Balanced Fertilization and Limited Productivity

Evidence from Indian Plots

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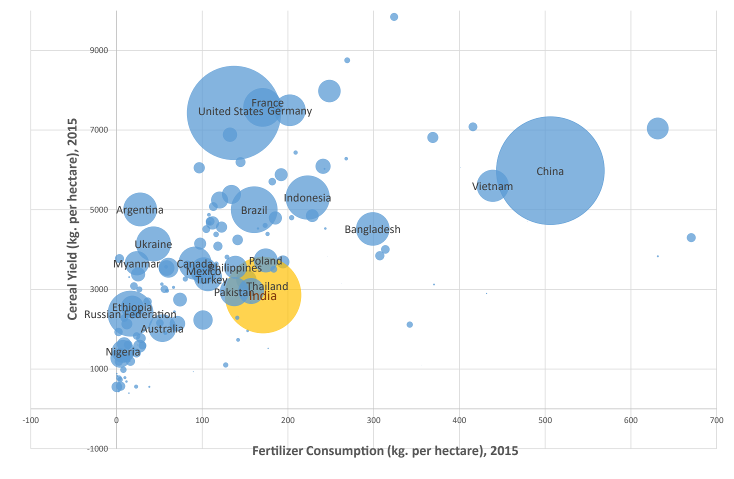
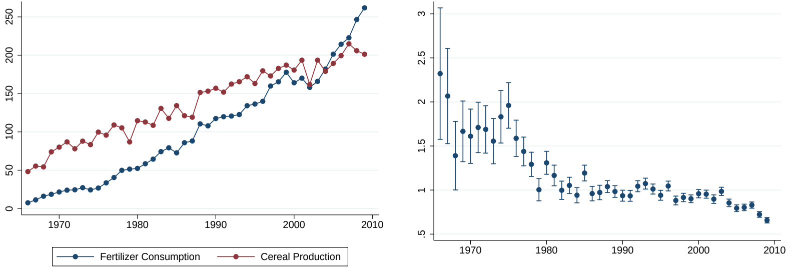
Introduction



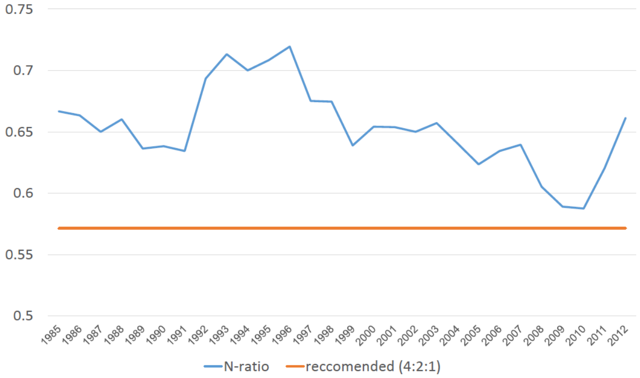
Source: `https://data.worldbank.org/indicator`, marker size proportional to cereal production in mt).

FigureFertilizer use and crop production, India



On the left: the decades after the green revolution when high-yield variety seeds and fertilizers were introduced in India are characterized by a strong positive relationship between fertilizer application and crop production. Since late 1990's, there is a weakening of this relationship. On the right: Year-specific coefficients of this relationship at the district level diminish with time.

FigureNitrogen ratio, India



Actual nitrogen ratio for all of India, compared to the ratio derived from the 4:2:1 recommendation (57% N to total NPK). During most periods, the actual ratio was much higher than the recommendation. In 2007-2009 the ratio seems to come closer to 57% but in 2010 the N-ratio went up again, following a deregulation of P and K fertilizer prices.

