Identifying the Effect of Investment in Irrigation on Inefficiency in Food Production in India

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ABSTRACT

This paper investigates the technical inefficiencies in food crop production across all states and union territories in India. We utilize a stochastic frontier production model to estimate frontier cereal production and technical inefficiency using Maximum Likelihood Estimation on cross-sectional data.

In our analysis, we determined that there exists technical inefficiency in the production of major cereal products in India. However, we found that while investment in irrigation was a determinant of the total output of cereal products, it was not a determinant of inefficiency. Thus, investment in irrigation was associated with a positive change in output, but not convergence with frontier production.

INTRODUCTION

India is the seventh-largest country by area, the second-most populous country with over 1.33 billion people, and the most populous democracy in the world.

58 percent of India's population is employed in the agricultural sector (and its allies). The importance of this sector is also evident from the fact that Gross Value Added (GVA) was estimated to be US$ 271.00 billion in FY18. During 2017-18 crop year, food grain production was estimated to be a record 284.83 million tonnes. Total agricultural exports have grown at a CAGR of 16.45 percent over FY10-18 to reach US$ 38.21 billion in FY18.

According to the Food and Agriculture Organization (FAO) of the UN, agriculture accounts for 70 percent of global water withdrawal. Agriculture in India accounts for nearly 90 percent of all water use. Producing 1 kilo of rice requires about 3,500 litres of water, 1 kilo of beef some 15,000 litres, and a cup of coffee about 140 litres. This puts significant stress on water sources in India. Though India accounts for approximately 17 percent of the world's population, it has only 4 percent of the world's water resources. The irrigation infrastructure in the country is made up of a network of canals from rivers (covers 22 million ha of cultivated land), ground water (covers 39 million ha of cultivated land), well-based systems, tanks and other rainwater harvesting systems. But two-thirds of cultivation is still dependent on monsoons. According to the UN, a country is said to experience "water stress" when water availability drops to less than 1700 m^3 per capita per year and "water scarcity"' if it is less than 500 m^3 per capita per year. The per capita water availability in India in 2010 was 1588 m^3 (as compared to 5200 m^3 in 1951). 54 percent of the country faces high water stress. As the global population grows, the demand for food, and therefore water, increases.

Furthermore, existing water sources are suspect to pollution and contamination particularly from population stress, industrial waste and agricultural expansion. There is also mounting concern regarding the depleting water tables, especially in large urban centers. In urban cities, water tables are falling 2-3 meters every year (Tata Institute of Social Sciences). Climate change will exacerbate the water shortage and cause erratic weather patterns or cyclones that can further impede agricultural yield. In developing countries, most households spend 50-80 percent of their income on food. During a spike in food prices in 2007-2008, an additional 110 million people fell below the global poverty line and increased the undernourished population by 44 million. Since supply of water is effectively fixed and demand increasing exponentially, improvements in water infrastructure, especially irrigation facilities, will be critical in managing India's ability to sustain and improve agricultural yield.

Empirical measures of (in)efficiency are necessary to gauge the gain in output from improving production. Policy implications stemming from significant levels of inefficiency could be that it is more cost effective to achieve short run increases in farm output, and thus income, by concentrating on improving efficiency rather than introducing new technologies (Belbase and Grabowski, 1985, Shapiro and Müller, 1977).

LITERARY REVIEW

You et al. study the irrigation potential in Africa and show that agricultural productivity can be improved by at least 50 percent. They find that the profitability from irrigation potential is significant in both small-scale and large-scale systems. However, in Africa only 6 percent of total cultivated is equipped for irrigation. In our region of interest, India, irrigation practices and infrastructure are better established. However, only 35 percent of the total agricultural land is reliably irrigated. Therefore, there is potential for improvements in productivity as well as efficiency. Water infrastructure employed and constructed in rural and agricultural communities are a necessity to improve availability, predictability, and timeliness of water access for producing high yield crops and livestock (Loucks and Van Beek 2017).

Suhag and Goyal also try to estimate technical inefficiency using the stochastic frontier model on wheat farms in Haryana, India. They observe that mean technical efficiency varied from 0.4346 to 0.9598 in the 3rd year of their study. Moreover, mean technical efficiency increased through the years, declining from 0.9172 in the first year to 0.9025 in the third year, implying that realized output can be increased by around 10 percent without requiring any additional resources. They state that the observed inefficiency, as well as increased inefficiency, could be due to various socio-economic and technological factors. However, without access to data, they were not able to determine the specific nature of the inefficiency term. Given that India is a high water-stress zone, water infrastructure and irrigation (in)efficiency is an important factor to consider.

Another analysis conducted by Paul S Omaza and J.K Olayemi in 2010 explores the technical inefficiency in food crop production among farmers in Gombe State, Nigeria. They too made use of a stochastic production frontier model and the method of maximum-likelihood estimation to identify that there was scope to increase output from existing hectares of food crops, if resources were properly harnessed and efficiently allocated. The low agricultural productivity in Nigeria is evident from the comparison of the actual yields of major crops with potential yields. The technical inefficiency effects of individual farmers were modeled for cross-sectional data, and efficiencies of sample food crop farmers in Gombe State of Nigeria were predicted. The results of their empirical analysis suggest that more than 90 percent of the variation in input among the farms is due to differences in technical efficiency. The estimated range of technical efficiencies among farmers varied from 0.13 and 0.89 with a mean technical efficiency of 0.69. Moreover, they reject their hypothesis that farmer-specific factors do not influence the efficiency of food production and conclude that total technical efficiency in food crop production in Gombe could be improved by 31 percent through better utilisation of the available resources.

Yet another paper by Joachim Nyemeck Binam et al estimates the total efficiency of small farmers in the slash and burn agriculture zone of Cameroon. They use survey data from 450 farmers in 15 villages during the growing season in 2001-02. Agriculture in Cameroon is a major source of employment (70 percent of overall employment), GDP (30 percent of total GDP) as well as foreign exchange earnings (40 percent of total).[1] A remarkable feature of the slash and burn agricultural zone is its dual structure of farming system, i.e., farming practices that produce both perennial export crops (coffee, cocoa, banana) as well as annual food for subsistence and local markets. They specify the stochastic production function to

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[1]Source: Living conditions of populations and poverty profile in Cameroon in 2001: first results. Directorate of Statistics and National Accounts, May 2002, Yaoundé-RC.

be Cobb-Douglas and found the function coefficients for the MLE to be 0.90, 0.84, 0.94 implying decreasing returns to scale. The technical efficiencies (TE) indices range from 48 percent to 95 percent for the pure groundnut farming system with an average of 71 percent. Thus, if the average farmer in the sample were to achieve the TE level of their most efficient counterpart then they could realise approximately 25 percent savings in costs.

DATA

Summary statistics:

Total Production of cereals (in 1000 tonnes)

	Percentiles	Smallest		
1%	4	4		
5%	24	24		
10%	52	24	Obs	33
25%	235	52	Sum of Wgt.	33
50%	1547		Mean	6856.182
		Largest	Std. Dev.	9835.791
75%	11566	16471		
90%	16471	18875	Variance	9.67e+07
95%	27847	27847	Skewness	2.172406
99%	45211	45211	Kurtosis	8.363565

We can see from the above summary statistics table that there is significant variation in the total production of cereals (in 1000 tonnes) across states. Uttar Pradesh is the largest producer of cereal in India with 45,221,000 tonnes of cereal. The lowest producer is the union territory of Daman and Diu with just 4000 tonnes of total cereal produced. The standard deviation is also very high, indicating great variance in total production of cereal by states.

