Seasonal Effects of Water Quality: The Hidden Costs of the Green Revolution to Infant and Child Health in India

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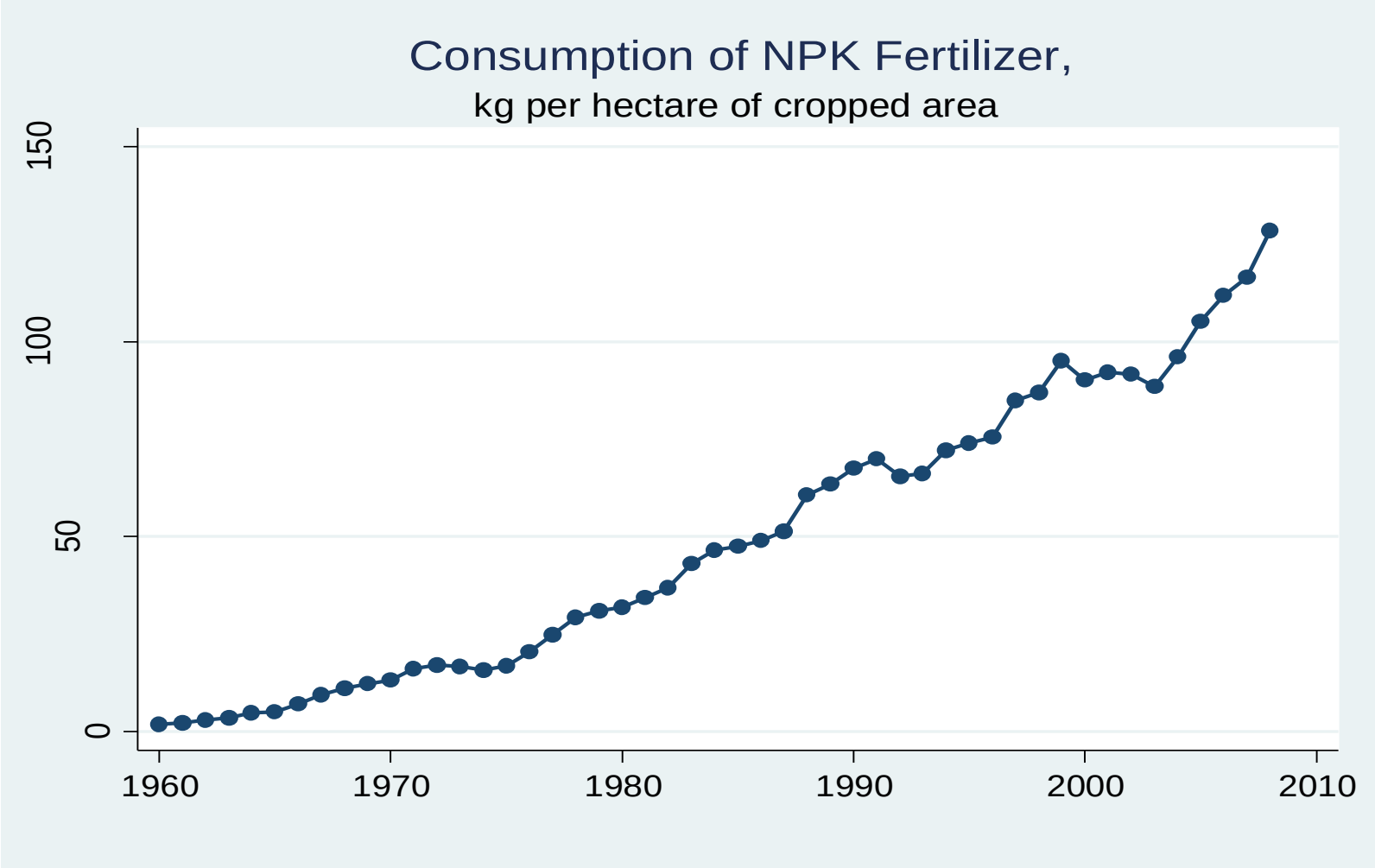
Motivation

- Green Revolution (1965-late 1970s)
  - increased agricultural production and helped achieve food security
  - exacted a toll on the country's environment: contamination of water
  - technologies: HYV seeds, "double-cropping", irrigation, pesticides, and nitrogenous fertilizer
  - HYV seeds need more fertilizer and water than do indigenous seeds

- Synthetic nitrogen based fertilizers such as Urea and Nitrogen-Phosphate-Potassium (NPK)
  - heavily over-used
  - seepage into surface and ground water through soil run-offs

Trend in consumption of NPK fertilizer in India



Motivation

- Goal of study: evaluate the infant and child health implications of exposure to fertilizer agrichemicals
  - focus on fertilizers because they have relatively clear application times
  - concentrations of agrichemicals in water vary seasonally
  - water contamination also varies regionally (northern India plants winter crops; southern India plants summer crops)
  - focus on agrichemicals in water as it is considered a reliable measure of human exposure

Why is this relevant?

- In rural India, women are at the forefront of farming activities
  - 55-60 percent of the labor force, so directly exposed
  - their children are exposed both *in utero* and after birth to toxins
  - rates of stunting and wasting among Indian children are higher than predicted given per capita income and infant mortality rates (Deaton and Dreze, 2009)

- Negative externalities of motile agrichemical-contaminated water

Why is this relevant?

