Seasonal Effects of Water Quality on Infant and Child Health in India

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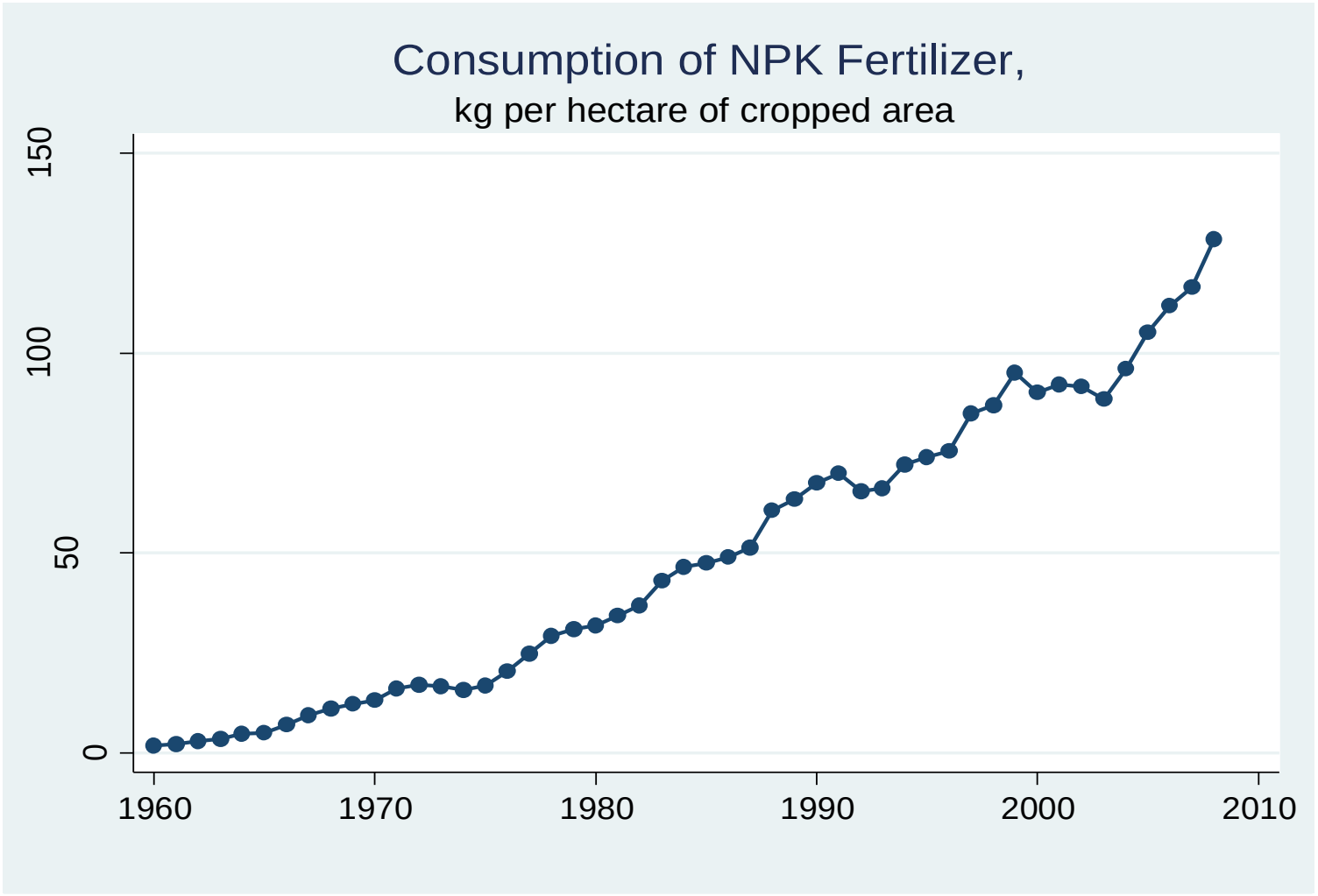
Motivation