Introduction

- Study fertilizer use and productivity at the farmer level.
- Use plot level data of inputs and yield from across India.
- Estimate the relationship between fertilizer use and yield using:
  - Semi-parametric estimation
  - Quadratic form with 2SLS

Questions:

- Do farmers over-use nitrogen?
- Can we characterize the optimal ratio and quantify the amount wasted by farmers and potentially lost to the environment?

data

TableObservations in the data: Cultivators, Parcels, Plots, Seasons

Year	Cultivators	Parcels[1]	Plots[2]	Plot-Season[3]
2000-01	7,814	17,812	22,320	27,848
2001-02	7,178	16,233	19,871	25,709
2002-03	7,674	17,340	22,490	28,747
2003-04	7,816	17,940	23,412	30,688
2004-05	7,763	17,942	23,546	30,902
2005-06	7,978	18,868	25,374	33,181
2006-07	4,257	10,494	13,925	18,174
2007-08	6,869	16,274	21,039	27,014
2008-09	7,886	18,895	24,392	32,321
2009-10	7,705	18,268	23,947	31,225
2010-11	7,940	18,970	24,940	33,376
2011-12	7,995	18,892	24,539	32,734
Total	88,875	207,928	269,795	351,919

[1] Parcel - a section of land with the same ownership and characeristics; [2] Plot - a section of land devoted to a specific crop; [3] Plot-Season - a plot cultivated in one season.

TableObservations by Crop and Year

Crop	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Paddy	12,695	11,465	11,222	11,862	11,675	12,809	6,450	10,772	12,730	12,173	12,253	12,114
Wheat	4,750	3,440	4,980	5,398	5,299	5,326	2,392	3,911	5,525	4,597	6,017	5,925
Cotton	1,299	1,358	1,167	1,313	1,611	1,457	523	1,453	1,403	1,692	1,742	2,016
Maize	1,177	970	1,200	1,309	1,323	1,551	1,047	1,217	1,469	1,276	1,413	1,388
Others	11,539	10,311	11,964	12,920	12,837	12,920	8,636	9,580	10,966	11,227	11,972	10,882

Table Dominant fertilization practices, by crop

	N	No fertilizer	NP	NPK
Cotton	8%	6%	55%	31%
Maize	38%	14%	30%	18%
Paddy	19%	9%	26%	45%
Wheat	8%	4%	73%	15%

Table Average yield, by crop and fertilization practice

	N	no fertilizer	NP	NPK
Cotton	12.35	7.98	15.30	14.88
	(7.94)	(6.44)	(8.63)	(8.10)
Maize	15.23	12.72	24.17	37.77
	(9.02)	(8.34)	(14.28)	(19.19)
Paddy	26.43	22.09	35.85	40.42
	(13.36)	(8.23)	(14.99)	(14.00)
Wheat	19.69	10.20	33.28	25.46
	(10.09)	(7.41)	(10.88)	(11.65)

Figure Distribution of the Nitrogen ratio, by crop

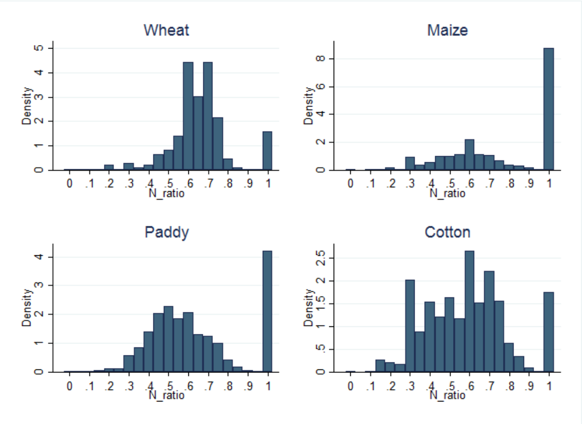
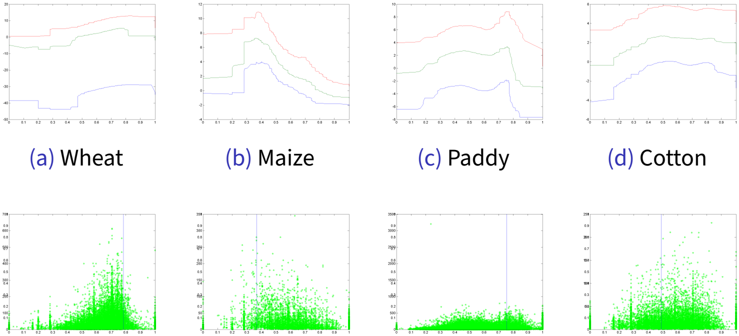