- Seasonal exposure to water toxins can have inter-generational effects
  - documented link in biomedical studies between low-birth weight and coronary heart disease which is inheritable
  - transmission occurs even without any additional exposure to chemical contaminants in water
  - Behrman and Rosenzweig (2004) note importance of fetal health/nutrition

Preview of results

- Presence of agrichemicals in water in month of conception significantly increases infant and neo-natal mortality
  - 10 percent increase leads to rise in infant mortality by about 4.6 percent
  - 10 percent increase leads to rise in neo-natal mortality by about 6.2 percent

- Agrichemicals in month of conception have significant negative impacts on height-for-age and weight-for-age z scores as of age 5

- Negative effects are most evident for vulnerable populations
  - children of uneducated poor women in rural India

Preview of results

- Some evidence that exposure beyond the first month matters (first, second and third trimester exposure)

- Results robust to checks on instruments and omitted variables such as rainfall, temperature, diseases, timing of conception and parental characteristics

Previous literature

- Economics: risks of toxins in developing countries
  - impact of air and water pollution on child and adult health
    - Pitt *et al*. (2006)
    - Jayachandran (2009)
    - Greenstone and Hanna (2011)
    - Arceo-Gomez *et al*. (2012)
  - impact of increased access to clean water
    - Galiani, Gertler and Schargrodsky (2005)
    - Zhang (2012)
    - Ebenstein (2012)

Previous literature

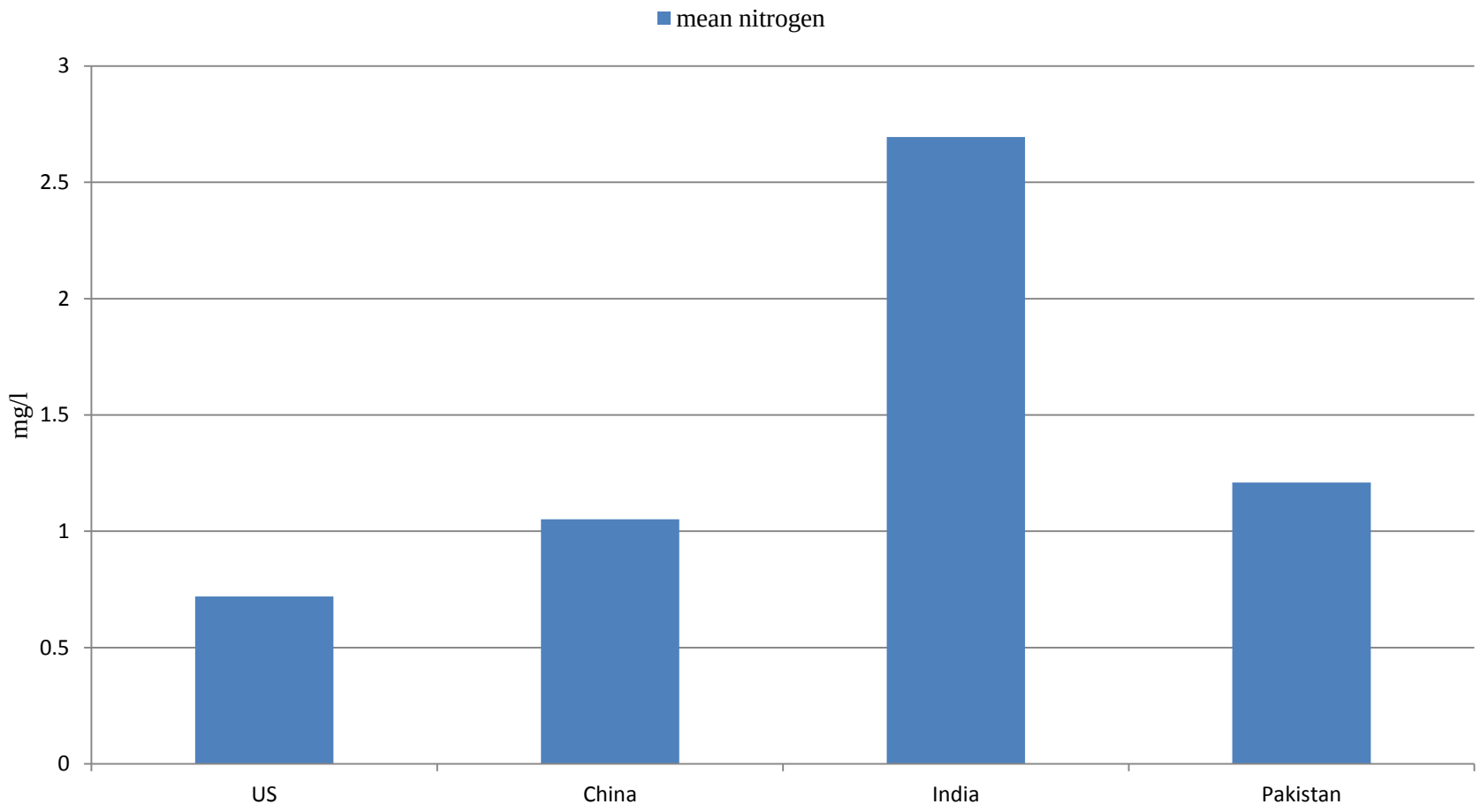
- Biomedical studies: risks of toxins in the developed world
  - impact of water toxins on infant health
    - Garry *et al*. (2002)
    - Winchester *et al*. (2008)

- Public health studies: risks of toxins in developing countries
  - impact of exposure to chemicals on infant health
    - Restropo *et al*. (1990)
    - Heeren *et al*. (2003)

Cross-country comparison

- Water pollution concentrations are higher in India than in other countries like the US or China
- Average nitrogen level in Indian water bodies significantly exceeds levels in US and China over a comparable time period
- True even in relation to Pakistan, neighbor that shares agricultural and socio-economic practices

Cross-country comparison of the prevalence of nitrogen in water from 1980-1996.



