, evaluated at *t*=1975.

Table 5 - Determinants of TFR Decline

Variable Label	**Equation 1** - TFRRAT Estimated Coefficient	Elasticity[a]	Contrib. to total R^2	**Equation 2** B TFRRAT Estimated Coefficient	Elasticity[a]	Contrib. to total R^2	**Eq. 3** – RLWAGER Estimated Coefficient
Demand for Children Variables							
RLWAGER 1961-81	-0.43**	-0.04		-1.79*	-0.20		
VTOPOPR 1961-81	2.93ε-4			-0.001		0.01	
RLWAGE 1961	0.01		0.04	0.004			
VTOPOP 1961	-4.73ε-4***	-0.31		-4.64ε-4***	-0.30		
Supply of Children Variables							
CERCALR 1961-81	0.11			-0.004			
CERCAL 1961	1.80ε-5**	0.17	0.06	2.14ε-5**	0.20	0.10	
Sociocultural Factor and Demographic Variables							
PRPTRBE 1971	-0.11***	-0.06		-0.12**	-0.06		
PRPWIDW 1971	0.42***	0.31		0.34**	0.25		
PRPCULR 1961-81	4.45***	-0.04		4.82**	-0.05		
LITFEM1 1971-81	0.28**	0.08	0.39	0.22		0.32	
LITFEM2 1971-81	-0.36***	-0.23		-0.26**	-0.17		
MARFEM1 1971-81	0.15**	-0.10		0.13			
MARFEM2 1971-81	0.32*	-0.05		0.39*	-0.06		
MARFEM3 1971-81	-0.45			-0.55			
Labor Supply Variables							
GCALABR 1961-81	--	--		0.04			0.12
FRMPRPR 1961-81	--	--		3.69			1.35
GCALAB 1961	--	--		-0.001		0.02	0.01***
FRMPRP 1961	--	--		0.16*	0.64		0.02
HYV-Related Technology Variables							
PHYVMZR	--	--		-0.10			0.04
PHYVJWR	--	--		-0.01			0.02
PHYVBJR	--	--		0.12*	0.07	0.03	0.03
PHYVWHR	--	--		-0.18*	-0.15		-0.10***
PHYVRCR	--	--		-0.12*	-0.13		-0.02
GIAGCAR[a] 1961-81	--	--		2.57			1.85***
NPKGCAR 1961-81	--	--		0.04			-0.41
Mechanization							
TRCNCAR 1961-81	--	--		-5.70ε-4			-0.03***
Agricultural Area							
GCAR 1961-81	--	--		0.001			
GCANCAR 1961-81	--	--		-0.61			
Constant	-0.17***			-0.22**			0.02
$\bar{R}^2$ =	0.49			0.49			0.32
N =	131			131			131

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

[a] Evaluated at dependent and independent variable mean values.