Total Capital Expenditures to Major, Medium
Irrigation, Flood Control (in millio

	Percentiles	Smallest		
1%	16.1	16.1		
5%	52.9	52.9		
10%	374.55	244.1	Obs	30
25%	903.9	505	Sum of Wgt.	30
50%	4989.05		Mean	14441.8
		Largest	Std. Dev.	23956.7
75%	13669.8	36240.1		
90%	41946.4	47652.7	Variance	5.74e+08
95%	90749.1	90749.1	Skewness	2.347383
99%	91314.9	91314.9	Kurtosis	7.676095

Likewise, there is a large variation in capital expenditures on irrigation across states. The biggest spender on irrigation is Maharashtra, which is also the third largest producer of cereals. However, Uttar Pradesh, the highest producer of cereals, only invests around one-third of that amount into its irrigation infrastructure.

Summary of Datasets (2010-2011):

Variables per state	Source
Total food grain production for cereals	Ministry of Statistics and Programme Implementation (via Open Government Data (OGD))
Number of cultivators	Census Data, 2011
Number of agricultural labourers	Census Data, 2011
Consumption of fertilizer (in 1000 tonnes)	Department of Agriculture and Cooperation, INM Division
Land area under cultivation (in 1000 hectares)	NITI Aayog/Planning Commission (via OGD)
Total Capital Disbursements in Agriculture and Allied Activities (in millions of Rs)	Reserve Bank of India
Total Capital Expenditures to Major, Medium Irrigation, Flood Control (in millions of Rs)	Reserve Bank of India
Average PAR in area	International Journal of Energy and Environmental Engineering

Negative Observations

In order to make the frontier function identifiable, all inputs are assumed to be strictly positive values. This creates a problem with Uttar Pradesh, which reports negative expenditure on agricultural capital in 2010 and 2011. There is only one observation in (lncapex) where this boundary is violated. Running an ML estimation using the all the variables specified above, a significance test on lncapex (H_0 : $\beta = 0$) results in a z-statistic of -0.75, a p-value of 0.453, which fails to reject that lncapex is not significant. Thus, rather than applying a truncated normal distribution which resulted in higher AIC statistics. We remove lncapex from the model to keep Uttar Pradesh as an observation.

METHODOLOGY

The Stochastic Frontier Production Function

The frontier production function has been used by econometricians since it was used and cited by Farrell (1957). The model has been primarily employed to measure the efficiency of production by comparing actual production to a theoretical optimal production given specific inputs.

The model used by Aigner and Chu (1968) and Schmidt (1976) specifies the frontier production as $y_i \leq f(x_i, \beta) + \varepsilon_i$, where y is the maximum possible output given x inputs and an estimated parameter β for a cross-section of N firms. To balance the model with respect to outliers, Timmer (1971) and Dugger (1974) employed "probabilistic frontiers" where some proportion of each cross-section of firms were placed above the frontier. This method is justified by appealing to statistical error since the frontier is theoretically the maximum possible production.

According to Aigner, Lovell, and Schmidt (1977) attempting to estimate the parameters of this equation using maximum likelihood estimation would violate the regularity conditions of the ML estimator, since the range of y is dependent on the parameters that would be estimated, which means the usual methods cannot be invoked to determine the asymptotic distribution of the parameters.

To overcome this issue, Aigner, Amemiya, and Poirier (1976) propose two sources of noise between observed production of firms, related to the frontier production function: 1) a firm's ability to optimize the use of "best practices" in production (its production efficiency) and 2) statistical error.
This such that:

$$\epsilon_i = \begin{cases} \dfrac{\epsilon_i^*}{\sqrt{1-\theta}} & if\ \epsilon^* > 0 \\ \dfrac{\epsilon_i^*}{\sqrt{\theta}} & if\ \epsilon^* \leq 0 \end{cases}$$

where $\varepsilon \sim N(0, \sigma^2)$ and $0 < \theta < 1$ is the "relative variability" between the two sources of error. Therefore, as $\theta \to 1$ the negative error case (inefficiency) has more influence in the ML estimate. This addresses issues with "probabilistic frontiers" mentioned above, although it is still implicit in the model. D. Aigner et al (1977) suggest modeling the error process implied by the behavioral considerations of the scenario of interest.

This specification of error yields the stochastic frontier production function:

$$y_i \leq f(x_i, \beta) + v_i - u_i$$

where each firm's maximum possible production must lie on or below the frontier production function, plus a disturbance term, v. The disturbance term, v, would capture external events uncorrelated to the inputs captured in x, for example, random weather effects, market shocks, etc. Any additional variation would represent a deviation from the maximum possible production (inefficiency) and would be captured by the random variable u_i.

Aigner, Lovell, and Schmidt (1977) demonstrate an ML, iterated least squares, and Monte Carlo simulation method for estimating σ^2 , λ , and β for the stochastic function above —where the MSE under the linear model is a consistent estimator for σ^2 — as well as applying a linear model for $f(x_i, \beta)$. Under the linear model: $y_i = X'\beta + v_i - u_i$, where $X'\beta + v_i$ is the maximum production possible (frontier production) in a region given a set of inputs X. In terms of the research question, X are factors that affect production and are not controllable by producers in the region—including soil quality, temperature, sunlight requirements, etc.

Based on existing literature on specifying production functions for agriculture, we will use a Cobb-Douglas specification of the frontier production function, where u_i is the exogenous inefficiency term, defined as the relative difference between the maximum production in a set of regions with similar inputs (the frontier production) and the observed output for each region in the set. Theoretically, this results in a relative measure bounded from (0,1) where 1 is the optimum production achievable given x inputs; however, values over 1 are possible due to statistical noise.

$$Stochastic\ production\ function:$$

$$ln\,(TC_{ij}) = \beta_0 + \beta_1\, ln\,(L_i) + \beta_2\, ln\,(F_i) + \beta_3\, ln\,(IRR_i) + \beta_4\, ln\,(PAR_i) + \beta_5\, ln\,(LA_{ij}) + \beta_6\, ln\,(KE_i) + V_{ij} - U_{ij}$$

$$\begin{aligned}
&Where\ i\ represents\ each\ state\ \ and\ j\ represnts\ each\ type\ of\ cereal\\
&TC\ = Total\ Cereal\ Production\ in\ 1000\ tonnes\\
&L = Agricultural\ Labor\\
&F = Amount\ of\ Fertilizer\ utilites\ in\ 1000\ tonnes\\
&IRR = Irrigation\ Expenditure\ in\ Rs.\\
&LA = Land\ Area\ in\ Hectares\ for\ the\ crop\\
&KE\ = Capital\ Expenditure\ in\ Rs.\\
&PAR\ = Average\ Photosynthetically\ Active\ Radiation\\
&V\ = error\ term\\
&U\ = technical\ inefficiency\ term
\end{aligned}$$

Distribution of inefficiency and error terms

Frontier production function models have typically used a half-normal (the u_i 's are half-normally distributed $N^+(0, \sigma_u^2)$) , an exponential (the u_i 's are independently exponentially distributed with variance σ_u^2), or a truncated normal distributions (same as half-normal but with a truncation point at 0) to specify the inefficiency random variable. Using AIC as a goodness-of-fit measure, we run an ML estimation on each of the frontier production functions for total cereal production (an aggregate of all grain production) for each potential distribution.

Table 1 shows that this assessment disqualifies a truncated model and points to half-normal or an exponential specification for u .