- Green Revolution (1965-late 1970s)
  - increased agricultural production and helped achieve food security
  - 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

- 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


Consumption of NPK Fertilizer,
kg per hectare of cropped area
150
100
50
0
1960
1970
1980
1990
2000
2010

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

- 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 fertilizer chemicals in water in month of conception significantly increases likelihood of 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

- Some evidence that first, second and third trimester exposure matters

- 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)
  - impact of increased access to clean water
    - Galiani, Gertler and Schargrodsky (2005)

- 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)

Identification methodology

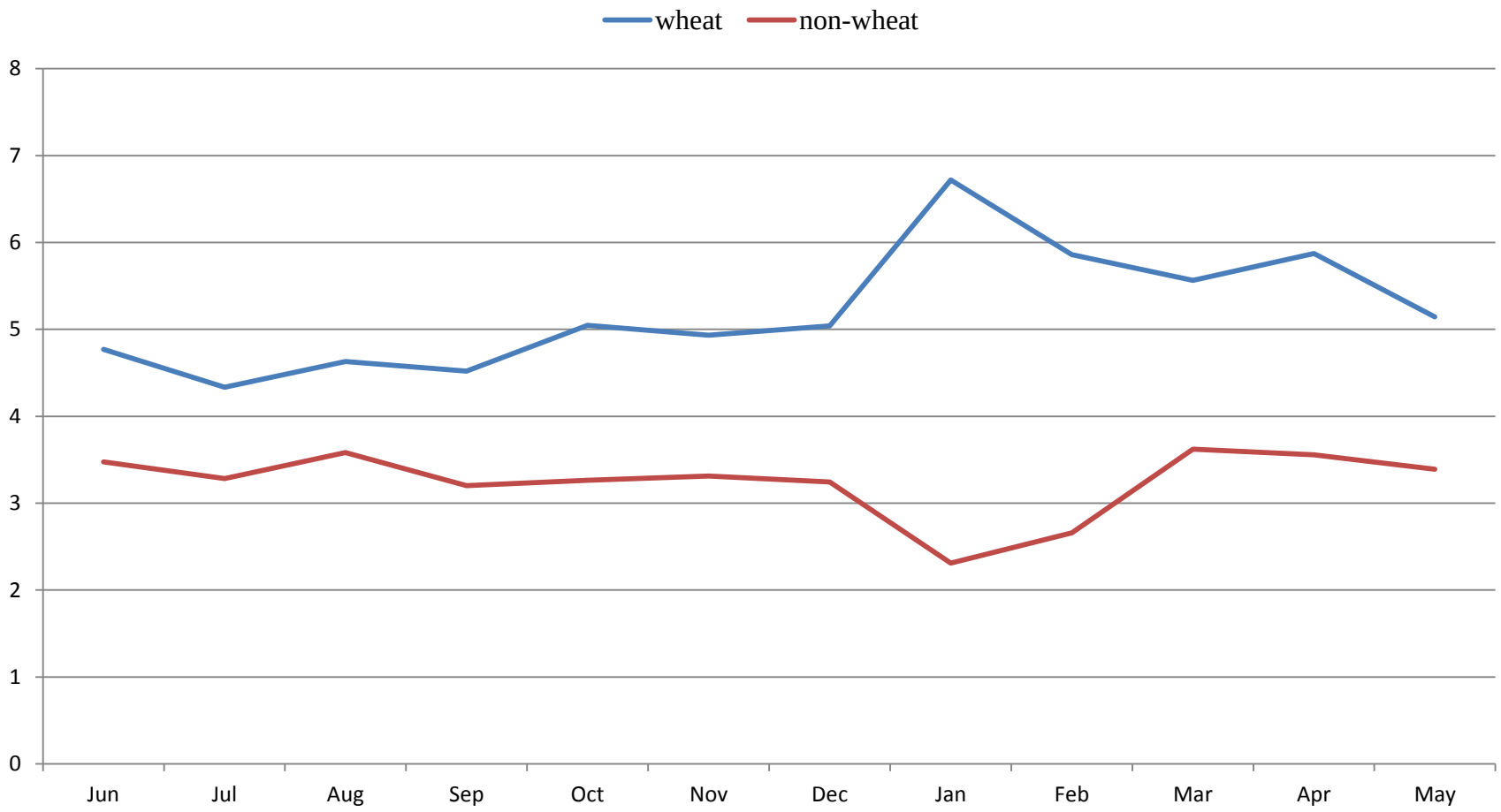
- Identify fertilizer agrichemical impacts using two sources of variation for the main crops of rice and wheat
  - exogeneity in soil endowments which makes some states more suitable for rice and others for wheat
    - bulk of wheat production – UP, Punjab, Haryana, Gujarat, Bihar, MP
    - bulk of rice 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
- Control for other indicators of water quality
  - levels of biochemical oxygen demand (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:

