

Rainfall shocks and fertilizer use: a district-level study of India

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ONLINE APPENDIX

Table A1. Summary statistics and definition of variables, 1966-2009

Variables	Definition	No. of observations	Mean	Standard deviation	Minimum	Maximum
NPK fertilizer (kg/ha)	Sum of nitrogen (N), phosphorus (P) and potassium (K) fertilizers divided by GCA	13,136	58.77	61.34	0	614.49
Nitrogenous fertilizer (kg/ha)	Quantity of nitrogenous fertilizer consumption over GCA	13,136	38.06	40.63	0	338.37
Irrigated area (%)	Share of gross area irrigated over gross cropped area	12,349	33.65	25.88	0	100
High yielding varieties (HYV) area (%)	Share of gross area irrigated over gross cropped area	10,248	23.74	20.32	0	100
Cropping intensity (%)	Share of gross cropped area to the net cropped area	13,340	131.36	24.19	100	365.2
Annual rainfall (mm)	Total annual rainfall received	12,507	1123.84	724.63	9.1	8409
Drought Index	Defined in eq. (2)	12,507	0.39	0.53	0	3.77

Note: Unit of analysis is district.

Source: Author's calculations.

Table A2. Estimated regression coefficients for effects of irrigation and rainfall on the rate of fertilizer consumption, 1966-2009

Explanatory variable	ln (NPK consumption/ha)		
	(1)	(2)	(3)
Constant	2.984*** (-0.202)	2.998*** (-0.204)	2.948*** (-0.208)
Annual rainfall (mm)	0.0001** (0.000)		0.0001** (0.000)
Previous year annual rainfall (mm)		0.0001*** (0.000)	0.0001*** (0.000)
Share of irrigated area (%)	0.013*** (-0.002)	0.013*** (-0.002)	0.013*** (-0.002)
HYV Area (%)	-0.003** (-0.001)	-0.002* (-0.001)	-0.002* (-0.001)
Cropping intensity (%)	-0.002 (-0.001)	-0.001 (-0.001)	-0.001 (-0.002)
District and Time fixed effects	Yes	Yes	Yes
State specific time trends	Yes	Yes	Yes
Observations	8915	8683	8526
Adjusted R ²	0.935	0.936	0.936
Within R ²	0.034	0.034	0.036

Notes: ***, ** and * indicate levels of significance at 1%, 5% and 10%, respectively. Two-way clustered standard errors (district and state × year) are reported in the parentheses.

Source: Author's calculations.

Table A3. Unit root test for panel stationarity

Variables	Fisher type (Phillips–Perron unit-root tests)	
	H ₀ : All panels contain unit root H ₁ : At least one panel is stationary (lags = 2)	
	Modified inverse chi ² pm	P-value
NPK fertilizer	30.43	0.000
Log of NPK fertilizer	85.07	0.000
Annual rainfall	231.89	0.000
Drought index (DI)	228.02	0.000
Irrigation	46.39	0.000
HYV	29.38	0.000
Cropping intensity	72.64	0.000

Source: Author's calculations.

Table A4. Estimated regression coefficients for effects of irrigation and different levels of rainfall shock (RS1) on the rate of fertilizer consumption, 1966-2009