To avoid relative cost changes, we will be modeling individual cereal grains, instead of aggregate cereal production. Thus, we run a similar AIC/BIC analysis for each grain. Table 2 shows that the results for each grain seems evenly divided between both distributions. If we look at the difference in the AIC values, however, we notice that the exponential distribution outperform the half-normal by a much higher factor in general (highlighted in green). Both the half-normally and exponentially distributed u models fail to converge for certain grains. These non-converged estimates will be reported along with the converged estimates obtained from a half-normal distribution for comparison.[2]

Empirical Analysis

Tables 2 & 3 show the MLE output after dropping capital expenditure. Immediately, we observe that the coefficients for (lnlabor) are negative for certain estimates. While this may seem counterintuitive, closer inspection shows that these coefficients apply to rice, maize, wheat, and barley, which are among the top four most produced crops in India. Therefore, one can expect that these markets are already well-established with sufficient labor, such that additional labor would experience diminishing marginal returns.

Graphs 1-2[3] show a scatterplot of the estimated frontier production for each of the cereals in our analysis. The 45-degree line represents frontier production (u=0), where the distance below the 45-degree represents the magnitude of the inefficiency term. We note that with major crops (rice, wheat, and maize), most states lie close to the frontier as opposed to other grains. This is particularly the case with states where the particular cereal is grown in large amounts. Intuitively, this may be because agricultural practices have matured in terms of efficiency in these states given the importance of the cereal. For example, with rice, Rajasthan, Himachal Pradesh, and Delhi produce relatively lower quantities of rice (as seen in the data). Ragi, Jowar, Barley, and Bajra have more dispersion away from the frontier.

An important observation from the MLE output[4] is that the coefficients on irrigation expenditure (in logs) are surprisingly negative. To evaluate the variable from another angle, we then introduce an irrigation dummy into the graph, where the dummy takes the value 1 if the state is above the median irrigation expenditure (in log). We notice a stark difference in states above the median versus the states below the median. States above the median are clustered towards the top right quadrant of the graph. While these states are not necessarily closer to the efficient frontier, they indicate that states that have high irrigation expenditure (in logs) also have high total cereal production (in logs). Since our analysis is based on cross-sectional data, it is hard to ascertain whether this is due to quantity or efficiency effects. A time-series analysis should be conducted to determine the effects of changes in irrigation expenditures and efficiency.

The other two variables, lnaveragelatpar and lnfertilizer are introduced as controls. The average Photosynthetically active radiation (PAR) values when adjusted for latitudes from the equator was used as a measure of direct sunlight in these regions. As expected, the coefficients take positive values for all cereals, except rice. lnfertilizer also has positive coefficients for all values.

[2] See Appendix, table 2
[3] See Appendix, G1-2
[4] See Appendix, ML1-ML4

CONCLUSION

We were able to find statistically significant results for inefficiency in food production across multiple cereal products and across high- and low- producing states. However, we were not able to find a significant effect of investment in irrigation on the observed production in the sample year. Plotting investments in irrigation on observed production, we were able to find a strong relationship between investment in irrigation and observed cereal output despite not being able to find such a relationship between inefficiency and investment in irrigation. This suggests that increases in investment in irrigation are associated with increases in output in both relatively efficient and inefficient states.

These are important results given that future strain on India's water tables and increasing contamination of environmental water will reduce undeveloped[5] sources of water and increase the marginal costs of irrigation, affecting future production either through efficiency or total production. The risk of reverse causality bias, i.e. an increase in total crop production, resulting from better use of arable land or improved farming practices, for example, leading to an increase in irrigation expenditure.

Further research into the efficiency effects of water management and food production are possible based on the findings of this paper. One topic of interest would be a cost-benefit analysis on a collection of irrigation techniques to measure the benefit to efficiency. This would help explain the direction of the change in total food production relative to efficiency, which was not achievable using cross-sectional data alone.

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[5] Natural water that is accessible without the use of machinery

APPENDIX

Table 1:

Distribution of u	AIC	BIC
Half-normal	28.67475	39.99762
Exponential	28.67485	39.99772
Truncated-normal	30.67475	43.25571

Table 2:

Grain (distribution)	AIC	BIC	Convergence	Better-fit distribution
Rice (hnormal)	9.290614	19.35539	Yes	Exponential
Rice (exponential)	6.133249	17.45612	Yes	
Jowar (hnormal)	17.60819	21.97235	Yes	Half-normal
Jowar (exponential)	17.60827	21.97243	No	
Bajra (hnormal)	17.94712	23.03166	Yes	Half-normal or Exponential
Bajra (exponential)	17.94713	23.03168	Yes	
Maize (hnormal)	27.22372	36.64815	No	Exponential
Maize (exponential)	27.36605	37.96853	Yes	
Ragi (hnormal)	23.41752	27.29677	No	Exponential
Ragi (exponential)	19.31229	23.67645	Yes	
Millet (hnormal)	37.02348	45.52343	Yes	Half-Normal
Millet (exponential)	37.02352	45.52347	No	
Wheat (hnormal)	29.40071	38.3623	Yes	Half-normal

Wheat (exponential)	29.40071	38.3623	Yes	or Exponential
Barley (hnormal)	8.640089	13.00425	Yes	Half-normal
Barley (exponential)	8.640127	13.00429	No	

Table 3: State-wise Inefficiency, u_i (in logs) – half-normal estimates

state	urice_h	ujowar_h	ubajra_h	umaize_h	uragi_h	umille~h	uwheat_h	ubarle~h
ANDAMAN & NICOBAR ISLANDS	.	.	.	.	.	.	.	.
ANDHRA PRADESH	7.69e-09	.3225396	.0203302	4.89e-06	.0000115	.0087002	.3525547	.
ARUNACHAL PRADESH	.3171601	.	.	.5897552	.	.0087534	.4774315	.
ASSAM	.3758078	.	.	1.1084	.	.008892	.7861798	.
BIHAR	.7782597	.3638477	.0202242	.252318	.0000132	.0087985	.3820703	.0034753
CHANDIGARH	.	.	.	.	.	.	.	.
CHHATTISGARH	.6837805	3.78e-07	.	.7784339	1.733674	.0090924	.857568	.0036009
DADRA & NAGAR HAVELI	.	.	.	.	.	.	.	.
DAMAN & DIU	.	.	.	.	.	.	.	.
DELHI	7.52e-09	4.24e-07	.0199737	.	.	.	1.03e-08	.
GOA	.6074529	.	.	.	.	.	.	.
GUJARAT	.4223195	.0967497	.0211261	1.009295	.3466932	.0086533	1.01e-08	.
HARYANA	.2306804	.121415	.0200454	.4952003	.	.	1.05e-08	.0034905
HIMACHAL PRADESH	.492282	.	.	.4102117	.0000113	.0089904	.8995865	.0034219