$$F_{jtm_c} = \gamma_0 + \gamma_1 \, (R_j \; x \; M^R) + \; \gamma_2 (W_j \; x \; M^W) + \vartheta_{ij}$$

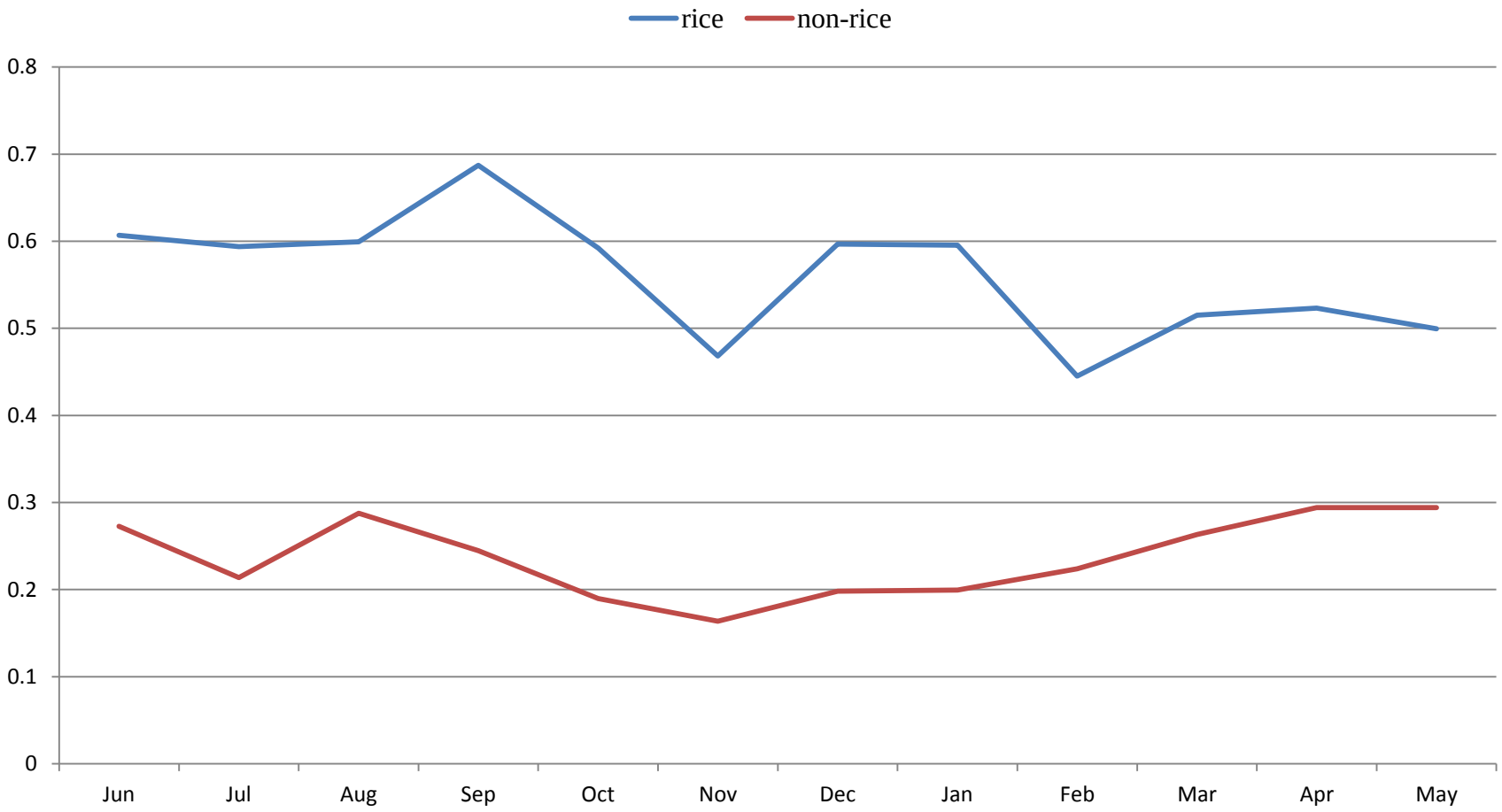
Water quality data

- 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 in India