Explanatory variable	Dependent variable= ln (NPK consumption)				
	(1)	(2)	(3)	(4)	(5)
Constant	3.048*** (-0.0607)	3.120*** (-0.0630)	3.115*** (-0.0649)	2.952*** (-0.0750)	3.124*** (-0.2105)
Current year rainfall					
Excess (Positive deviation)	Base		Base	Base	Base
Deficit (Negative deviation)	-0.020 (-0.0190)		-0.022 (-0.0198)	-0.026 (-0.0210)	-0.027 (-0.0212)
Previous year rainfall status					
Excess (Positive deviation)		Base	Base	Base	Base
Deficit (Negative deviation)		-0.041** (-0.0201)	-0.042** (-0.0202)	-0.043** (-0.0213)	-0.042** (-0.0213)
Irrigation share	0.010*** (-0.0018)	0.009*** (-0.0018)	0.010*** (-0.0019)	0.012*** (-0.0023)	0.013*** (-0.0023)
Current year rainfall Status*Irrigation					
Excess*Irrigation	Base		Base	Base	Base
Deficit*Irrigation	-0.0004 (-0.0004)		-0.0003 (-0.0004)	-0.0001 (-0.0005)	-0.0001 (-0.0005)
Previous year rainfall Status*Irrigation					
Excess*Irrigation		Base	Base	Base	Base
Deficit*Irrigation		0.0000 (-0.0004)	0.0000 (-0.0004)	0.0001 (-0.0005)	0.0001 (-0.0005)
HYV Area (%)				-0.0020* (-0.0011)	-0.0021* (-0.0011)
Cropping intensity (%)					-0.0014 (-0.0015)
District and Time fixed effects	Yes	Yes	Yes	Yes	Yes
State specific trend	Yes	Yes	Yes	Yes	Yes
Observations	11098	10852	10488	8526	8526
Adjusted R ²	0.934	0.935	0.935	0.936	0.936

Marginal effects at mean					
Negative shock	-0.034*** (-0.011)		-0.033*** (-0.011)	-0.029** (-0.013)	-0.030** (-0.013)
Negative shock (Lag=1)		-0.042*** (-0.010)	-0.042*** (-0.010)	0.041*** (-0.011)	-0.041*** (-0.011)
Irrigation share	0.010*** (-0.002)	0.009*** (-0.002)	0.009*** (-0.002)	0.012*** (-0.002)	0.013*** (-0.002)

Notes: ***, ** and * indicate levels of significance at 1%, 5% and 10%, respectively. Two-way clustered standard errors (district and state \times year) are reported in the parentheses.

Source: Author's calculations.

Table A5. Estimated regression coefficients for effects of irrigation and different levels of rainfall shock (RS2 and RS3) on the rate of fertilizer consumption, 1966-2009

Explanatory Variable	Dependent variable= ln(NPK consumption)			
	1 (RS2)	2 (RS2)	3 (RS3)	4 (RS3)
Constant	3.094*** (-0.0631)	3.093*** (-0.2066)	3.119*** (-0.0607)	3.144*** (-0.2095)
Current year rainfall				
Normal	Base	Base	Base	Base
Excess (Positive deviation)	0.006 (-0.0228)	0.025 (-0.0268)	0.003 (-0.0223)	0.014 (-0.0248)
Deficit (Negative deviation)	-0.042* (-0.0238)	-0.047* (-0.0263)	-0.072*** (-0.0204)	-0.079*** (-0.0221)
Previous year rainfall status				
Normal	Base	Base	Base	Base
Excess (Positive deviation)	0.021 (-0.0238)	0.042 (-0.0274)	0.020 (-0.0208)	0.031 (-0.0235)
Deficit (Negative deviation)	-0.073** (-0.0290)	-0.061** (-0.0292)	-0.093*** (-0.0276)	-0.100*** (-0.0271)
Irrigation share	0.009*** (-0.0019)	0.012*** (-0.0024)	0.009*** (-0.0018)	0.012*** (-0.0023)
Current year rainfall Status*Irrigation				
Normal*Irrigation	Base	Base	Base	Base
Excess*Irrigation	0.0005 (-0.0005)	0.0002 (-0.0006)	0.0005 (-0.0004)	0.0004 (-0.0005)
Deficit*Irrigation	0.0005 (-0.0005)	0.0007 (-0.0006)	0.0008* (-0.0004)	0.0010** (-0.0005)
Previous year rainfall Status*Irrigation				
Normal*Irrigation	Base	Base	Base	Base
Excess*Irrigation	0.0003 (-0.0005)	-0.0002 (-0.0006)	0.0003 (-0.0004)	0.0001 (-0.0005)
Deficit*Irrigation	0.0011** (-0.0006)	0.0011* (-0.0006)	0.0013** (-0.0005)	0.0016*** (-0.0006)
HYV Area (%)		-0.0020* (-0.0011)		-0.0019* (-0.0011)
Cropping intensity (%)		-0.0014 (-0.0016)		-0.0016 (-0.0016)
District and Time fixed effects	Yes	Yes	Yes	Yes
State specific trend	Yes	Yes	Yes	Yes
Observations	10488	8526	10488	8526
Adjusted R ²	0.935	0.936	0.935	0.936
Within R ²	0.026	0.035	0.032	0.042