JAMMU & KASHMIR	.2958611	.	.0217225	.1500846	.	.0088536	1.065715	.003543
JHARKHAND	.6655188	.	.	1.172497	1.096774	.0089501	.5058062	.
KARNATAKA	.1158491	3.89e-07	.021591	.4506884	.0000131	.008916	.9034504	.
KERALA	.3228689	.5909449	.	.	.	.	.	.
LAKSHADWEEP	.	.	.	.	.	.	.	.
MADHYA PRADESH	.916622	4.23e-07	.0197547	1.304966	.	.0089003	.555979	.0035511
MAHARASHTRA	.4211184	.6055143	.0216898	.608465	.459739	.0088599	.380149	.0034974
MANIPUR	7.55e-09	.	.	4.78e-06	.	.	1.01e-08	.
MEGHALAYA	.2070451	.	.	.1947394	.	.0088497	.	.
MIZORAM	.8914346	.	.	.4895202	.	.	.	.
NAGALAND	.2211346	.	.0210927	5.25e-06	.	.0088193	.3169695	.003523
ODISHA	.6914336	1.05997	.0222493	.4327822	.8264246	.0089753	.3924587	.
PUDUCHERRY	.5101635	.	.	.	.	.	.	.
PUNJAB	7.53e-09	.	.0209046	4.97e-06	.	.	.0334598	.0035015
RAJASTHAN	8.21e-09	.1677313	.0219004	.5025278	.	.0088773	.0564669	.0035321
SIKKIM	.	.	.	.	.	.	.	.
TAMIL NADU	7.41e-09	.2942605	.0204336	4.71e-06	.0000113	.0087135	.	.
TRIPURA	.2890109	.	.	.7363996	.	.	.	.
UTTAR PRADESH	.1427538	3.99e-07	.0195064	.7132535	.	.0088157	1.03e-08	.003519
UTTARAKHAND	.5074038	.	.	.6939176	.2254657	.0086173	.5400312	.0035841
WEST BENGAL	.2415845	.	.	.0272863	.3042212	.0088305	1.00e-08	.0034978

Table 4: State-wise Inefficiency, u_i (in logs) – exponential estimates

state	urice_e	ujowar_e	ubajra_e	umaize_e	uragi_e	umille~e	uwheat_e	ubarle~e
ANDAMAN & NICOBAR ISLANDS	.	.	.	.	.	.	.	.
ANDHRA PRADESH	.0697621	.433846	.008174	.0727267	4.26e-09	.0105965	.3525547	.
ARUNACHAL PRADESH	.1124021	.	.	.1246585	.	.0107344	.4774315	.
ASSAM	.171243	.	.	.1995061	.	.0111055	.7861798	.
BIHAR	.4855126	.4390548	.0081445	.0972259	4.30e-09	.0108532	.3820703	.0043327
CHANDIGARH	.	.	.	.	.	.	.	.
CHHATTISGARH	.2720857	1.32e-08	.	.139742	1.640421	.0116743	.857568	.004691
DADRA & NAGAR HAVELI	.	.	.	.	.	.	.	.
DAMAN & DIU	.	.	.	.	.	.	.	.
DELHI	.0710286	1.35e-08	.0080749	.	.	.	1.02e-08	.
GOA	.1791973	.	.	.	.	.	.	.
GUJARAT	.1711776	.1505806	.0083958	.1779729	.1617706	.010477	1.02e-08	.
HARYANA	.1112119	1.34e-08	.0080948	.112451	.	.	1.05e-08	.0043739
HIMACHAL PRADESH	.2050969	.	.	.1207811	4.23e-09	.0113798	.8995865	.0041918
JAMMU & KASHMIR	.1631715	.	.0085625	.1096024	.	.011001	1.065715	.0045207
JHARKHAND	.276787	.	.	.2378413	1.246456	.0112662	.5058062	.
KARNATAKA	.0858057	1.41e-08	.0085257	.1068036	4.24e-09	.0111714	.9034504	.
KERALA	.1293444	.4762564	.	.	.	.	.	.
LAKSHADWEEP	.	.	.	.	.	.	.	.

MADHYA PRADESH	.5190125	1.30e-08	.008014	.2494786	.	.0111283	.555979	.0045439
MAHARASHTRA	.1624877	.6491171	.0085533	.1088394	.6404653	.011018	.380149	.0043928
MANIPUR	.0783737	.	.	.0793584	.	.	1.01e-08	.
MEGHALAYA	.1189288	.	.	.0947724	.	.0109902	.	.
MIZORAM	.4234535	.	.	.1122599	.	.	.	.
NAGALAND	.1215668	.	.0083865	.1047485	.	.0109088	.3169695	.0044639
ODISHA	.2713385	1.123577	.0087102	.1008033	.9604813	.0113371	.3924587	.
PUDUCHERRY	.1787226	.	.	.	.	.	.	.
PUNJAB	.0730186	.	.008334	.0894556	.	.	.0334598	.0044042
RAJASTHAN	.1060534	.0095243	.0086123	.1300226	.	.0110651	.0564669	.0044896
SIKKIM	.	.	.	.	.	.	.	.
TAMIL NADU	.0737671	.1133122	.0082028	.0784657	4.25e-09	.0106309	.	.
TRIPURA	.1085204	.	.	.1468345	.	.	.	.
UTTAR PRADESH	.1171841	1.34e-08	.0079449	.1397681	.	.010899	1.02e-08	.0044528
UTTARAKHAND	.2030011	.	.	.1430187	.0490899	.0103865	.5400312	.0046406
WEST BENGAL	.10792	.	.	.0804711	4.32e-09	.0109385	9.96e-09	.0043938

ML1: MLE output for Exponential Distribution (with Capex)

Coefficient for exponetial distirbution (with Capex)

	-1	-2	-3	-4	-5	-6	-7	-8
	lnriceprod~n	lnjowarpro~n	lnbajrapro~n	lnmaizepro~n	lnragiprod~n	lnmilletpr~n	lnwheatpro~n	lnbarleypr~n
main								
lnlabor	-0.157***	0.511**	0.0608	0.262***	1.029***	0.0019	-0.240*	-0.212***
	(-49936.48)	-2.5	-0.53	-60611.1	-130648.6	-0.01	(-1.75)	(-3.00)
lnfertilizer	0.0610***	0.125	0.103	0.0361***	-0.771***	0.0211	0.155	0.561***
	-48015.57	-0.44	-0.96	-23445.78	(-123234.81)	-0.15	-1.59	-8.73
lnirrigati~x	-0.00976***	-0.208	-0.168*	-0.0393***	-0.247***	-0.0937	-0.0898	-0.558***
	(-5977.91)	(-1.07)	(-1.67)	(-32213.77)	(-99931.02)	(-0.88)	(-1.20)	(-8.91)
lncapex	0.0371***	-0.0956	-0.0175	-0.0427***	-0.0523***	0.0161	0.0166	0.00538
	-18681.73	(-1.03)	(-0.22)	(-35502.11)	(-27865.54)	-0.24	-0.29	-0.13
lnaveragel~r	-0.385***	1.794**	1.222**	0.332***	2.371***	0.781	0.0679	0.989***
	(-29198.45)	-2	-2.5	-19138.04	-143218.42	-1.07	-0.13	-2.65
lnriceland	1.187***							
	-653030.79							
lnjowarland		0.962***						
		-12.84						
lnbajraland			1.040***					
			-23.02					
lnmaizeland				0.963***				
				-305577.24				
lnragiland					1.244***			
					-1200411.26			
lnmilletsl~d						0.833***		
						-9.67		
lnwheatland							1.068***	
							-23.27	
lnbarleyland								1.235***
								-33.84
_cons	4.064***	-17.67**	-7.720***	-4.231***	-24.00***	-4.267	3.316	-1.916
	-44250.39	(-2.48)	(-2.65)	(-52704.36)	(-152991.09)	(-0.96)	-0.93	(-0.78)
lnsig2v								
_cons	-39.65	-2.871***	-2.843***	-38.81	-40.9	-1.837***	-2.269***	-3.619***
	(-0.05)	(-6.95)	(-6.92)	(-0.05)	(-0.03)	(-5.49)	(-6.49)	(-8.48)
lnsig2u								
_cons	-2.456***	-10.02	-9.991	-1.610***	-1.891***	-8.979	-9.397	-10.75
	(-6.26)	(-0.12)	(-0.06)	(-3.94)	(-3.27)	(-0.09)	(-0.05)	(-0.07)
N	26	12	13	24	12	19	20	12
t	statistics	in	parentheses					
*	p<0.10,	**	p<0.05,	***	p<0.01			