Figure Semi-parametric estimation results



(a) Wheat (b) Maize (c) Paddy (d) Cotton

(e) Wheat (f) Maize (g) Paddy (h) Cotton

Quadratic specification

I specify a quadratic relationship between the ratio of nitrogen and yield:

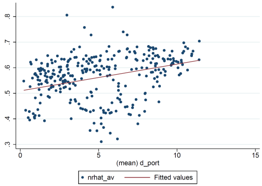
$$Yield_{csp} = \alpha_{cs} + \beta_{1cs} Nratio_{csp} + \beta_{2cs} Nratio^2_{csp} + X_{csp}\gamma_{cs} + \varepsilon_{cs} \quad (1)$$

$Yield_{csp}$ is crop yield (quintals per hectare of land) for crop c on plot p with soil type s. $Nratio_c sp$ is the amount of nitrogen used divided by total fertilizer for crop c om plot p. X_{csp} includes farm capital and irrigation status.

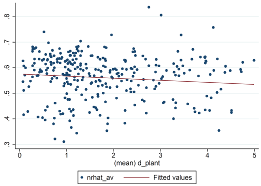
$$\begin{aligned} Yield_{csp} = \alpha_{cs} + \beta_{1cs} Nratio_{csp} + \beta_{2cs} Nratio^2_{csp} + \beta_{3cs} Nratio_{csp} \cdot irrigated_{csp} + \\ \beta_{4cs} Nratio^2_{csp} \cdot irrigated_{csp} + X_{csp}\gamma_{cs} + \varepsilon_{cs} \end{aligned} \quad (2)$$

- Inputs are usually endogenous in a production function. What about the nitrogen ratio?
- Solution: use input prices / distances from production locations as IV's.

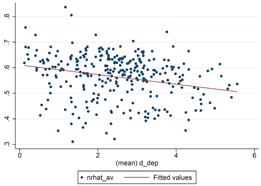
FigureN-ratio on Distances from Supply Sources



(a) Ports



(b) Plants



(c) Deposits

P and K fertilizers are mainly imported so their costs are associated with the distance from the nearest port. More than half of the nitrogen fertilizers consumed are domestically produced, so their costs are more related to distances from plants and natural deposit locations. The obtained relationships of the nitrogen ratio with these distances are therefor in the expected directions.

Results

Table Optimal ratios, OLS

	Wheat		Paddy		Maize		Cotton	
	irrigated	rainfed	irrigated	rainfed	irrigated	rainfed	irrigated	rainfed
Red	0.56***	0^c	0.51***	0.44***	0.48***	0.58***	0.83***	0.99
	(0.13)		(0.01)	(0.011)	(0.02)	(0.02)	(0.18)	(0.70)
	[0.00]		[0.00]	[0.00]	[0.00]	[0.00]	[0.35]	[0.993]
Alluvial	0.73***	0.68***	0.67***	0.44***	0^c	0^c	0.65***	0.64***
	(0.00)	(0.01)	(0.01)	(0.015)			(0.01)	(0.03)
	[0.00]	[0.00]	[0.00]	[0.00]			[0.00]	[0.00]
Black	0.70***	0.79***	0.79***	0.62***	0.72***	0.70***	0.63***	0.72***
	(0.01)	(0.04)	(0.02)	(0.015)	(0.02)	(0.01)	(0.01)	(0.10)
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.004]

Standard errors in parentheses $^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$; In square brackets p-values for f-test: $H_0 : Nratio = 1$; c - corner solution.

TableOptimal ratios, IV input prices

	Wheat		Paddy		Maize		Cotton	
	irrigated	rainfed	irrigated	rainfed	irrigated	rainfed	irrigated	rainfed
Red	0.74	2.23	0.48***	1^c	0.59***	2.50	0.52***	-0.52
	(0.83)	(13.46)	(0.10)		(0.03)	(52.53)	(0.09)	(2.85)
	[0.76]	[0.93]	[0.00]		[0.00]	[0.98]	[0.00]	[0.59]
Alluvial	1^c	0.65***	0.79***	0.47***	0.21	0.79***	0.62***	0.76***
		(0.05)	(0.02)	(0.04)	(0.48)	(0.02)	(0.03)	(0.07)
		[0.00]	[0.00]	[0.00]	[0.10]	[0.00]	[0.00]	[0.00]
Black	-0.03	0.72***	0.96***	-0.16	0.81***	1.18	-0.95	0.13
	(0.92)	(0.11)	(0.08)	(1.06)	(0.11)	(5.80)	(5.53)	(0.25)
	[0.26]	[0.01]	[0.61]	[0.28]	[0.08]	[0.95]	[0.72]	[0.00]