Notes: ***, ** and * indicate levels of significance at 1%, 5% and 10%, respectively. Two-way clustered standard errors (district and state × year) are reported in the parentheses.

Source: Author's calculations.

Table A6. Estimated regression coefficients for effects of irrigation and drought intensity (DI) on the rate of fertilizer consumption, 1966-2009

Explanatory variable	Linear		Log-Linear	
	(1)	(2)	(3)	(4)
Constant	20.940** (-9.6716)	22.766** (-9.8421)	3.074*** (-0.2068)	3.1392*** (-0.2121)
Drought	-1.532 (-1.2628)	-1.649 (-1.2943)	-0.066* (-0.0342)	-0.070** (-0.0352)
Drought ²	1.108* (-0.6641)	1.177* (-0.6939)	0.016 (-0.0176)	0.015 (-0.0184)
Drought (lag= 1)		-3.172*** (-1.1202)		-0.099*** (-0.0326)
Drought ² (lag=1)		1.788*** (-0.601)		0.026* (-0.0151)
Irrigation share	0.764*** (-0.1345)	0.759*** (-0.1367)	0.013*** (-0.0023)	0.012*** (-0.0023)
Irrigation*Drought	-0.042* (-0.0227)	-0.039* (-0.0222)	0.0003 (-0.0005)	0.0003 (-0.0004)
Irrigation*Drought (lag =1)		-0.015 (-0.0243)		0.001 (-0.0004)
HYV Area (%)	0.242*** (-0.0592)	0.233*** (-0.0600)	-0.003** (-0.0012)	-0.002* (-0.0011)
Cropping intensity (%)	0.011 (-0.0617)	0.012 (-0.0618)	-0.002 (-0.0015)	-0.001 (-0.0016)
State-specific trend	Yes	Yes	Yes	Yes
District and Time fixed effects	Yes	Yes	Yes	Yes
Observations	8954	8563	8915	8526
Adjusted R ²	0.881	0.883	0.935	0.936
Within R ²	0.057	0.055	0.034	0.037
Marginal effects (at mean DI = 0.73, DI (lag=1) = 0.72, Irrigation share = 33.64)				
Drought	-1.319** (-2.358)	-1.233** (-2.242)	-0.032** (-2.520)	-0.036*** (-2.956)
Drought (lag= 1)		-1.090** (-2.130)		-0.041*** (-3.828)
Irrigation share	0.733*** (-5.630)	0.720*** (-5.465)	0.013*** (-5.805)	0.013*** (-5.539)

Notes: ***, ** and * indicate levels of significance at 1%, 5% and 10%, respectively. Two-way clustered standard errors (district and state × year) are reported in the parentheses.

Source: Author's calculations.

Table A7. Estimated regression coefficients for effects of irrigation and drought intensity (DI) on the rate of fertilizer consumption, 1966-2009