ML2: MLE output for Half-Normal Distribution (with Capex)

Coefficient for hnormal distirbution (with Capex)								
	-1	-2	-3	-4	-5	-6	-7	-8
	lnriceprod~n	lnjowarpro~n	lnbajrapro~n	lnmaizepro~n	lnragiprod~n	lnmilletpr~n	lnwheatpro~n	lnbarleypr~n
main								
lnlabor	-0.176***	0.511**	0.0608	0.0506	0.254	0.00191	-0.240*	-0.212***
	(-2.62)	-2.5	-0.53	-0.36	-1.27	-0.01	(-1.75)	(-3.00)
lnfertilizer	0.0697***	0.125	0.103	0.0385***	-0.129	0.0211	0.155	0.561***
	-2.69	-0.44	-0.96	-4.77	(-0.50)	-0.15	-1.59	-8.73
lnirrigati~x	-0.00341	-0.208	-0.168*	-0.0073	-0.188	-0.0937	-0.0898	-0.558***
	(-0.10)	(-1.07)	(-1.67)	(-0.31)	(-0.99)	(-0.88)	(-1.20)	(-8.91)
lncapex	0.0381*	-0.0956	-0.0175	-0.00191	0.0745	0.0161	0.0166	0.00539
	-1.95	(-1.03)	(-0.22)	(-0.06)	-0.75	-0.24	-0.29	-0.13
lnaveragel~r	-0.248***	1.794**	1.222**	1.049***	1.399**	0.781	0.0679	0.989***
	(-2.65)	-2	-2.5	-5.32	-2.26	-1.07	-0.13	-2.65
lnriceland	1.168***							
	-52.27							
lnjowarland		0.962***						
		-12.84						
lnbajraland			1.040***					
			-23.03					
lnmaizeland				1.058***				
				-13.29				
lnragiland					1.140***			
					-99.57			
lnmilletsl~d						0.833***		
						-9.67		
lnwheatland							1.068***	
							-23.27	
lnbarleyland								1.235***
								-33.84
_cons	3.507	-17.68**	-7.722**	-6.581	-10.91	-4.271	3.326	-1.918
	(.)	(-2.47)	(-2.56)	(.)	(.)	(-0.94)	-0.9	(-0.77)
lnsig2v								
_cons	-27.9	-2.871***	-2.842***	-27.19	-25.17	-1.837***	-2.270***	-3.618***
	(-0.18)	(-7.02)	(-7.05)	(-0.17)	(-0.16)	(-5.59)	(-5.50)	(-8.79)
lnsig2u								
_cons	-1.710***	-11.67	-10.17	-0.984***	-0.833**	-9.522	-7.391	-11.62
	(-6.16)	(-0.03)	(-0.03)	(-3.41)	(-2.04)	(-0.03)	(-0.06)	(-0.03)
N	26	12	13	24	12	19	20	12
t	statistics	in	parentheses					
*	p<0.10,	**	p<0.05,	***	p<0.01			

ML3: MLE output for Exponential Distribution (without Capex)

Coefficients for exponential distribution (no Capex)

	-1	-2	-3	-4	-5	-6	-7	-8
	lnriceprod~n	lnjowarpro~n	lnbajrapro~n	lnmaizepro~n	lnragiprod~n	lnmilletpr~n	lnwheatpro~n	lnbarleypr~n
main								
lnlabor	-0.134	0.557***	0.0159	-0.102	0.898***	0.013	-0.288***	-0.212***
	(-1.58)	-28407	-0.13	(-0.60)	-179123.48	-0.06	(-77155.79)	(-3.27)
lnfertilizer	0.0891	-0.391***	-0.0135	0.0973	-0.684***	0.0214	0.108***	0.559***
	-1.49	(-179547.25)	(-0.14)	-1.15	(-173679.10)	-0.16	-41042.66	-9.39
lnirrigati~x	-0.0426	0.222***	-0.0536	-0.0816	-0.189***	-0.0928	-0.00412***	-0.554***
	(-0.84)	-7919.33	(-0.62)	(-1.04)	(-224296.35)	(-0.90)	(-2727.73)	(-10.25)
lnaveragel~r	0.238	0.977***	1.030**	1.224**	2.003***	0.723	-0.0582***	0.984***
	-0.66	-19987.49	-1.98	-2.46	-265543.24	-1.11	(-6294.93)	-2.89
lnriceland	1.039***							
	-20							
lnjowarland		0.904***						
		-221731.17						
lnbajraland			1.053***					
			-27.64					
lnmaizeland				1.118***				
				-16.27				
lnragiland					1.222***			
					-2124424.91			
lnmilletsl~d						0.836***		
						-10.08		
lnwheatland							1.079***	
							-1598156.84	
lnbarleyland								1.234***
								-36.35
_cons	1.025	-13.88***	-6.209*	-5.746*	-21.00***	-3.98	4.809***	-1.87
	-0.37	(-39182.28)	(-1.81)	(-1.66)	(-227559.71)	(-0.94)	-52461.96	(-0.81)
lnsig2v								
_cons	-3.197***	-39.66	-2.431***	-2.148**	-42.01	-1.882***	-40.22	-3.697***
	(-2.63)	(-0.04)	(-6.00)	(-2.47)	(-0.03)	(-5.81)	(-0.04)	(-9.18)
lnsig2u								
_cons	-3.45	-2.833***	-9.579	-4.138	-1.875***	-9.024	-1.901***	-10.83
	(-1.63)	(-5.30)	(-0.04)	(-0.64)	(-3.25)	(-0.10)	(-4.46)	(-0.10)
N	29	14	15	25	12	20	22	13