Identification methodology

- Identify fertilizer agrichemical impacts using two sources of variation for the main crops of rice and wheat
  - exogeneity in soil endowments which makes some states more suitable for rice and others for wheat
    - bulk of wheat production – UP, Punjab, Haryana, Gujarat, Bihar, MP
    - bulk of rice production – AP, WB, Assam, Tamil Nadu, Kerala, Orissa
  - exogeneity in timing of crop cycles of each crop
    - rice is mainly a *kharif* (monsoon) crop: sown in June-August and reaped in autumn
    - wheat is a *rabi* (winter) crop: sown in November-April and harvested in spring

Identification methodology

- Control for other indicators of water quality
  - levels of biochemical oxygen demand (BOD)

- Measurement errors
  - in fertilizer agrichemical variable
  - in BOD

- Correct for measurement error in fertilizer and BOD using normalized crop area x crop cycles (planting months) as identifying instruments

- First stage for fertilizer

$$F_{jtm_c} = \gamma_0 + \gamma_1 \, (R_{jt} \; x \; M^R) + \; \gamma_2 (W_{jt} \; x \; M^W) + \vartheta_{ijt}$$

Water data

- Central Pollution Control Board (CPCB) of India:
  - established by the Water Act of 1974
  - GEMS and MINARS programs to monitor water quality

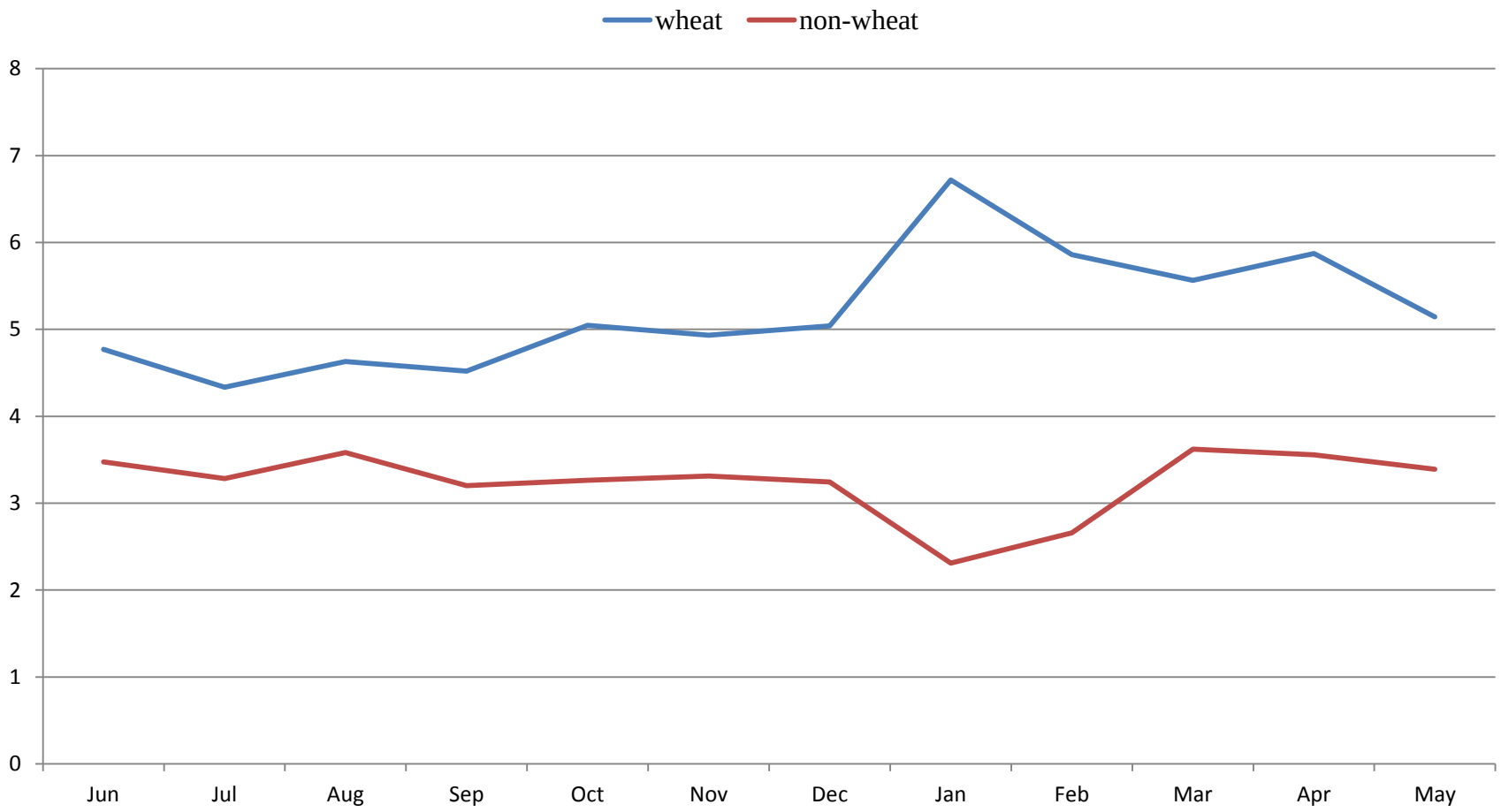
- Location of monitoring stations:
  - major rivers/tributaries, wells, lakes, creeks, ponds, canals, and tanks throughout India
  - 870 stations as of 2005