Explanatory variable	Linear		Log-Linear	
	(1)	(2)	(3)	(4)
Constant	-4490.000 (-699.902)	-4600.000 (-707.370)	167.273*** (-9.147)	-152.187*** (-9.640)
Drought	-2.537 (-2.044)	-3.8485* (-2.078)	-0.032 (-0.045)	-0.022 (-0.045)
Drought ²	1.482 (-0.974)	1.7397* (-1.015)	0.028 (-0.020)	0.026 (-0.021)
Drought (lag= 1)		-3.295* (-1.889)		-0.073* (-0.044)
Drought ² (lag=1)		2.017** (-0.885)		0.037** (-0.018)
Irrigation share	0.761*** (-0.177)	0.763*** (-0.180)	0.015*** (-0.003)	0.015*** (-0.003)
Irrigation*Drought	0.005 (-0.033)	0.020 (-0.032)	-0.001* (-0.001)	-0.001* (-0.001)
Irrigation*Drought (lag =1)		0.031 (-0.034)		-0.001 (-0.001)
HYV Area (%)	0.374*** (-0.092)	0.339*** (-0.093)	-0.004** (-0.002)	-0.003* (-0.002)
Cropping intensity (%)	-0.052 (-0.104)	-0.053 (-0.105)	0.001 (-0.002)	0.001 (-0.002)
District-specific trend	Yes	Yes	Yes	Yes
District and Time fixed effects	Yes	Yes	Yes	Yes
Observations	8954	8563	8915	8526
Adjusted R ²	0.818	0.821	0.917	0.917
Within R ²	0.640	0.637	0.82	0.812

Notes: ***, ** and * indicate levels of significance at 1%, 5% and 10%, respectively. Two-way clustered standard errors (district and state × year) are reported in the parentheses.

Source: Author's calculations.

Table A8. Estimated regression coefficients for effects of gross cropped area and drought intensity on the rate of fertilizer consumption, 1966-2009

Explanatory variable	Dependent variable			
	Gross cropped area ('000 ha)	Ln (Gross cropped area in '000 ha)	NPK Consumption ('000 tons)	Ln (NPK Consumption) ('000 tons)
	(1)	(2)	(3)	(4)
Constant	593.619*** (-1.8496)	6.183*** (-0.0032)	-27.290** (-11.046)	8.812*** (-0.1388)
Gross cropped area (1000 ha)			0.0709*** (-0.0171)	0.0008*** (-0.0002)
Drought	-27.332*** (-5.6629)	-0.045*** (-0.0086)	0.2272 (-1.024)	-0.0812** (-0.0345)
Drought ²	1.208 (-3.8045)	0.003 (-0.0062)	0.7984 (-0.5594)	0.0106 (-0.0173)
Drought (lag= 1)	-3.726 (-4.2356)	-0.007 (-0.0072)	-1.9877** (-0.8705)	-0.1008*** (-0.0328)
Drought ² (lag=1)	1.484 (-2.2973)	0.003 (-0.0038)	0.9840** (-0.3819)	0.0290* (-0.0151)
Irrigation share (%)			0.4327*** (-0.1281)	0.0109*** (-0.0023)
Irrigation*Drought			-0.021 (-0.024)	0.0002 (-0.0005)
Irrigation*Drought (lag =1)			0.0163 (-0.022)	0.0005 (-0.0004)
HYV Area (%)			0.0966** (-0.0464)	-0.0023** (-0.0011)
State-specific trend	Yes	Yes	Yes	Yes
District and Time fixed effects	Yes	Yes	Yes	Yes
Observations	11592	11592	8563	8526
Adjusted R ²	0.96	0.98	0.88	0.945
Within R ²	0.034	0.033	0.109	0.056

Notes: ***, ** and * indicate levels of significance at 1%, 5% and 10% respectively. Two-way clustered standard errors (district and state \times year) are reported in the parentheses.

Source: Author's calculations.

Table A9. Estimated regression coefficients for effects of irrigation and monsoon drought intensity on the rate of fertilizer consumption, 1966-2009