t statistics in parentheses

* p<0.10, ** p<0.05, *** p<0.01

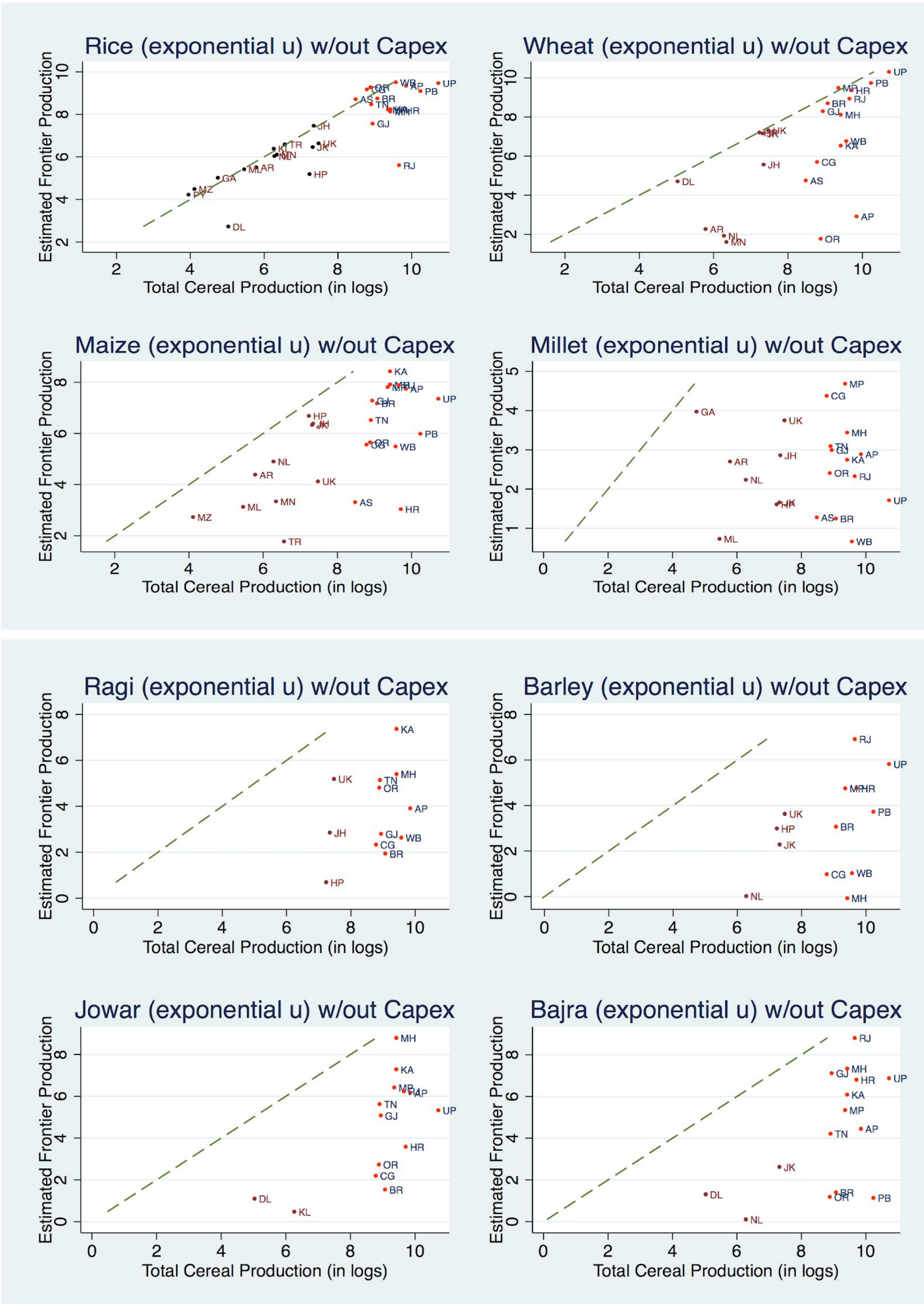
ML4: MLE output for Half-Normal Distribution (with Capex)

Coefficients for hnormal distribution (no Capex)

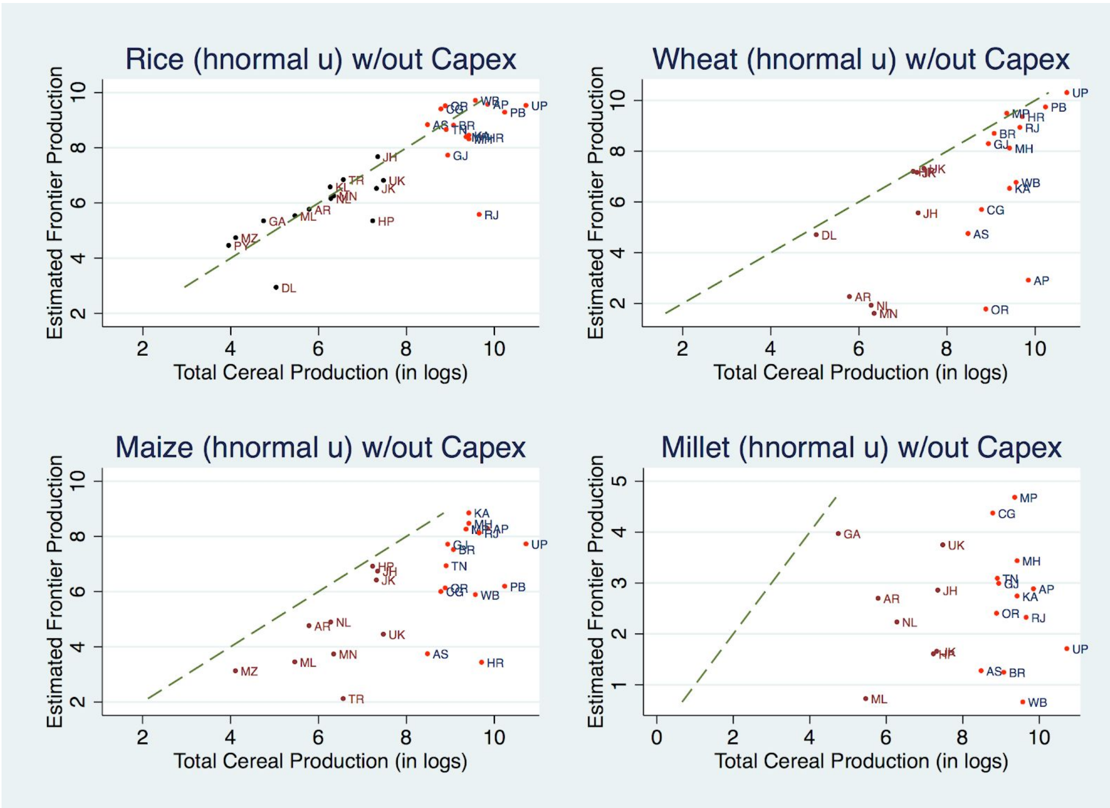
	-1	-2	-3	-4	-5	-6	-7	-8
	lnriceprod~n	lnjowarpro~n	lnbajrapro~n	lnmaizepro~n	lnragiprod~n	lnmilletpr~n	lnwheatpro~n	lnbarleypr~n
main								
lnlabor	-0.167***	0.577***	0.0159	0.0103***	0.407***	0.013	-0.288***	-0.212***
	(-63577.32)	-2113.86	-0.13	-34.19	-112.06	-0.06	(-88299.49)	(-3.27)
lnfertilizer	0.0766***	-0.343***	-0.0135	0.0333***	-0.221***	0.0214	0.108***	0.559***
	-33363.31	(-373.04)	(-0.14)	-373.72	(-57.57)	-0.16	-46885.87	-9.39
lnirrigati~x	-0.0341***	0.0677***	-0.0536	-0.00364***	-0.276***	-0.0928	-0.00412***	-0.554***
	(-14835.37)	-36.6	(-0.62)	(-49.74)	(-232.97)	(-0.90)	(-3082.77)	(-10.25)
lnaveragel~r	0.597***	1.212***	1.030**	1.429***	1.916***	0.723	-0.0582***	0.984***
	-40739.43	-524.65	-1.98	-2618.29	-274.25	-1.11	(-6966.94)	-2.89
lnriceland	1.071***							
	-351367.14							
lnjowarland		0.929***						
		-3168.62						
lnbajraland			1.053***					
			-27.64					
lnmaizeland				1.061***				
				-4319.92				
lnragiland					1.168***			
					-1174.42			
lnmilletsl~d						0.836***		
						-10.08		
lnwheatland							1.079***	
							-1661928.64	
lnbarleyland								1.234***
								-36.36
_cons	-0.797***	-14.63	-6.197	-8.399	-14.75	-3.982	4.809***	-1.871
	(-8471.18)	(.)	(-1.57)	(.)	(.)	(-0.90)	-60454.55	(-0.80)
lnsig2v								
_cons	-40.88	-32.83	-2.433***	-27.56	-25.84	-1.881***	-40.2	-3.697***
	(-0.02)	(-0.05)	(-3.60)	(-0.17)	(-0.14)	(-5.76)	(-0.04)	(-9.27)
lnsig2u								
_cons	-1.598***	-1.844***	-7.291	-0.957***	-0.805**	-9.005	-1.321***	-10.85
	(-6.08)	(-4.88)	(-0.04)	(-3.38)	(-1.97)	(-0.03)	(-4.38)	(-0.04)
N	29	14	15	25	12	20	22	13