Standard errors in parentheses $^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$; In square brackets p-values for f-test: $H_0 : Nratio = 1$; c - corner solution.

Profitability

Table Profitability of shift to optimal nitrogen ratio

		Wheat red	Wheat alluvial	Wheat black	Maize red	Maize alluvial	Maize black	Paddy red	Paddy alluvial	Paddy black	Cotton red	Cotton alluvial	Cotton black
rainfed	Δ Yield	0.0	5.9	1.1	1.9	-2.0	0.6	8.9	3.8	3.2	-2.6	2.5	0.2
	Δ Cost	10.6	221.7	127.8	196.2	100.6	112.6	327.4	475.0	200.8	389.6	257.8	-426.4
	Δ Profit	-8.9	4,781.8	781.2	1,045.1	-1,417.7	303.9	5,772.4	2,139.0	1,947.8	-7,005.0	5,938.8	1,046.4
irrigated	Δ Yield	-15.1	-10.7	-12.5	4.7	15.8	6.2	13.4	2.3	5.3	2.3	0.3	-6.5
	Δ Cost	10.6	221.7	127.8	196.2	100.6	112.6	327.4	475.0	200.8	389.6	257.8	-426.4
	Δ Profit	-179.7	11,597.3	7,688.7	2,801.8	-5,460.9	6,324.8	5,604.8	-2,668.2	8,383.1	6,096.4	11,484.2	-13,844.3

$P_{Cotton} = 2,529, P_{Maize} = 659.3, P_{Paddy} = 682.1, P_{Wheat} = 855.05, P_N = 11.5, P_{PK} = 16.7$