Explanatory variable	Dependent variable			
	N	Log of N	NPK	Log of NPK
	consumption	consumption	consumption	consumption
	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)
	(1)	(2)	(3)	(4)
	(Annual DI)	(Annual DI)	(Monsoon DI)	(Monsoon DI)
Constant	12.743** (-6.0865)	2.680*** (-0.2021)	23.327** (-9.8044)	3.121*** (-0.2038)
Drought	-0.328 (-0.8192)	-0.076** (-0.0346)	-1.980 (-1.5633)	-0.065** (-0.0324)
Drought ²	0.748* (-0.4202)	0.018 (-0.0177)	0.641 (-0.8565)	0.013 (-0.0169)
Drought (lag= 1)	-1.584** (-0.7412)	-0.077** (-0.0332)	-3.904*** (-1.2895)	-0.106*** (-0.0320)
Drought ² (lag=1)	1.068*** (-0.3663)	0.018 (-0.0142)	1.118* (-0.6372)	0.034** (-0.0134)
Irrigation share (%)	0.505*** (-0.0855)	0.012*** (-0.0022)	0.723*** (-0.1364)	0.012*** (-0.0023)
Irrigation*Drought	-0.0460*** (-0.0151)	0.0004 (-0.0004)	-0.0005 (-0.0262)	0.0004 (-0.0005)
Irrigation*Drought (lag =1)	-0.0142 (-0.0173)	0.0005 (-0.0004)	0.0311 (-0.0259)	0.0005 (-0.0004)
HYV Area (%)	0.202*** (-0.0386)	-0.001 (-0.0011)	0.246*** (-0.0594)	-0.002 (-0.0011)
Cropping intensity (%)	0.007 (-0.0403)	-0.001 (-0.0015)	0.013 (-0.0615)	-0.001 (-0.0015)
State-specific trend	Yes	Yes	Yes	Yes
District and Time fixed effects	Yes	Yes	Yes	Yes
Observations	8563	8519	8700	8663
Adjusted R ²	0.906	0.934	0.883	0.935
Within R ²	0.777	0.037	0.056	0.036

Notes: ***, ** and * indicate levels of significance at 1%, 5% and 10%, respectively. Two way clustered standard errors (district and state \times year) are reported in the parentheses.

Source: Author's calculations.

Table A10. Descriptive statistics of drought index (DI) and fertilizer use, by agro-ecological region (AER), 1966-2009

AER	N	Drought years (%)	Mean DI	Min DI	Max DI	Mean NPK (kg/ha)
Humid	3,937	64.14	0.39	0	3.77	52.54
SA Temperate	2,718	69.50	0.38	0	2.83	75.76
SA Tropic	5,038	59.05	0.39	0	2.76	55.71
Arid	814	55.41	0.39	0	2.38	42.89

Note: SA Temperate = Semi-arid Temperate; SA Tropic = Semi-arid Tropic.

Source: Author's calculations.

Table A11. Estimated regression coefficients and marginal elasticities for drought intensity on rate of fertilizer consumption, by agro-climatic region, 1966-2009

Explanatory Variable	Dependent Variable = NPK consumption (kg/ha)			
	Humid	Semi-Arid Temperate	Semi-Arid Tropic	Arid
Constant	39.398*** (-14.302)	-17.821 (-23.115)	37.334** (-15.086)	-9.224 (-23.698)
Drought	-1.240 (-2.1378)	-6.755* (-3.9538)	-2.205 (-1.7759)	0.450 (-1.9063)
Drought ²	0.280 (-0.8299)	1.736 (-1.9845)	1.660* (-0.9291)	-1.683 (-1.0719)
Drought (lag= 1)	-2.011 (-1.951)	-8.302** (-4.058)	-2.694* (-1.448)	0.180 (-2.4586)
Drought ² (lag=1)	1.271* (-0.7584)	4.241** (-1.703)	1.350* (-0.8029)	-0.245 (-1.6516)
Irrigation share (%)	0.498* (-0.2853)	0.522** (-0.2279)	1.225*** (-0.1963)	0.812*** (-0.199)
Irrigation*Drought	0.010 (-0.0395)	0.005 (-0.0518)	-0.053 (-0.0403)	-0.053 (-0.0347)
Irrigation*Drought (lag =1)	-0.004 (-0.029)	-0.011 (-0.051)	-0.020 (-0.0413)	-0.086*** (-0.0287)
HYV Area (%)	0.231* (-0.1258)	0.316*** (-0.0773)	0.108 (-0.0828)	0.214 (-0.1571)
Cropping intensity (%)	-0.049 (-0.0663)	0.332** (-0.1604)	-0.157 (-0.1157)	0.175 (-0.1739)
State specific trend	Yes	Yes	Yes	Yes
District and Time fixed effects	Yes	Yes	Yes	Yes
Observations	8563	8519	8700	8663
Adjusted R ²	0.906	0.934	0.883	0.935
Within R ²	0.021	0.090	0.076	0.205
Marginal elasticity (at mean)	DI = 0.74, Lag DI= 0.73, Irrigation share = 25.10	DI = 0.72, Lag DI= 0.71, Irrigation share = 55.83	DI = 0.72, Lag DI= 0.71, Irrigation share = 25.28	DI = 0.74, Lag DI= 0.73, Irrigation share = 35.09
Drought	-0.008 (-0.011)	-0.047** (-0.020)	-0.017 (-0.012)	-0.067** (-0.026)
Drought (lag=1)	-0.004 (-0.009)	-0.034* (-0.020)	-0.019* (-0.011)	-0.055*** (-0.021)
Irrigation share (%)	0.254* (-0.147)	0.473*** (-0.173)	0.607*** (-0.100)	0.592*** (-0.173)