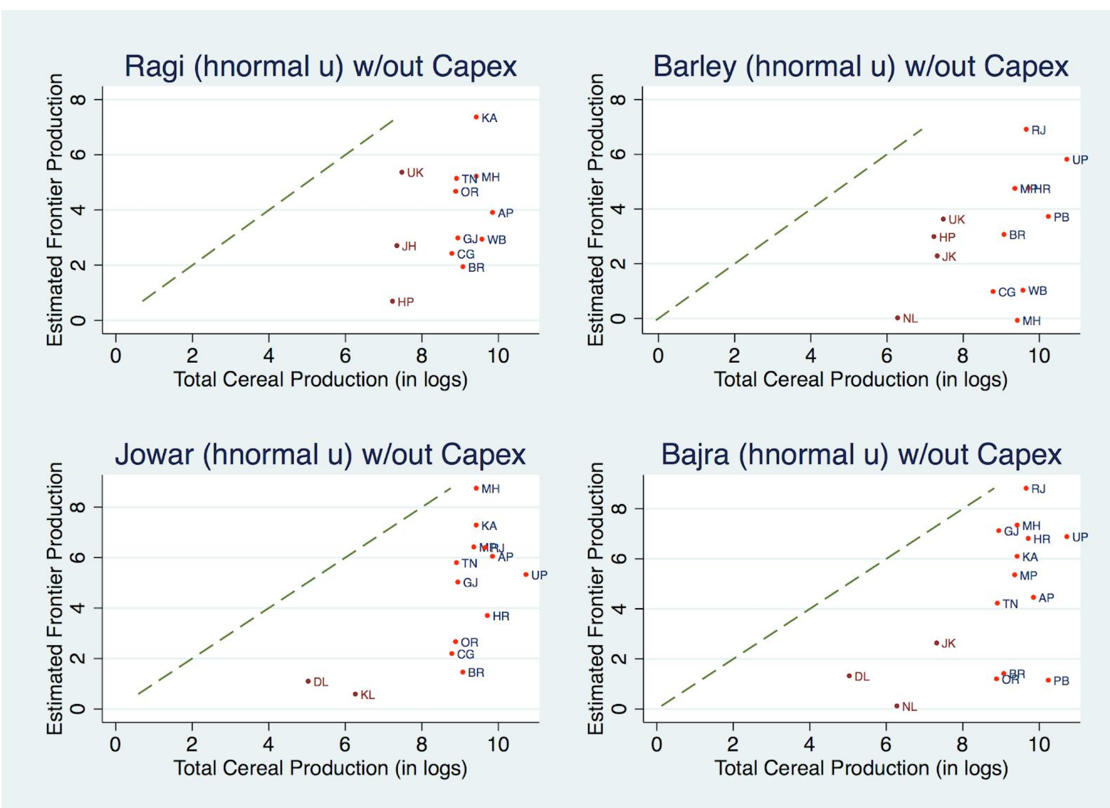
t statistics in parentheses
* $p<0.10$, ** $p<0.05$, *** $p<0.01$

G1: Estimated frontier production (optimal) output per state versus observed total crop production for each crop- with exponentially distributed u_i