Water data

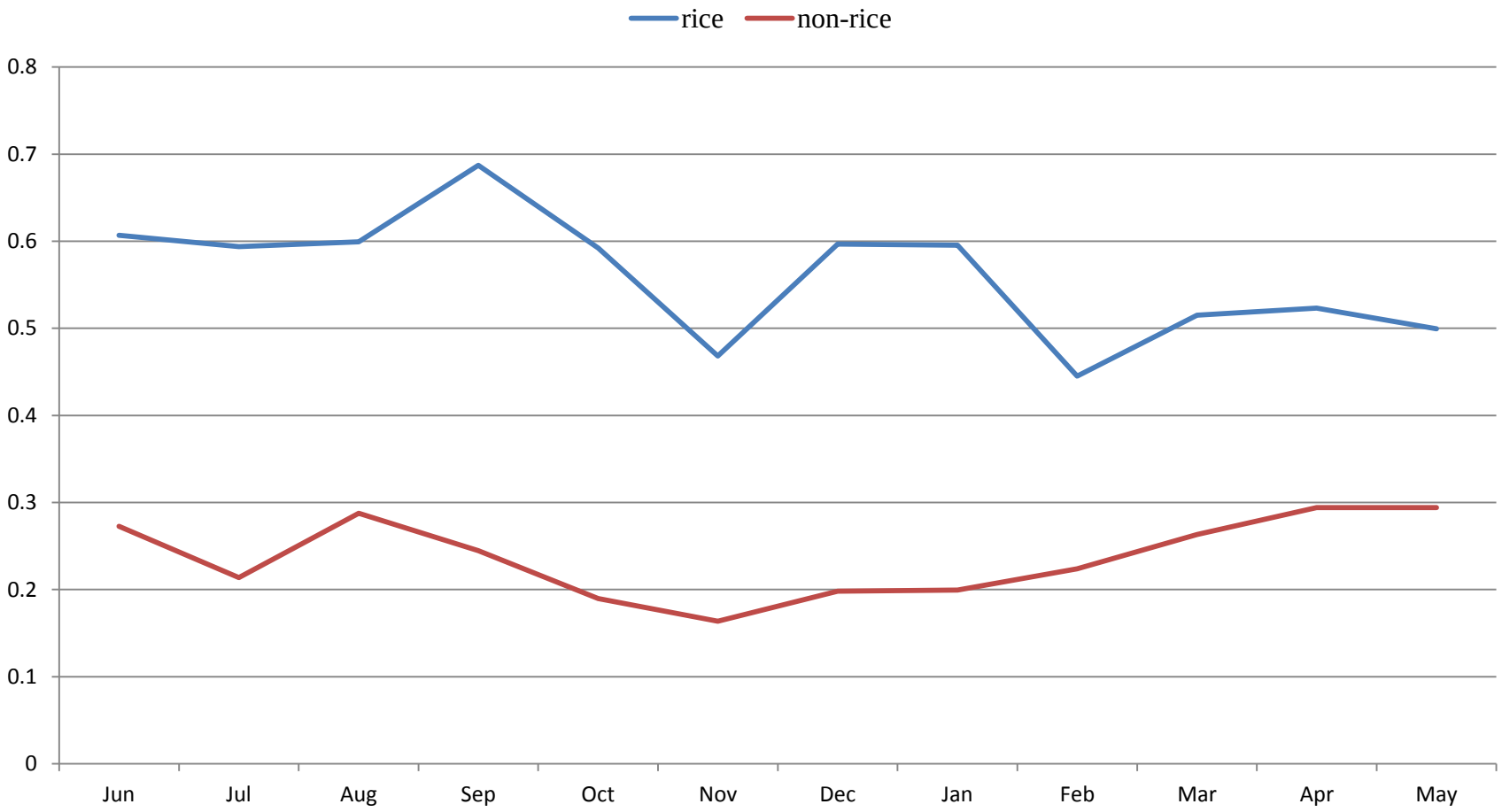
- CPCB collects statistics on:
  - microbiology, nutrients, organic matter, major ions, metals, and physical/ chemical characteristics of water

- Sources of our water data:
  - UNEP/GEMS (1978 to 2005 data – subset of monitoring stations)
  - CPCB electronic files (2005 only)
  - Greenstone and Hanna (1986 to 2005 data – 489 stations in 424 cities)
  - CPCB year books (annual data from 1978 to 2005)

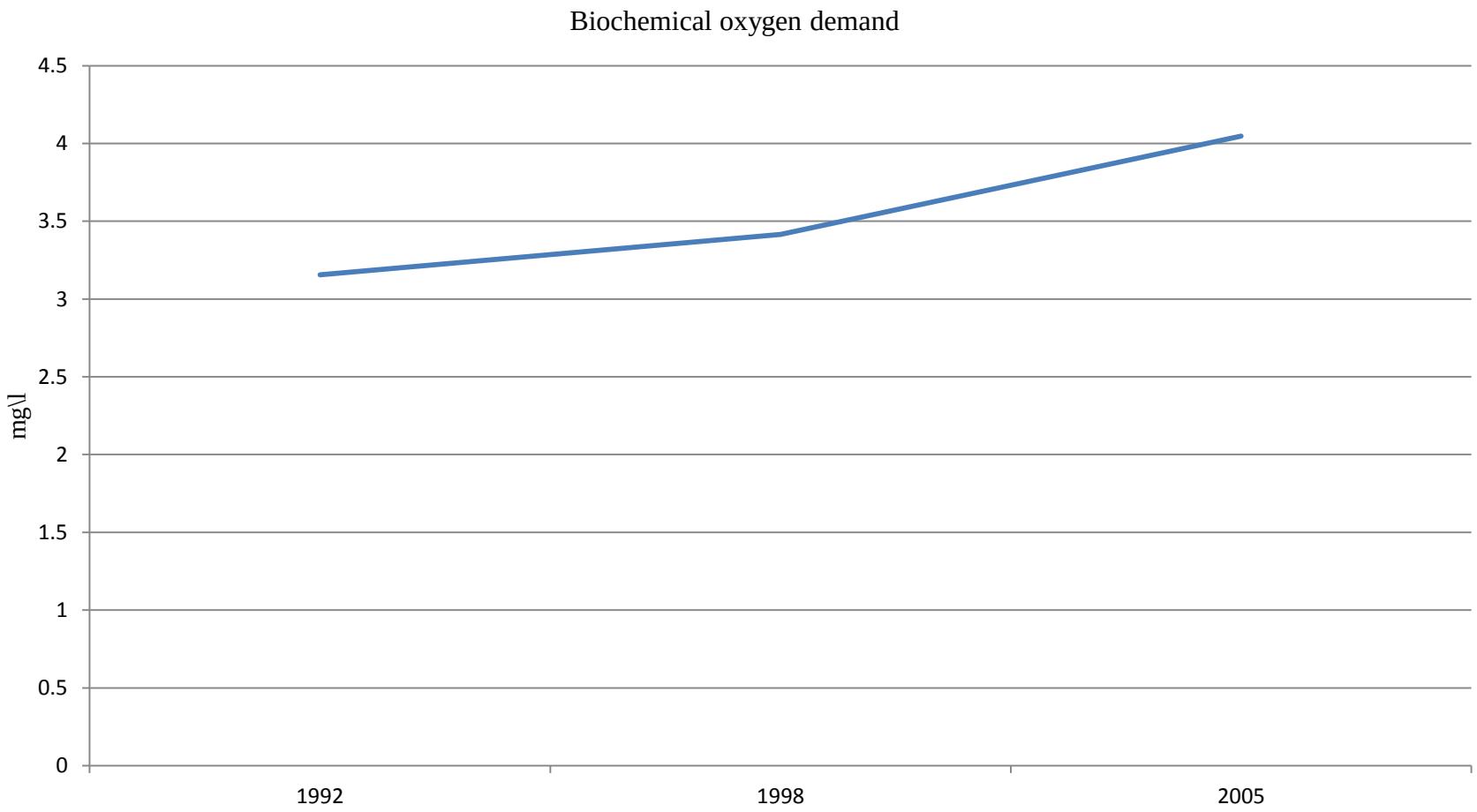
Mean nitrogen concentration in water by month from 1978-2005 for wheat