Notes: ***, ** and * indicate levels of significance at 1%, 5% and 10%, respectively. Two-way clustered standard errors (district and state × year) are reported in the parentheses.

Source: Author's calculations.

Table A12. Distribution of drought index (DI) (Lag=1) and mean fertilizer use, 1966-2009

DI (lag=1) Groups	Observations	Percentage in total	Mean	Mean NPK (kg/ha)
DI = 0	5793	47.46	0	59.67
DI ≤ 1	4703	38.53	0.46	59.83
DI ≤ 2	1579	12.94	1.35	60.98
DI > 2	130	1.07	2.31	49.91

Source: Author's calculations.

Table A13. Estimated regression coefficients for effects of irrigation and drought intensity (DI) on rate of fertilizer consumption, Punjab and Haryana (combined), 1966-2009

Explanatory variable	Log-Linear	
	(1)	(2)
Constant	3.750*** (-0.3150)	3.433*** (-0.3577)
Drought	0.074 (-0.1510)	0.090 (-0.1568)
Drought ²	0.007 (-0.0379)	-0.008 (-0.0329)
Drought (lag= 1)	0.122 (-0.1470)	0.157 (-0.1434)
Drought ² (lag=1)	0.030 (-0.0342)	0.021 (-0.0303)
Irrigation share	0.010** (-0.0040)	0.011** (-0.0039)
Irrigation*Drought	-0.001 (-0.0013)	-0.001 (-0.0013)
Irrigation*Drought (lag =1)	-0.002 (-0.0012)	-0.002 (-0.0012)
HYV Area (%)		0.001 (-0.0022)
Cropping intensity (%)		0.001 (-0.0019)
State-specific trend	Yes	Yes
District and Time fixed effects	Yes	Yes
Observations	698	684
Adjusted R ²	0.952	0.952
Within R ²	0.057	0.071

Notes: ***, ** and * indicate levels of significance at 1%, 5% and 10%, respectively. Two-way clustered standard errors (district and state × year) are reported in the parentheses.

Source: Author's calculations.