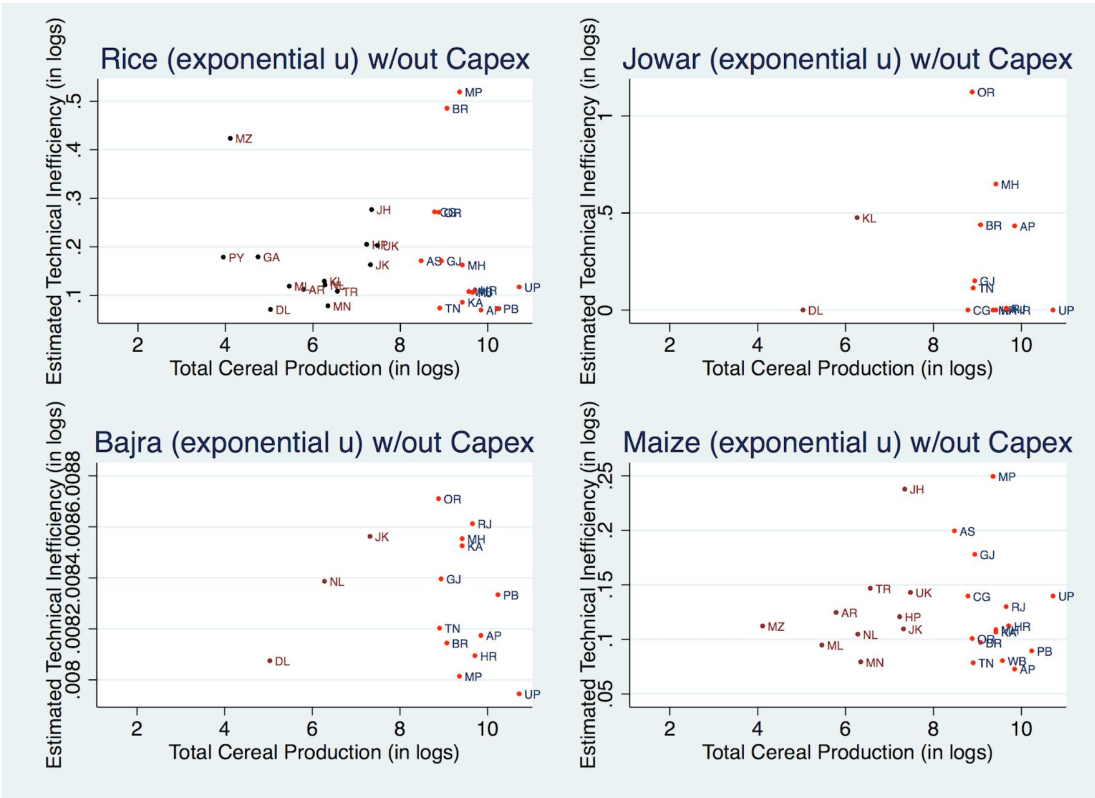


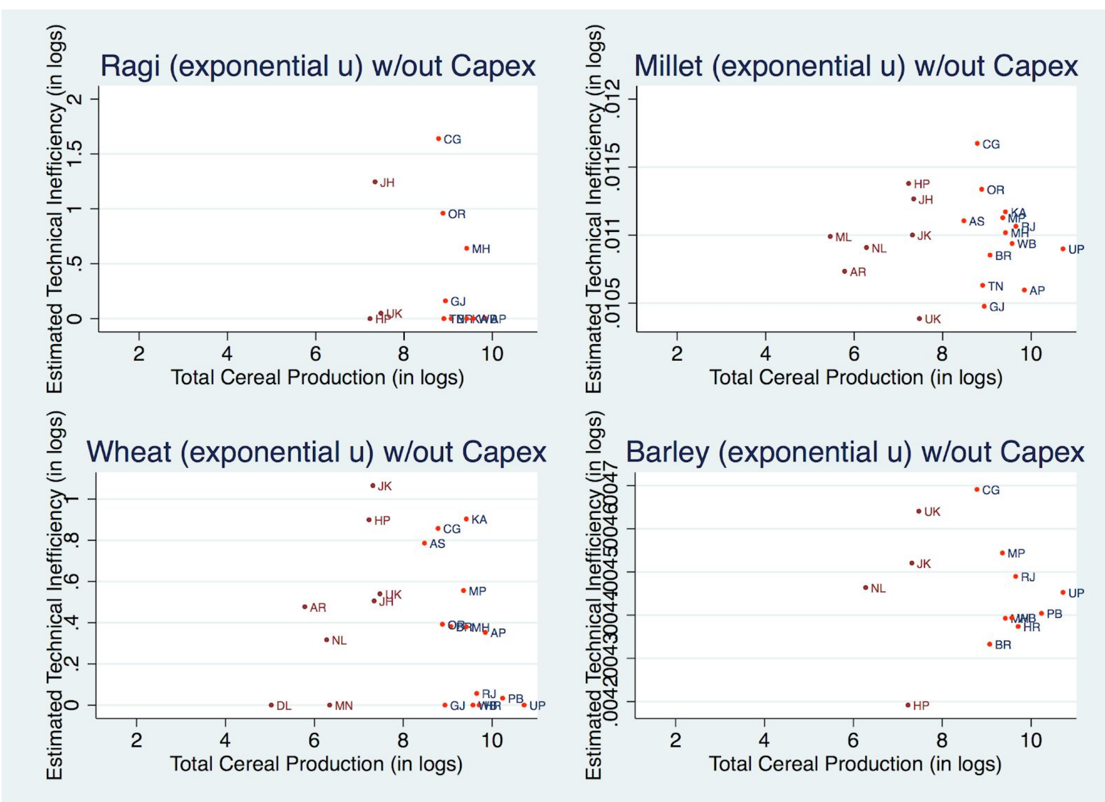
G2: Estimated frontier production (optimal) output per state versus observed total crop production for each crop - with half-normally distributed u_i



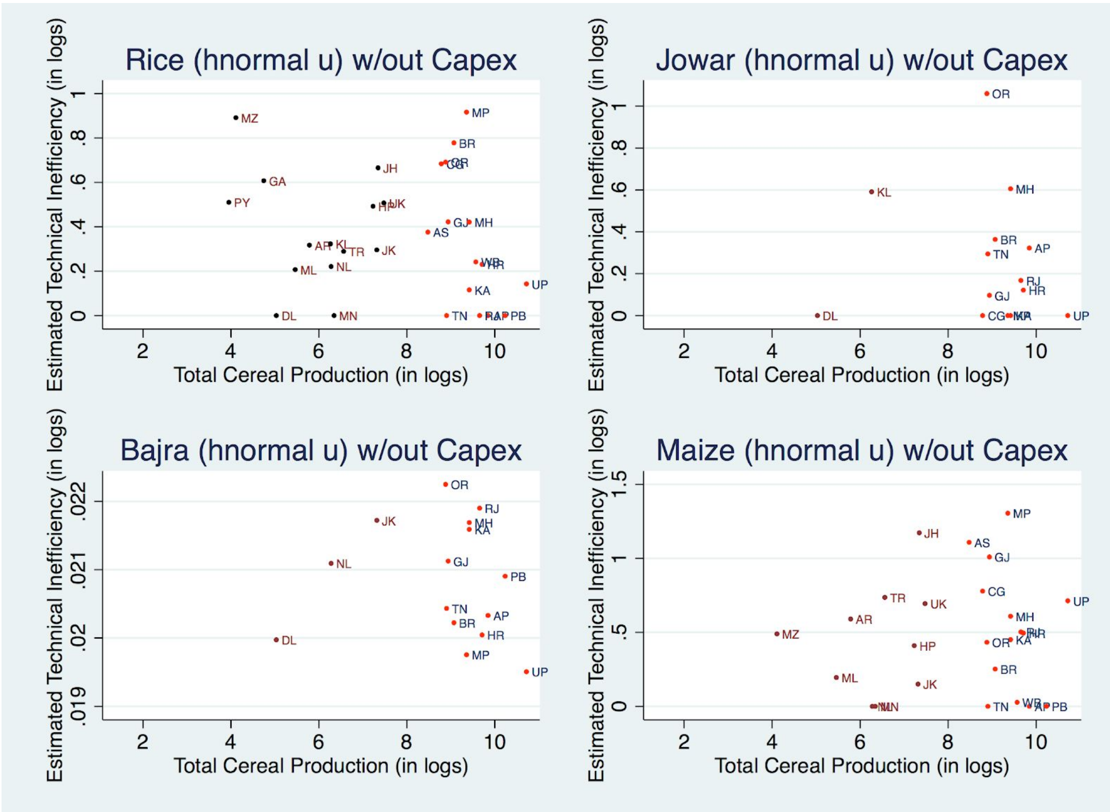


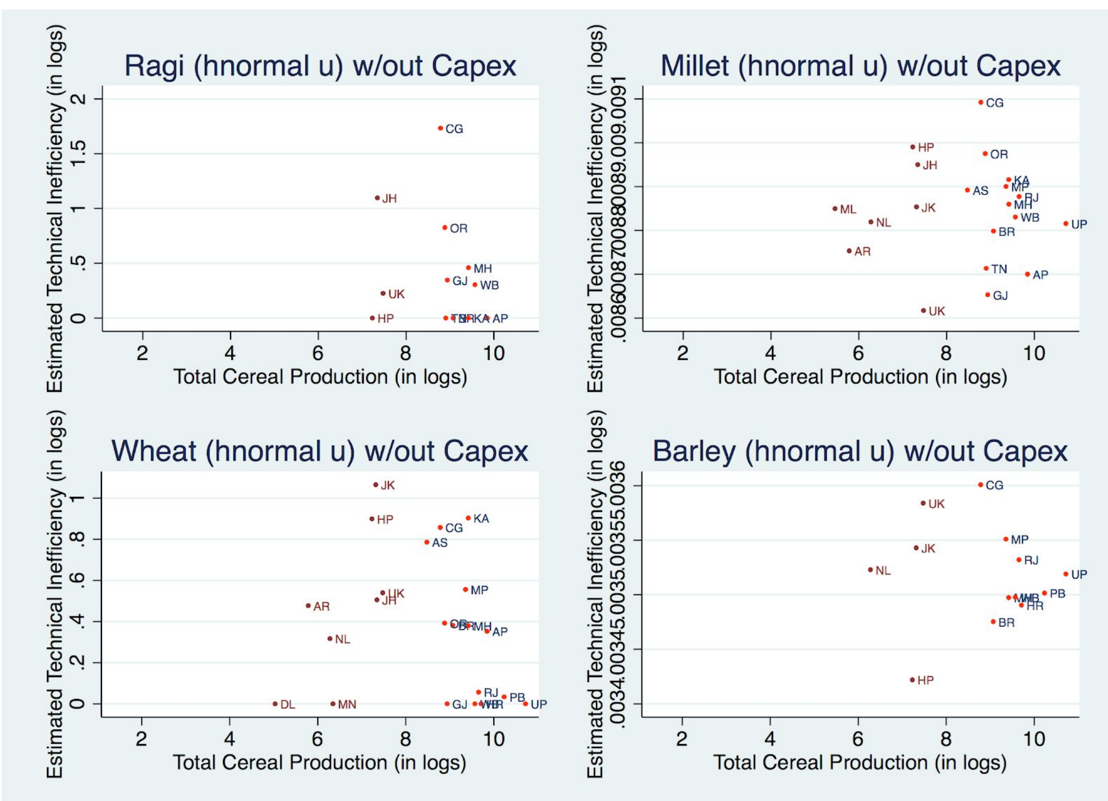
G3: Inefficiencies in total output per state versus observed total crop production for each crop - with exponentially distributed u_i





G4: Estimated technical inefficiency per state versus total crop production for each crop- with half-normally distributed u_i





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