  - 870 stations as of 2005
- 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)

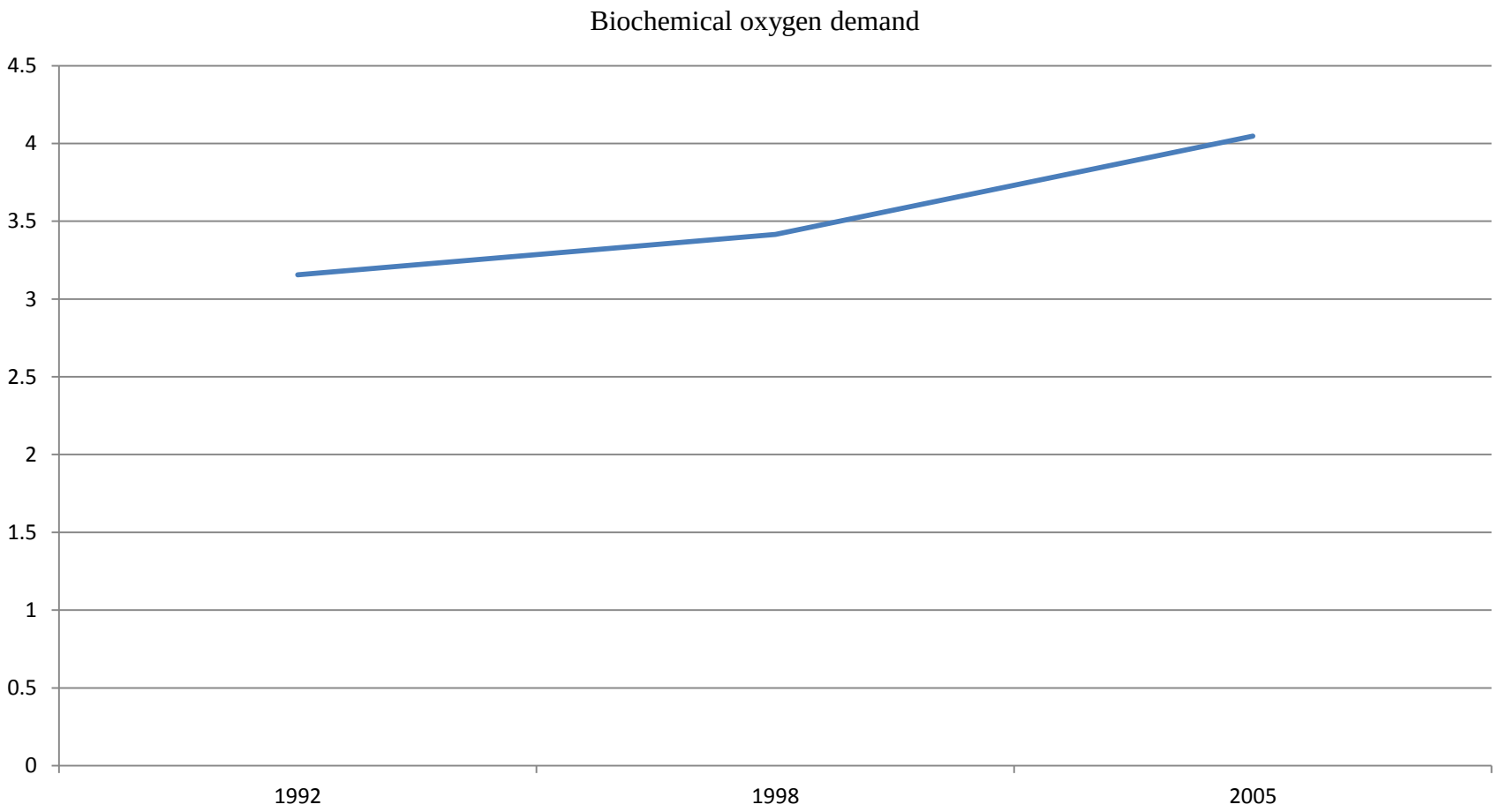
Mean nitrogen concentration in water by month from 1978-2005 for wheat