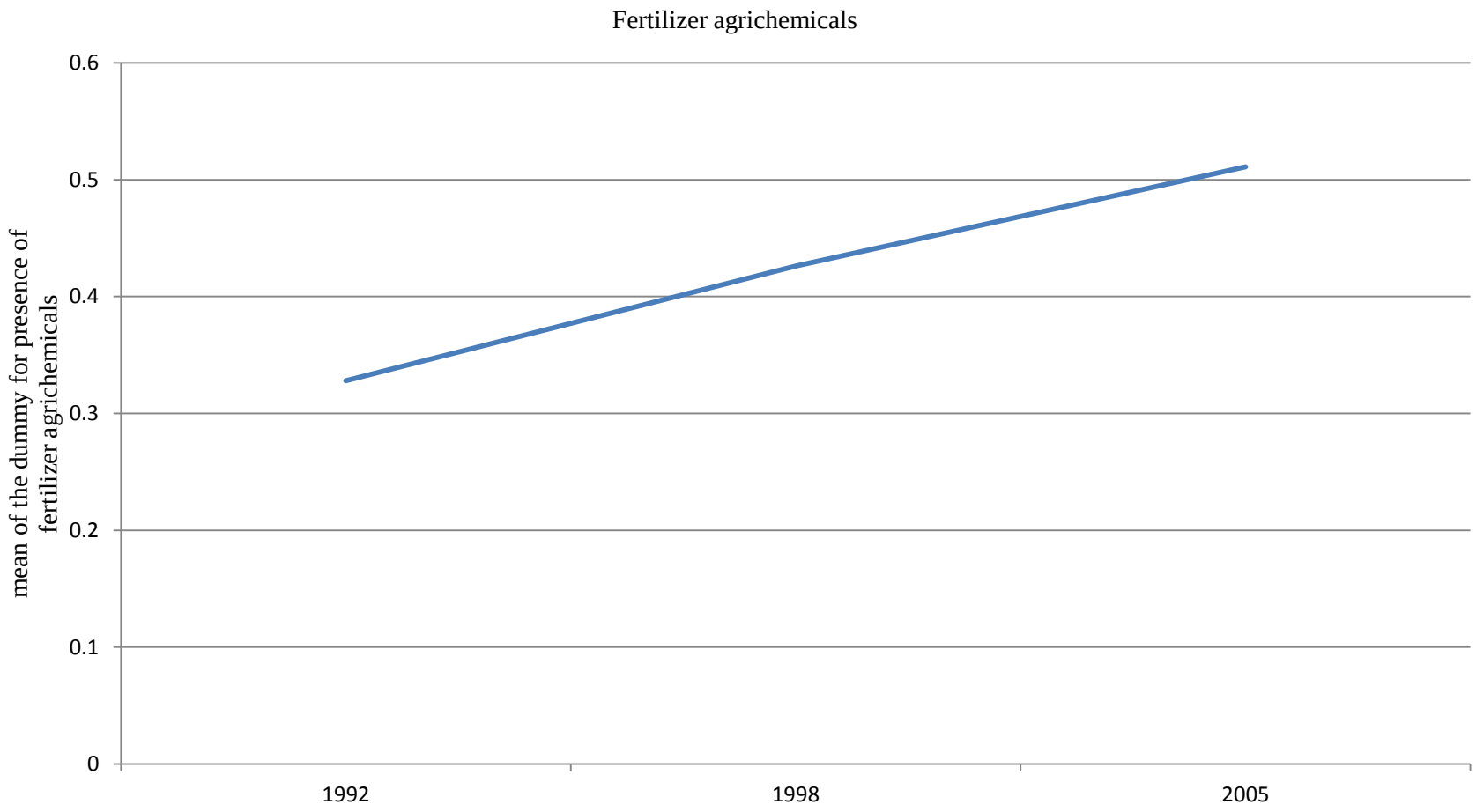
Mean phosphate concentration in water by month from 1978 – 2005 for rice



Trend in biochemical oxygen demand over time



Trend in presence of fertilizer agrichemicals in water over time



Demographic outcomes and controls

- Indian National Family Health Surveys (NFHS) from 1992, 1998, and 2005
- Questions are asked of all women between 15-49 years of age
- Repeated cross-sections with national coverage
- Information on child-specific, women-specific, and household-specific characteristics
  - month and year of conception determined by using month and year of birth, assuming 9 month gestation cycle
- Estimation sample has child health outcomes matched with agrichemical and BOD presence in month of conception + other controls

Demographic outcomes and controls

- Use additional information on variables for robustness checks from
  - Economic Organization Public Policy Program database (EOPP at LSE)
  - *Vital Statistics of India*, various years
  - *Statistical Abstract of India*, various years
  - Directorate of Economics and Statistics, Department of Agriculture

