Technical Efficiency of Rice Production in India

A Study Using Stochastic Frontier Analysis to Estimate Technical Efficiency and Its Determinants

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Table of Contents

Executive Summary

Technical efficiency of agriculture production is an important element in the pursuit of output growth in developing country agriculture. A high level of technical efficiency implies that inputs are being maximized given the available technology. In this situation, output growth will be achieved through the introduction of new technology that will shift the production frontier outward. Low technical efficiency signals that output growth can be achieved given current inputs and available technology. One of the challenges for agricultural growth in developing countries is in knowing the degree of technical efficiency among farmers and, if low technical efficiency is common, recognizing what factors will increase efficiency.

This paper uses household survey data from the 2009 Kharif season in four states in India to estimate technical efficiency of rice production and analyze the determinants of technical efficiency. Technical efficiency scores and determinants of technical inefficiency were jointly estimated using a stochastic frontier analysis of production functions. The maximum likelihood approach in FRONTIER 4.1 was employed.

On average, across the full sample (using a full-sample production frontier) farmers were operating with 52.89 percent efficiency. Farmers in Tamil Nadu were significantly more efficient than farmers in other areas (eastern Uttar Pradesh and Bihar/West Bengal). The number of years of formal education of the household head is positively and significantly correlated with technical inefficiency. Households with heads that are upper caste are significantly less efficient than households with non-upper caste heads. Households with concrete floors are significantly less efficient than that do not have them. Households that have a Below the Poverty Line card are significantly less efficient than those that do not have them. Households with access to piped water are significantly more efficient than those without access.

The positive effects of formal education, caste and concrete floors on technical inefficiency are counter-intuitive results. Increased education, higher social status and increased household wealth would be expected to have a positive correlation with technical efficiency. A possible explanation may be that, better educated and higher caste households with more income own more land area and thus do not need to farm their land as intensively as households farming a smaller farm base. Alternatively, agriculture may not be the primary income generating activity for these households and thus they devote less time and managerial energy to agriculture.

In order to increase technical efficiency in rice production, several policy goals have been identified. Because of the significant positive effect of fertilizer and pesticide use on output, increased fertilizer and pesticide use should be encouraged. In addition, due to the significant positive correlation between access to piped water and technical efficiency, increasing access to water infrastructure should be a priority. Given the high level of technical efficiency in Tamil Nadu, public investment in the state should be directed toward research and development for new technologies that will shift the production frontier outward. Lower degrees of technical efficiency in eastern Uttar Pradesh and Bihar/West Bengal mean that output growth can be achieved with current technology and thus public investment should be directed to measures that improve technical efficiency, such as training and infrastructure.

Part I: Background

Rice is one of the primary crops grown and consumed in India. The significance of this crop for the national economy and domestic food security cannot be understated. India has achieved remarkable success in the last half century to achieve national self-sufficiency in rice production. This output growth has been achieved through both expansion of the land base and intensification of production. From 1960-61 to 2010-11 the area planted with rice increased 26 percent, from 34.13 to 42.86 million hectares.[1] Over this time period average yield more than doubled, from 409.9 to 906.1 kg per acre and output increased 178 percent, from 34.58 to 95.98 million tonnes.[2] In 2010 India was the second largest producer of rice in the world. In 2010-2011 India exported 2.37 million tonnes of Basmati rice, valued at 113.55 billion rupees (2.1 billion current USD). Non-Basmati rice exports were significantly less, amounting to roughly 100 thousand tonnes and valued at 2.3 billion rupees (40 million current USD).[3]

Rice is a significant component of the Indian diet. In 2009-2010 annual rice consumption was estimated to be 74.7 kg per person in rural areas and 56.64 kg per person in urban areas.[4] Over the last several decades India has exhibited the puzzling trend of declining per capita calorie consumption. Annual per capita consumption of rice in rural areas has fallen steadily from 82.61 kg in 1993-1994, to 80.18 kg in 1999-2000, to 77.62 kg in 2004-2005, and to 74.7 kg in 2009-2010. In urban areas annual per capita consumption has similarly fallen from 62.42 kg in 1993-1994, to 62.05 kg in 1999-2000, to 57.31 kg in 2004-2005, and to 56.64 kg in 2009-2010.[5] However, despite this decline, rice consumption still represents a significant component of total calorie consumption. In 2009-2010, rice represented just over 50 percent of total cereal consumption.[6]

Despite the recent declining trend in rice consumption, the projections for population growth in the next decade will necessitate an increase in the domestic rice supply. According to the UN Population Division, in 2010 India was home to 1.22 billion people; in 2025 the population is projected to reach 1.46 billion people. To meet the needs of this population, the total demand for rice in 2025 is projected to be 104.7-108.6 million tons.[7] Meeting this demand with domestically produced rice would require a 9-13 percent increase over 2010-2011 production quantities.[8] Thus, if India is to remain self-sufficient in rice supply,[9] domestic rice production must continue to grow.