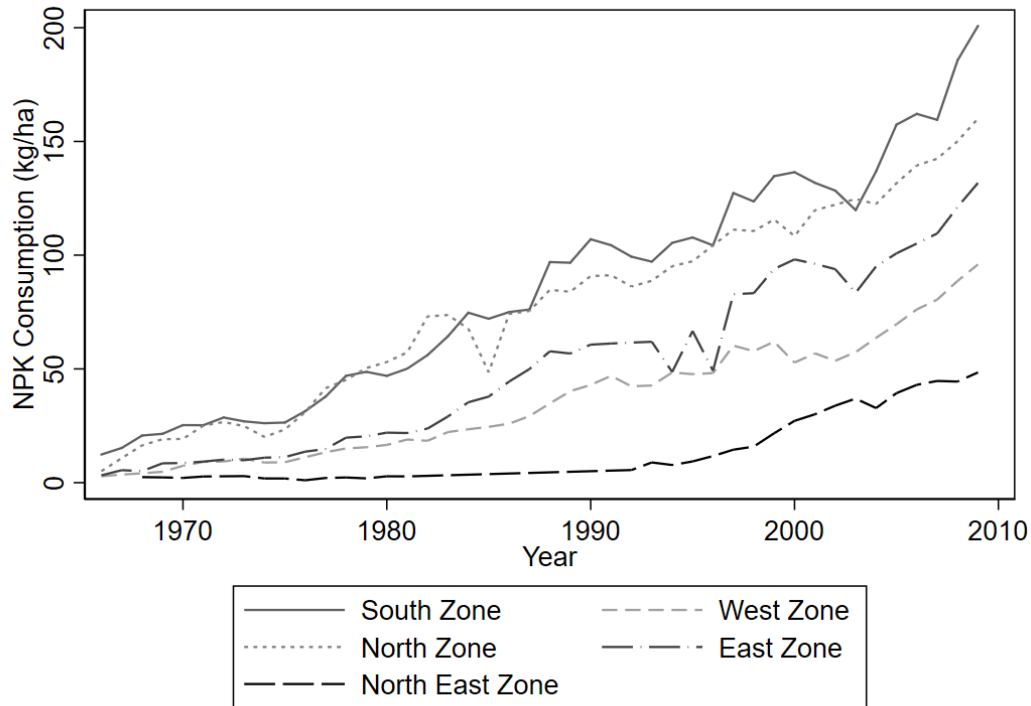


Figure A1. Region-wise fertilizer consumption (kg/ha) in India, 1966-2009.

Notes: South Zone = Andhra Pradesh, Telangana, Karnataka, Kerala, Tamil Nadu; West Zone = Gujarat, Madhya Pradesh, Chhattisgarh, Maharashtra, Rajasthan; North Zone = Haryana, Punjab, Uttar Pradesh, Uttarakhand, Himachal Pradesh; East Zone = Bihar, Jharkhand, Odisha, West Bengal; Northeast Zone = Assam.

Source: Author's calculation from ICRISAT-TCI District Level Database for India (DLD-India).

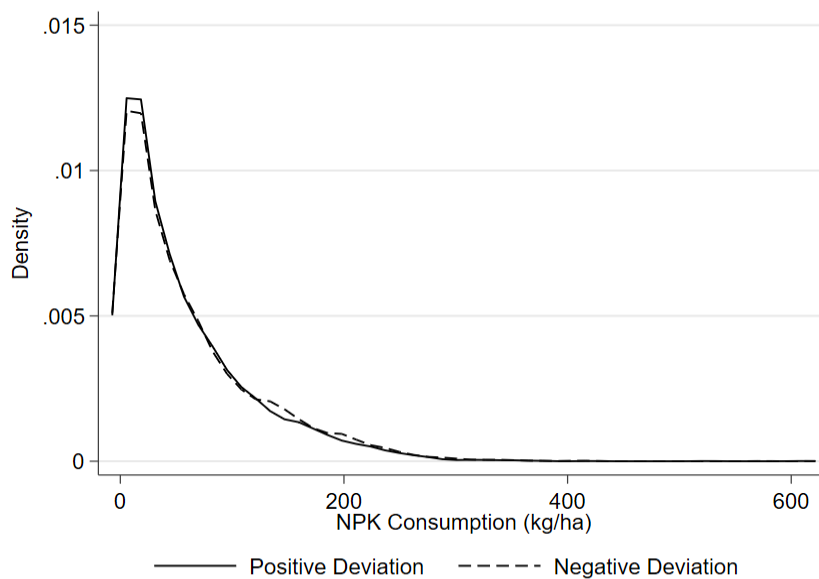


Figure A2. Kernel density plot of NPK consumption by rainfall shock status.