Summary statistics for key variables

Variables	*All areas*		*Wheat areas*		*Rice areas*	
	Mean	SD	Mean	SD	Mean	SD
Water Pollutants						
Level of BOD in conception month	0.004	(0.007)	0.004	(0.010)	0.002	(0.002)
Dummy for agrichemicals in con. month	0.452	(0.498)	0.390	(0.488)	0.461	(0.499)
Child-specific						
Order of birth	2.942	(1.969)	3.255	(2.124)	2.550	(1.693)
Dummy for child was nursed	0.947	(0.225)	0.960	(0.195)	0.929	(0.257)
Male child	0.513	(0.500)	0.501	(0.500)	0.510	(0.500)
Age of child	2.579	(1.667)	2.637	(1.673)	2.453	(1.609)
Women-specific						
Women's age	31.89	(7.193)	32.553	(7.192)	31.08	(7.078)
Dummy for woman is literate	0.348	(0.476)	0.269	(0.444)	0.445	(0.497)
Dummy for woman is currently working	0.390	(0.488)	0.334	(0.472)	0.401	(0.490)
Woman's body mass index	20.22	(3.680)	20.102	(3.481)	20.44	(3.861)
Dummy for woman consumes fruits	0.317	(0.465)	0.247	(0.431)	0.362	(0.481)
Dummy for woman consumes veges.	0.970	(0.170)	0.971	(0.167)	0.958	(0.201)
Dummy for woman consumes eggs	0.278	(0.448)	0.145	(0.352)	0.513	(0.500)
Dummy for wom. con. chicken/meat/fish	0.247	(0.431)	0.106	(0.307)	0.492	(0.500)
Dummy for woman smokes	0.026	(0.160)	0.040	(0.195)	0.015	(0.120)
Dummy for had care with doctor	0.118	(0.323)	0.074	(0.262)	0.187	(0.390)
Husband's age	37.96	(8.816)	37.974	(9.104)	37.92	(8.460)
Dummy for husband has no education	0.338	(0.473)	0.359	(0.480)	0.342	(0.474)

Summary statistics for key variables

Household-specific	Mean	SD	Mean	SD	Mean	SD
Dummy for rural household	0.743	(0.437)	0.781	(0.413)	0.746	(0.436)
Dummy for household has male head	0.936	(0.244)	0.932	(0.252)	0.928	(0.259)
Dummy for household religion is Hinduism	0.813	(0.390)	0.823	(0.381)	0.794	(0.404)
Dummy for household religion is Islam	0.148	(0.356)	0.151	(0.358)	0.159	(0.366)
Dummy for household belongs to SC/ST	0.270	(0.444)	0.270	(0.444)	0.272	(0.445)
Dummy for household owns a television	0.327	(0.469)	0.281	(0.450)	0.339	(0.473)
Dummy for household owns a refrigerator	0.090	(0.286)	0.083	(0.276)	0.082	(0.274)
Dummy for household owns a motorcycle	0.121	(0.326)	0.116	(0.320)	0.103	(0.304)
Dummy for household has electricity	0.569	(0.495)	0.467	(0.499)	0.615	(0.487)
Source of drinking water: piped water	0.329	(0.470)	0.198	(0.398)	0.381	(0.486)
Source of drinking water: ground water	0.434	(0.496)	0.557	(0.497)	0.375	(0.484)
Source of drinking water: well water	0.203	(0.402)	0.221	(0.415)	0.203	(0.403)
Source of drinking water: surface water	0.024	(0.153)	0.018	(0.134)	0.029	(0.168)
State-specific						
Per capita net state domestic product (base 1980)	2.388	(1.094)	2.174	(1.169)	2.138	(0.523)
Rainfall in millimeters ($x10^{-2}$)	1.009	(1.404)	0.702	(1.029)	1.136	(1.136)
Average air temperature in degrees Celsius	25.411	(4.644)	24.028	(5.793)	27.46	(3.585)
Number of malaria/TB deaths norm. by state pop.	0.001	(0.002)	0.001	(0.001)	0.001	(0.002)
Average elevation in meters ($x10^{-2}$)	3.482	(1.152)	3.753	(1.450)	2.624	(0.568)

Outcomes studied

- Considered to be most impacted in the first trimester:
  - infant mortality
  - neonatal mortality
  - post-natal mortality

- Most impacted in other trimesters:
  - height-for-age z score (stunting)
  - weight-for-age z score (underweight)

Means and standard deviations of outcomes

Variables	*All areas*		*Wheat areas*		*Rice areas*	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Outcomes						
Born alive but died before 11 months (infant mort.)	0.074	(0.034)	0.088	(0.031)	0.059	(0.034)
Born alive but died in first month (neonatal mort.)	0.048	(0.024)	0.056	(0.022)	0.039	(0.025)
Born alive but died b/w 1-11 mths. (post-natal mort.)	0.026	(0.017)	0.032	(0.016)	0.020	(0.016)
Height-for-age z score	-1.861	(1.521)	-2.035	(1.546)	-1.636	(1.561)
Weight-for-age z score	-1.958	(1.136)	-2.049	(1.149)	-1.849	(1.141)

First stage regression results

- Use information on cropped area under rice in both *kharif* and summer seasons
- Effects of the rice and wheat instruments may be contaminated with time and state-level heterogeneity
- Include time dummies, state dummies and their interactions
- Identifying instruments perform less well for BOD
  - report tests for weak instruments in results table

First stage regression results

	Endogenous variable: Average of the dummy for presence of fertilizer in month of conception		*Endogenous variable: Log of the biochemical oxygen demand in month of conception*	
Autumn rice crop area x Autumn rice sowing months	0.834*	0.881*	0.445	1.095
	(0.452)	(0.503)	(0.493)	(0.689)
Summer rice crop area x Summer rice sowing months	3.636**	5.038***	1.654	4.138
	(1.711)	(1.495)	(1.161)	(2.699)
Wheat crop area x Wheat sowing months	0.868***	0.698***	0.249*	0.166
	(0.198)	(0.208)	(0.144)	(0.178)
Includes measures of crop area and crop sowing months	YES	YES	YES	YES
Includes month and year dummies, region dummies, and their interactions	NO	YES	NO	YES
R-squared	0.093	0.259	0.061	0.167
F-statistic	6.450	12.160	1.330	1.140
	[0.003]	[0.0001]	[0.292]	[0.356]
Observations	12201	12201	12201	12201