Despite the high level of yield growth in India since 1960, there still remains significant potential for further productivity gain. Across the country yields vary widely and there is a

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[1] Gov. of India 2012
[2] Gov. of India 2012
[3] Gov. of India 2012
[4] Gov. of India 2012
[5] Author's estimations
[6] Gov. of India 2012
[7] Ganesh-Kumar et al., 2012
[8] Author's estimations
[9] The question of whether or not self-sufficiency in cereal grains is an appropriate policy goal for India is a debatable. Self-sufficiency in food production is often times politically popular, but may not represent the most effective usage of domestic resources and labor.

significant yield gap between actual and potential outputs. In 2010-2011 average rice yields in India were 906.1 kg per acre. In the ten states with the highest levels of rice production, average yields ranged from a high of 1,367.9 kg per acre in Punjab to a low of 653.6 kg per acre in Odisha.[10] In the Indo-Gangetic Plains (IGP), where some of India's most productive cereal systems are located, Ladha et al. (2003) estimate that potential rice yields could be anywhere from 3,116.2 - 4,330.3 kg per acre.[11]

Given the projections for increased demand for rice in the near future, the constraints on land availability, and the existing yield gaps, continuing to intensify rice production across India should be a priority. Much attention has been dedicated to the adoption of new technologies designed to increase farm output. However, output growth is determined both by the technology available and the usage of that technology. In India, the large range of rice yields achieved across the country suggests that efficiency of production is a promising area in which substantial output gains could be made.

Objectives and Paper Overview

This paper will use recent survey data from India to analyze the determinants of technical efficiency in rice production. Using farm-level data from the 2009 Kharif season in four Indian states, this paper will employ a stochastic frontier analysis of production functions to estimate the level of technical efficiency of rice production and analyze farmer characteristics as determinants of technical efficiency. The purpose of this work is to better understand where public investments can best be directed to effectively increase technical efficiency of rice farmers in India. Increasing agricultural efficiency has the goal of increasing smallholder output, raising incomes and contributing to poverty reduction.

This paper follows in four parts. Part II will provide a brief overview of the literature exploring technical efficiency in rice farming in India. Part III will describe the study area, data used and estimation approach. Part IV will present and discuss the estimation results. Part V will conclude with a discussion of policy implications that can be drawn from the findings of this study.

[10] Gov. of India 2012
[11] Ladha et al., 2003

Part II: Overview of Technical Efficiency

Technical efficiency of agricultural production can be defined as a farmer's ability to produce maximum output given a certain set of inputs and technology. The degree of technical inefficiency reflects a farmer's failure to attain the highest possible level of output given the set of inputs and technology used. The highest level of output given a set of inputs is represented by the production frontier. Figure 1 is a depiction of a production frontier where the degree of technical efficiency is conditional on the level of inputs used.[12]

Figure 1: Technical Efficiency of Firms in Input-Output Space (From Battese, 1993)[13]

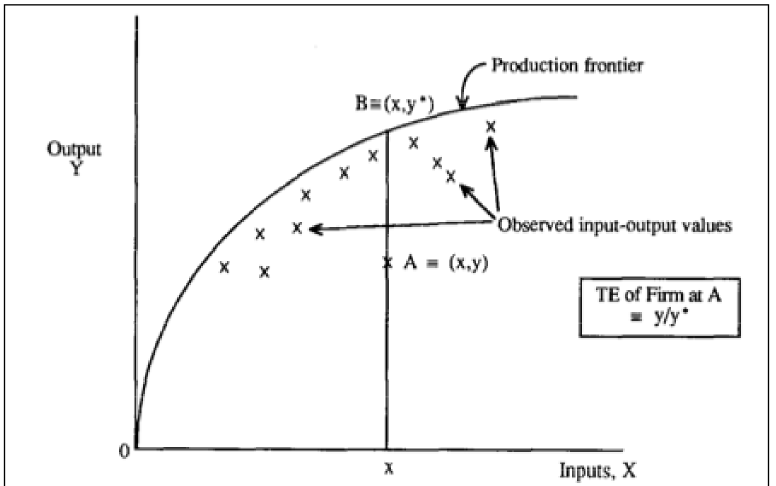

Fig. 2. Technical efficiency of firms in input–output space.

It is important to understand the distinction between technological change and technical efficiency. Technological change reflects a shift of the production frontier itself as new technologies may enable output per unit of input to be greater.[14] Technical efficiency can be a dominant factor in explaining the difference between potential and observed yields of crops for a given technology and input level. Consequently, there has been much work dedicated to estimating technical efficiency of agricultural production and understanding the determinants of this efficiency.