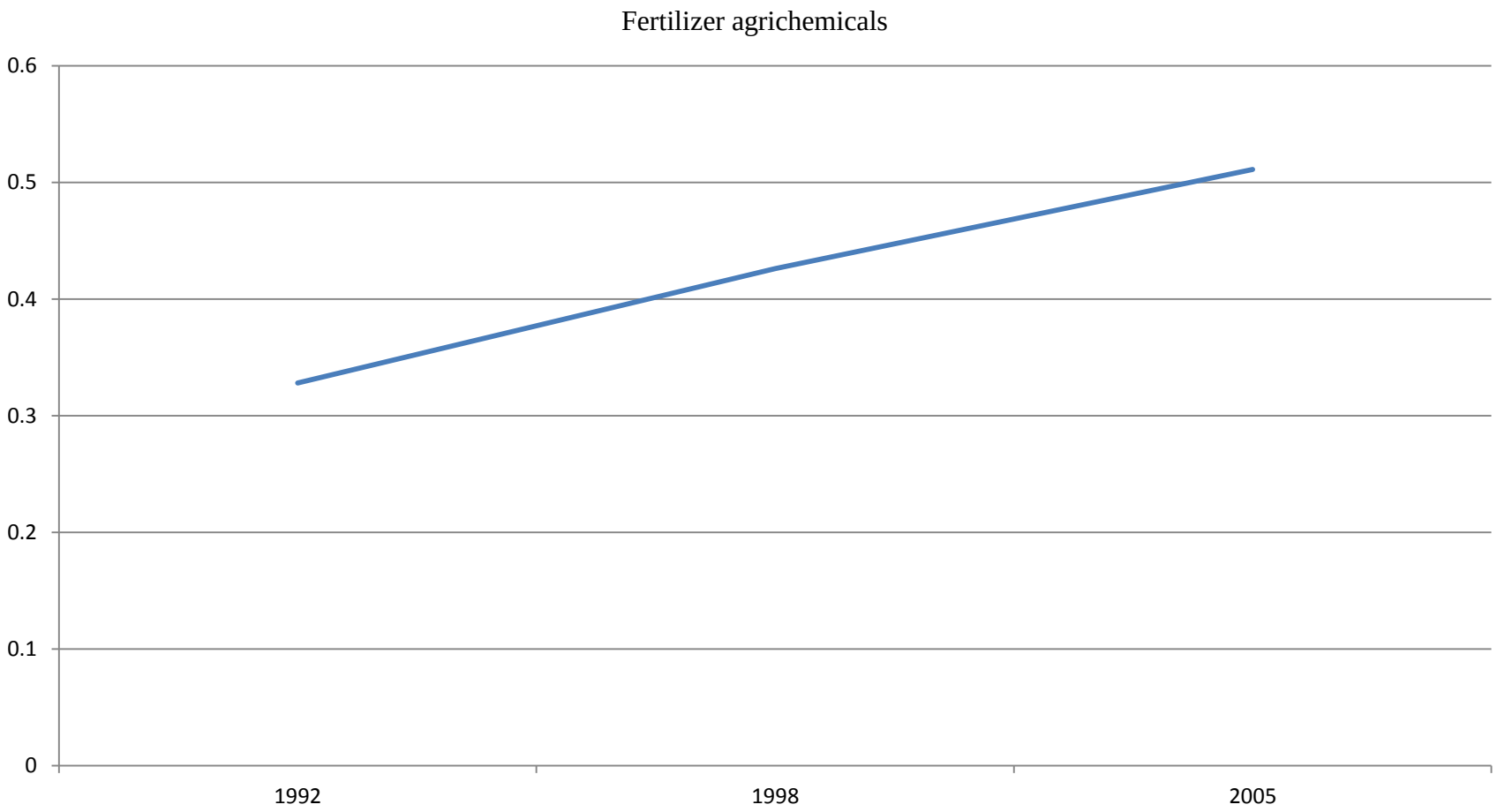
Mean phosphate concentration in water by month from 1978 – 2005 for rice