Sample size and results

- Until a child exits the hazard period, not possible to know whether she/he will die before the cut-off age => sample sizes differ for infant mortality and its components

- Results:
  - For a 10 percent rise in level of agro-toxins, average infant mortality rises by about 5 percent
  - For a similar magnitude increase, average neo-natal mortality rises by 6 percent
  - Significant impact even on HFA and WFA z scores

Main instrumental variables results

	Infant mortality	Neo-natal mortality	Post-natal mortality	HFA z score	WFA z score
Average of the dummy for the presence of agrichemicals in month of conception	0.078**	0.068*	0.001	-1.453*	-0.606*
	(0.031)	(0.013)	(0.008)	(0.809)	(0.360)
Log of the level of biochemical oxygen demand in month of conception	-0.037	-0.029	0.007	-0.579	-0.241
	(0.068)	(0.078)	(0.028)	(1.084)	(1.656)
Anderson-Rubin Wald test	21.200	13.160	0.370	11.910	7.810
	[0.0001]	[0.004]	[0.946]	[0.008]	[0.050]
Includes measures of crop area and crop sowing months	YES	YES	YES	YES	YES
Includes child, woman and husband characteristics, and state-specific chars.	YES	YES	YES	YES	YES
Includes month and year dummies, region dummies, and their interactions	YES	YES	YES	YES	YES
Number of observations	10497	12201	11046	10402	10526

Heterogeneity in impact of agrichemicals

- Disaggregate neo-natal mortality for the following sub-samples:
  - uneducated versus educated women
  - rural versus urban areas
  - poor versus rich households

- Negative consequences most evident among children of
  - uneducated poor women living in rural India

Disaggregated instrumental variables results for neo-natal mortality

	Neo-natal mortality					
	Illiterate women	Literate women	Rural areas	Urban areas	Poor households	Rich households
Average of the dummy for fertilizer chemicals in month of conception	0.077**	0.029*	0.077*	0.064*	0.084**	0.057
	(0.032)	(0.016)	(0.042)	(0.04)	(0.041)	(0.039)
Log of the level of BOD in month of conception	-0.049	0.029	-0.054	-0.070*	-0.074	0.000
	(0.062)	(0.046)	(0.069)	(0.040)	(0.099)	(0.060)
Includes measures of crop area and crop sowing months	YES	YES	YES	YES	YES	YES
Includes child, woman and husband characteristics, and state characteristics	YES	YES	YES	YES	YES	YES
Includes month and year dummies, state dummies, and their interactions	YES	YES	YES	YES	YES	YES
Number of observations	7141	5060	9563	2638	4168	8042

Trimester impacts

- Consider effects of long-term exposure beyond the month of conception
- Infant mortality is affected by exposure in all trimesters; but largest impact is in the first trimester
- Neo-natal mortality is significantly affected by exposure in the third trimester; exposure impacts in first and second trimesters are on the borderline of significance
- Summary: an additional modest effect from prolonged exposure to water toxins for some of the child health outcomes

Trimester impacts

	Infant mortality	Neo-natal mortality	Post-natal mortality	Height-for-age z score	Weight-for-age z score
First trimester months					
Average of dummy for presence	0.082*	0.075	0.005	-1.831*	-0.563
of fertilizer in the first trimester	(0.046)	(0.049)	(0.010)	(1.093)	(0.612)
Level of biochemical oxygen	-0.260	-0.195	-0.051	0.098	4.870
demand in first trimester x 10^{-2}	(0.387)	(0.378)	(0.066)	(1.637)	(4.701)
Number of observations	10437	12139	10982	10345	10468
Second trimester months					
Average of dummy for presence	0.068***	0.056	0.004	-1.431	-1.489
of fertilizer in the second trimester	(0.025)	(0.036)	(0.008)	(0.911)	(1.143)
Level of biochemical oxygen	-0.018	0.040	0.018	3.793	10.495
demand in second trimester x 10^{-2}	(0.144)	(0.178)	(0.089)	(3.269)	(15.329)
Number of observations	10421	12105	10960	10257	10379
Third trimester months					
Average of dummy for presence	0.070*	0.062*	0.001	2.812	2.266
of fertilizer in the third trimester	(0.040)	(0.034)	(0.007)	(2.757)	(1.986)
Level of biochemical oxygen	0.145	0.074	0.024	-2.874	-0.783
demand in third trimester x 10^{-2}	(0.146)	(0.090)	(0.046)	(2.907)	(2.344)
Number of observations	10400	12074	10937	10215	10338

Robustness checks

- Show the identifying instruments satisfy the exclusion restriction

- Main things to check for:
  - Correlation with omitted/confounding variables
  - Households do not time conception
  - Correlation with weather, disease
  - Correlation with pre-conception characteristics of households
  - Correlation with food shortages that often precede agricultural growing seasons (“hungry season”)
  - Correlation with women’s labor during sowing cycles

Robustness checks I

Identifying instruments	*Log of number of accidental deaths*	*Acc. to pre- or antenatal doctor*	*Log of the number of conceptions in a month*	*Rich household*	*Rainfall*	*Air temperature*
Autumn rice crop area x Autumn rice sowing months	0.001 (0.001)	-0.052 (0.155)	9.447 (8.153)	0.003 (0.050)	0.619 (1.064)	-0.355 (0.283)
Summer rice crop area x Summer rice sowing months	0.004 (0.003)	0.049 (0.289)	22.407 (25.268)	-0.091 (0.089)	0.536 (1.491)	-1.343*** (0.392)
Wheat crop area x Wheat sowing months	-0.0001 (0.0003)	-0.186 (0.115)	-1.416 (2.985)	0.018 (0.015)	1.846*** (0.537)	-0.916*** (0.219)
Includes measures of crop area and crop sowing months	YES	YES	YES	YES	YES	YES
Includes child, woman and husb.-specific characteristics, and state-specific characteristics	YES	YES	YES	YES	YES	YES
Includes month and year dumm., region dummies, and their interactions	YES	YES	YES	YES	YES	YES
R-squared	0.718	0.336	0.693	0.143	0.719	0.971
F-statistic	0.68 [0.576]	1.090 [0.373]	0.050 [0.686]	2.080 [0.131]	5.300 [0.006]	13.440 [0.0004]
Number of observations	8350	12979	6743	12979	12979	11574