The first empirical studies to measure technical efficiency for a cross-section of producers employed a deterministic frontier approach. The deterministic frontier approach assumes that any deviation from the frontier is due to inefficiency. The limitations of this approach arise due to the fact that it ignores any random factors that may influence the efficiency of a firm. Thus, the results of a deterministic frontier approach are highly sensitive to the selection of variables and data errors.[15]

Aigner, Lovell, and Schmidt (1977) and Meeusen and van den Broeck (1977) independently developed a stochastic frontier approach to overcome some of the limitations of the deterministic frontier approach. In the stochastic frontier approach the error term consists

[12] Battese, 1992
[13] Battese, 1992
[14] Bravo-Ureta and Pinheiro, 1993
[15] Bravo-Ureta and Pinheiro, 1993

of two components, one being random noise and the other being a one-sided residual term representing inefficiency. The stochastic frontier approach has been expanded and refined in numerous ways since it was developed.

A number of studies have been carried out using the stochastic frontier approach to measure technical efficiency of rice farmers in India. In a study using panel data from irrigated rice production in the Coimbatore district of Tamil Nadu, Kalirajan (1991) found a significant positive relationship between access to extension services and technical efficiency, yet no significant effect from farmer's years of formal schooling. Battese and Coelli (1992) analyzed data from 1975-1976 to 1984-1985 for rice farmers in a village in Andhra Pradesh. They found technical efficiency to be time invariant with constant returns to scale and a negative elasticity of bullock labor. In a follow-up study using data from three villages in Andhra Pradesh, Coelli and Battese (1996) found farmer age, farmer years of formal schooling and farm size to be significant positive explanatory variables for technical efficiency effects. In a study using data from 129 rice farmers from Tamil Nadu in 1992-1993, Tadesse, Bedassa and Krishnamoorthy (1997) estimated mean technical efficiency to be 83 percent. They also found that small and medium sized holdings operate at a higher level of technical efficiency than larger-sized farms.

In a study using farm-level data for rice growers in the state of Tamil Nadu, Mythili and Shanmugam (2000) estimated mean technical efficiency to be 82 percent, however technical efficiency varied widely across the state. In addition they found farm size had a significant negative effect on technical efficiency. Narala and Zala (2010) analyzed data from rice farms under irrigated conditions in Central Gujarat. They found mean technical efficiency to be 72.78 percent. In their sample operational area, experience in rice cultivation, education level of the farmer and distance of the field from a canal structure were significant positive determinants of technical efficiency. The number of working family members was a significant negative determinant of efficiency.

In addition to the work looking specifically at rice production in India, there are several studies relevant to this paper that examine farm-level technical efficiency more generally, both globally and in India. Bravo-Ureta et al. (2007) performed a meta-regression analysis that included 167 farm level technical efficiency studies of developing and developed countries. They found that the mean technical efficiency among rice studies (86 cases) was 72.4 percent, among low-income countries studies (58 cases) was 74.1 percent, and among Asian studies (189) cases was 74 percent.

Shanmugam and Venkataramani (2006) estimated technical efficiency of total agricultural production and its determinants for 248 districts across 12 major states in India using district level data for 1990-1991. They found mean technical efficiency to be 79 percent, with minimal variation across states. In addition they found literacy to be a significant, positive determinant and rural electrification to be a significant negative determinant of technical efficiency across the full sample. In specifically rice plurality districts, efficiency seemed to increase with improvements in literacy, road infrastructure and larger average land holdings.

Part III: Data and Methodology

Data

The data presented in this paper comes from the baseline household survey (gathered from June 2010 to March 2011) of the Cereal Systems Initiative for South Asia (CSISA). The CSISA project seeks to improve cereal productivity and farm income in four South Asian countries: India, Pakistan, Bangladesh and Nepal. The project's objective is to provide an overall strategy and a framework for contributing new science and technologies to accelerating short- and long-term cereal production growth in the project countries. Funding for the CSISA project comes from the Bill and Melinda Gates Foundation (BMGF) and the U.S. Agency for International Development (USAID). The International Rice Research Institute (IRRI) gathered the socio-economic data used in this study.

The household survey employed a stratified random sampling procedure to ensure a representative assessment of the farmers and households in the study area. Stratification took place at the district level. In each "hub"[16], through consultation with the hub managers and national partners, three districts were selected from among the complete lists of districts where CSISA is active. The purpose of this stratification was first, to capture the major cropping patterns present in the respective hubs and second, to consider the potential pattern of technology diffusion.

For each of the selected districts, hub managers provided complete lists of CSISA intervention villages and their respective sub-districts. Three CSISA-active sub-districts were randomly selected in each of the previously selected districts. In each sub-district two villages were randomly selected (one each amongst those with CSISA activity and those without CSISA activity). The Indian National Census Bureau provided complete village and household lists. In each village 18 households were randomly selected.[17]

This study employs data gathered in the baseline household survey from three CSISA hubs, eastern Uttar Pradesh (EUP), Bihar/West Bengal[18] and Tamil Nadu. The data used from the baseline household survey include rice production information for the largest plot of each household during 2009-2010 and information on various household characteristics.[19] The final sample includes 788 households from 10 districts that reported rice production data from the 2009 Kharif season.[20] Each household is represented once in the sample.