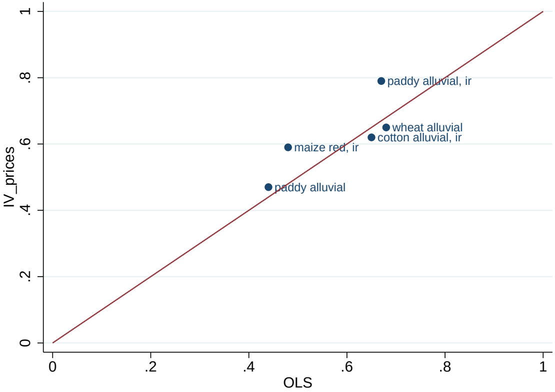
Variance reduction

Table Yield SD, tehsil level

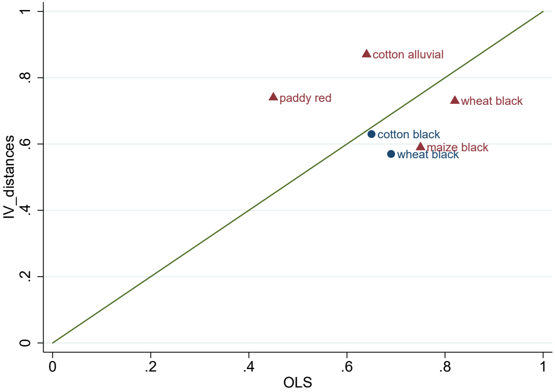
	OLS				IV-prices				IV-distances			
VARIABLES	Wheat	Maize	Paddy	Cotton	Wheat	Maize	Paddy	Cotton	Wheat	Maize	Paddy	Cotton
Nratio	0.234	1.751	-0.95	-2.534	37.54**	-2.706	-28.09*	-2.166	21.41**	-3.488	-2.868	1.059
	(1.031)	(2.152)	(1.367)	(1.486)	(16.540)	(16.410)	(17.020)	(3.944)	(8.629)	(4.019)	(36.420)	(8.002)
Irrigation	-2.868**	-1.103	0.565	1.917*	-4.768**	1.272	-5.031	2.850**	-5.306***	-0.758	-2.764	0.565
	(1.118)	(1.013)	(0.808)	(0.966)	(2.255)	(2.837)	(5.226)	(1.375)	(1.304)	(1.807)	(6.272)	(1.446)
Area	-0.501*	-0.591	0.418	-0.554**	-1.398***	-0.118	-1.161	-0.554*	-0.964***	-0.517	-0.477	-0.554**
	(0.242)	(0.974)	(0.627)	(0.223)	(0.540)	(1.441)	(1.930)	(0.335)	(0.345)	(0.881)	(1.774)	(0.259)
Total Fert.	0.0151***	0.00620***	0.0125**	0.00249	0.0327	-0.0305	0.0741	-0.0154	0.0308***	-0.00125	0.0461	0.0214*
	(0.002)	(0.002)	(0.004)	(0.002)	(0.032)	(0.025)	(0.050)	(0.013)	(0.008)	(0.014)	(0.059)	(0.011)
Capital	3.367*	-3.556	6.149	-0.412	-8.799	-4.489	8.689	1.955	-4.37	-1.506	5.448	-0.417
	(1.702)	(5.836)	(4.513)	(3.296)	(7.791)	(6.748)	(8.493)	(3.546)	(3.476)	(5.415)	(11.680)	(3.814)
soil: black	1.116**	-1.27	-0.254	0.404	3.517*	-2.112	-1.375	1.454	2.914***	-1.889	-1.366	-0.0407
	(0.484)	(1.469)	(1.132)	(0.441)	(1.957)	(2.145)	(1.427)	(1.371)	(0.863)	(1.372)	(2.085)	(0.616)
soil: red	1.819	3.186*	0.192	0.614	2.693	4.69	-6.538	2.007	-0.0935	2.713	-1.719	-0.0513
	(1.826)	(1.495)	(0.872)	(0.902)	(2.561)	(3.376)	(4.323)	(1.570)	(0.670)	(2.211)	(2.981)	(1.057)
Constant	4.803**	6.570***	5.123***	5.114***	-18.28*	12.06	20.27*	6.395**	-8.136	10.20***	4.884	0.812
	(1.752)	(1.916)	(1.250)	(1.081)	(9.674)	(12.340)	(10.890)	(2.557)	(5.454)	(1.952)	(25.770)	(5.678)
Obs.	428	145	486	189	426	145	486	189	417	135	470	180
R-squared	0.128	0.151	0.14	0.11						0.133		

Standard errors in parentheses are clustered at the tehsil level. $^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$

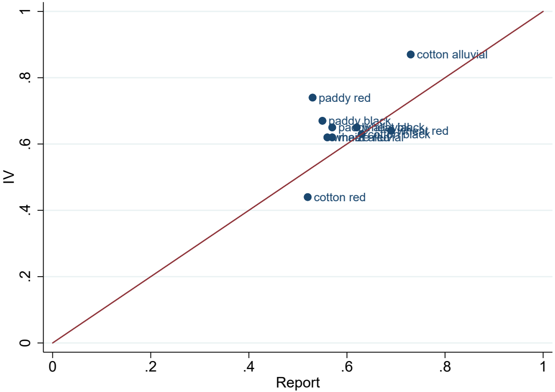
Figure Optimal ratio comparison OLS IV input prices



FigureOptimal ratio comparison OLS IV input distances



FigureOptimal ratio comparison Report IV input distances



Conclusion

- I estimated the relationship between the nitrogen ratio and yield using input-output survey data at the plot level.
- Many plots were found to use too much nitrogen, and could potentially benefit from simply reducing the amount of nitrogen (keeping the other fertilizers at the same level).
- The nitrogen only practice was almost always rejected as optimal (also confirmed in a profitability analysis).
- The optimal ratios obtained from the estimation were on average similar to ratios found in agronomic experiments, using a more flexible methodology.
- Extensions: water data, bio-fertilizer, inter-temporal and geographical spillovers.