Robustness checks II

Identifying instruments	*Diseases (malaria, TB)*	*Mother's education*	*Father's education*	*Asset ownership*	*Rural areas*	*Number of siblings*	*Consumption*
Autumn rice crop area x Autumn rice sowing months	0.212 (0.205)	-0.140 (0.238)	-0.926 (0.963)	-0.065 (0.109)	0.071 (0.059))	0.204 (0.128)	0.043 (0.052)
Summer rice crop area x Summer rice sowing months	0.722 (0.492)	-0.164 (0.482)	2.732 (3.432)	-0.336 (0.303)	-0.108 (0.203)	0.307 (0.356)	-0.033 (0.146)
Wheat crop area x Wheat sowing months	0.442 (0.640)	0.050 (0.084)	2.143 (1.551)	-0.017 0.055)	0.017 (0.030)	0.133 (0.096)	0.002 (0.031)
Includes measures of crop area and crop sowing months	YES	YES	YES	YES	YES	YES	YES
Includes child, woman and husb., and state characteristics	YES	YES	YES	YES	YES	YES	YES
Includes month and year dumm., region dummies, and their interactions	YES	YES	YES	YES	YES	YES	YES
R-squared	0.930	0.349	0.238	0.297	0.601	0.936	0.454
F-statistic	0.890 [0.469]	0.320 [0.812]	2.600 [0.077]	0.610 [0.612]	2.120 [0.125]	2.210 [0.114]	0.340 [0.795]
Number of observations	8350	12979	13002	12979	12979	12979	12979

Robustness checks III

	Infant mortality					*Neo-natal mortality*				
Average of the dummy for the presence of	0.075**	0.077**	0.035**	0.075**	0.075**	0.067*	0.061**	0.037***	0.079**	0.067*
fertilizer chemicals in month of conception	(0.031)	(0.041)	(0.014)	(0.034)	(0.031)	(0.040)	(0.027)	(0.014)	(0.035)	(0.041)
Log of the level of biochemical oxygen	-0.036	-0.017	-0.019	-0.044**	-0.035	-0.030	0.004	0.020	-0.035	-0.029
demand in month of conception	(0.066)	(0.051)	(0.027)	(0.022)	(0.070)	(0.081)	(0.034)	(0.023)	(0.023)	(0.084)
Rainfall	0.002					0.001				
	(0.002)					(0.002)				
Air temperature		-0.017					-0.006			
		(0.011)					(0.006)			
Log number of malaria cases and			-0.007					-0.005		
TB deaths			(0.010)					(0.011)		
Log of wheat yield				-0.003					-0.002	
				(0.005)					(0.007)	
Log of rice yield				-0.001					-0.001	
				(0.001)					(0.001)	
Woman is currently working					0.001					0.001
					(0.002)					(0.002)
Woman works in agriculture					0.001					0.001
					(0.001)					(0.001)
Woman works for family member					-0.001					-0.001
					(0.006)					(0.006)
Woman works for someone else					-0.002					-0.002
					(0.002)					(0.002)
Includes measures of crop area and crop sowing months	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Includes child, woman and husband-spec. characteristics, and state-specific charact.	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Includes month and year dummies, region dummies, and their interactions	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Other falsification tests

- Show that child health outcomes not affected by agrichemicals and BOD in water in
  - trimester before conception
  - six months preceding conception

Impact of agrichemicals before conception

	Infant mortality	Neo-natal mortality	Post-natal mortality	Height-for-age z score	Weight-for-age z score
Trimester before conception					
Average of dummy for presence	0.057	0.046	0.001	0.970	0.284
of fertilizer in the trimester before conception	(0.043)	(0.049)	(0.009)	(1.537)	(0.771)
Level of biochemical oxygen demand in the	0.144	0.204	-0.027	0.918	6.101
trimester before conception x 10^{-2}	(0.264)	(0.263)	(0.054)	(5.093)	(6.284)
Number of observations	10437	12139	10982	10345	10468
Six months before conception					
Average of dummy for presence of fertilizer in	0.085	0.062	0.005	2.716	0.806
six months before conception	(0.065)	(0.052)	(0.009)	(1.682)	(0.805)
Level of biochemical oxygen demand in the six	0.032	0.026*	0.004	-0.893	-0.249
months before conception x 10^{-2}	(0.020)	(0.014)	(0.007)	(0.596)	(0.288)
Number of observations	10550	12260	11100	10402	10526
Includes measures of crop area and crop sowing months	YES	YES	YES	YES	YES
Includes child, woman and husband-specific characteristics, and state-specific characteristics	YES	YES	YES	YES	YES
Includes month and year dummies, state dummies, and their interactions	YES	YES	YES	YES	YES

Conclusions and policy

- This study broadens our understanding of the health effects of fertilizer use on a vulnerable population – infants and young children in a developing country

- Noteworthy that month of conception exposure to agrichemicals in water has effects on short-term and long-term outcomes

- Relatively large negative impacts on infant and neo-natal mortality; this is in keeping with others studies
  - Cutler and Miller 2005
  - Galiani *et al*. 2005

- Findings highlight the tension between greater use of fertilizers to improve yields and the negative health effects from such use

Conclusions and policy

- Possible ameliorative strategies:
  - reliance on organic fertilizers
  - alternative farming techniques to improve soil productivity
  - programs to improve nutrition of mothers who are most exposed
  - early health intervention programs for low-birth weight babies
  - programs to raise consciousness