Source: Author's calculations.

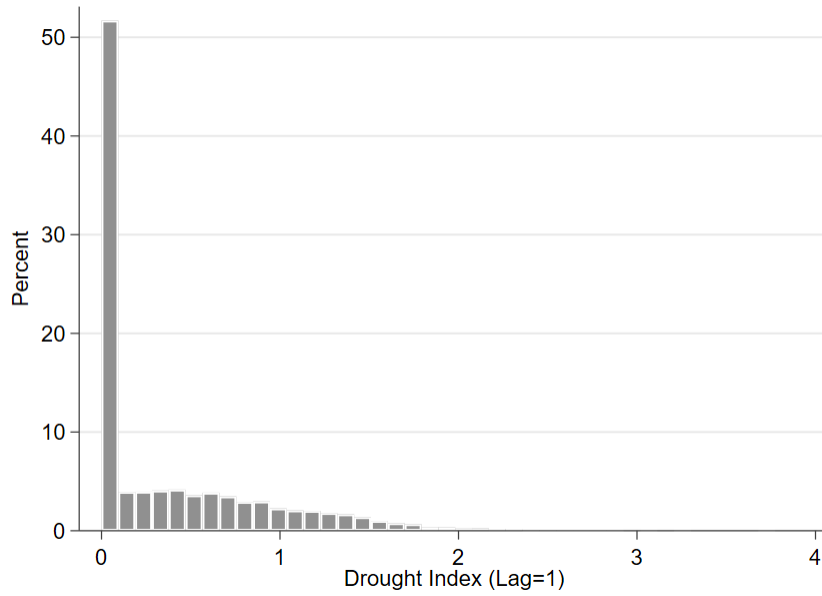


Figure A3. Frequency distribution of drought index (DI Lag=1).

Source: Author's calculation.

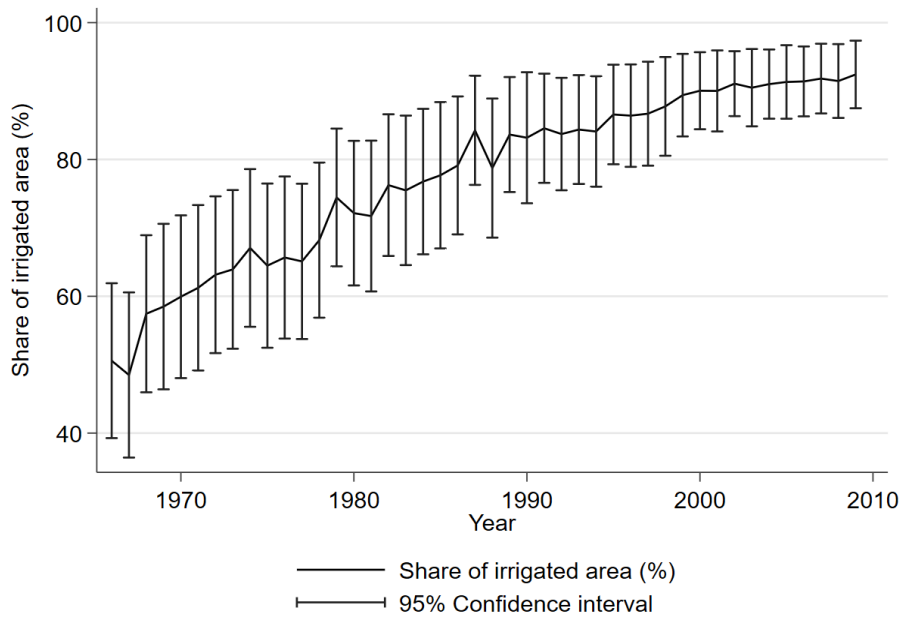


Figure A4. Share of irrigated area in the gross cropped area, Punjab and Haryana (combined), 1966-2009.

Source: Author's calculations.