Trend in biochemical oxygen demand over time



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

Outcomes studied

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

- Most impacted in the late second trimester and third trimesters:
  - height-for-age z score (stunting)
  - weight-for-age z score (underweight)

Means and standard deviations of outcomes by year

Outcomes	1992	1998	2005
Infant was born alive but died at or less than eleven months (infant mortality)	0.084	0.078	0.069
	(0.034)	(0.033)	(0.034)
Infant was born alive but died in the first month (neo-natal mortality)	0.053	0.050	0.046
	(0.023)	(0.023)	(0.025)
Infant was born alive but died between the first and eleventh month (post-natal mortality)	0.031	0.027	0.023
	(0.018)	(0.017)	(0.017)
Height-for-age z score for child	-2.182	-1.967	-1.746
	(1.683)	(1.662)	(1.558)
Weight-for-age z score for child	-2.176	-1.986	-1.936
	(1.235)	(1.298)	(1.153)

First stage results

	Endogenous variable: Average of the dummy for presence of fertilizer agrichemicals in month of conception		*Endogenous variable: Log of the level of 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

Main instrumental variables results

	Infant mortality	Neo-natal mortality	Post-natal mortality	Height-for-age z score	Weight-for-age z score
Average of the dummy for the presence of fertilizer chemicals 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-specific characteristics, and state-specific characteris.	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

Disaggregated instrumental variables results

	Neo-natal mortality					
	Uneducated women	Educated women	Rural areas	Urban areas	Poor households	Rich households
Average of the dummy for the presence of fertilizer chemicals in month of conception	0.077**	0.029*	0.077*	0.064*	0.072*	-0.059
	(0.032)	(0.016)	(0.042)	(0.035)	(0.040)	(0.040)
Log of the level of biochemical oxygen demand in month of conception	-0.049	0.029	-0.054	-0.070*	-0.037	0.104*
	(0.062)	(0.046)	(0.069)	(0.040)	(0.084)	(0.060)
Includes measures of crop area and crop sowing months	YES	YES	YES	YES	YES	YES
Includes child, woman and husband-specific characteristics, and state-specific characteris.	YES	YES	YES	YES	YES	YES
Includes month and year dummies, region dummies, and their interactions	YES	YES	YES	YES	YES	YES
Number of observations	7141	5060	9563	2638	11946	255

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. specific characteristics, and state-specific 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

Conclusions and policy

- Noteworthy that month of conception exposure to agrichemicals in water has effects on first trimester and longer-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 child health effects that result from such use

- 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