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[16] The project area was divided into nine "hubs" (state-level divisions). The hubs serve as venues for adaptive research and technology delivery.

[17] Pede et al., 2012

[18] The Bihar "hub" includes an additional two villages from the West Bengal state.

[19] The final sample includes 206 households from EUP, 324 from Tamil Nadu, and 258 from Bihar and West Bengal. Due to organizational problems in the baseline household survey implementation in EUP, information on household head years of formal education was not collected. Seeing as this may be a crucial determinant of technical efficiency, and the CSISA midline household survey (administered in late 2012) revisited the same farmers in EUP, this information was "borrowed" from the midline survey to complete the EUP dataset. Given that most farmers in the sample are older (all are over 20) it is probably safe to assume that their quantity of formal education will not have changed from the baseline to the midline.

[20] Eight households from the baseline survey that reported rice production data from the 2009-2010 Rabi season were excluded from the sample.

The Study Area

Tamil Nadu, EUP, Bihar and West Bengal are important rice-growing areas in India. Uttar Pradesh, Bihar and West Bengal lie within the Indo-Gangetic Plain (IGP), a fertile agricultural region encompassing most of north and eastern India where sequential rice-wheat cropping is prevalent. Tamil Nadu, which is located in sub-tropical south India, has a distinctly different climate from the IGP and multi-season rice production.

EUP, Bihar and the areas in West Bengal included in this study are part of the central Gangetic plains. This area is characterized by high population density and extensive rural poverty. In general, institutional support, infrastructure and markets are poorly developed. The predominant cropping pattern is a rice-wheat system. This area receives rainfall from the southwest monsoon from June to September.[21] Agricultural production is highly labor intensive, uses low levels of inputs and has relatively low productivity. The out-migration of male labor is common, as greater income-earning opportunities exist elsewhere.[22] However, groundwater is relatively abundant and cropping systems have a good potential for intensification.[23]

Tamil Nadu is representative of subtropical south India. The agricultural landscape is dominated by intensively irrigated double-cropped rice-rice systems. Rice production is highly dependent on the monsoon rains, which recharge water tanks and groundwater. The southwest monsoon is from June to September and the northeast monsoon is from October to December.[24] The challenges for further intensification in Tamil Nadu are productivity stagnation, water scarcity and resource degradation.[25]

Table 1: Selected Statistics for Total Rice Production in the Study Area[26]

	2010-2011			2009-2010
	Average Rice Yield (kg per acre)	Total Rice Production (million tonnes)	State Rice Production as % of Country Total	Rice Production Area Under Irrigation (%)
Uttar Pradesh	857	11.99	11.99	79.0
Bihar	443	3.10	3.23	56.7
West Bengal	1,069	13.05	13.6	48.2
Tamil Nadu	1,227	5.79	5.79	92.8

Methodology

This study follows the method of estimating a stochastic frontier production function proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977). Kumbhakar, Ghosh and McGuckin (1991) extended the stochastic frontier methodology by explicitly introducing determinants of technical efficiency in the model. Following the approach of numerous previous empirical studies[27], I have chosen to use the Cobb-Douglas form of the stochastic

[21] IRRI, 2009
[22] Aggarwal et al., 2004
[23] IRRI, 2009
[24] CSISA, 2012
[25] IRRI, 2009
[26] Gov. of India, 2012
[27] Tadesse and Krishnamoorthy (1997), Kalirajan (1981), and Battese and Coelli (1992)

frontier production with a log-log functional form. Production data is based on information from the largest plot grown of rice in the 2009 Kharif season for each household.

The production function is specified as:

$$\ln(yield_i) = \beta_0 + \beta_1 \ln(seed_i) + \beta_2 \ln(fert\_ai_i) + \beta_3 \ln(fuin\_ai_i) + \beta_4 \ln(lab\_tot_i) + \beta_5 \ln(till\_da_i) + \beta_6 \ln(till\_trac_i) + \beta_7 \ln(rain\_two_i) + \alpha D' + \varepsilon_i (V_i - U_i) \quad (1)$$

Where:
yield is rice production (kg/acre);
$\beta_0,\ldots, \beta_7$ are the parameters to be estimated;
seed is the seed application rate (kg/acre);
fert_ai is the application rate of active ingredient of fertilizer (kg/acre);
fuin_ai is the application rate of active ingredient of fungicide and insecticides (grams/acre);
lab_tot is the total labor used for all stages of production (person-days/acre);[28]
till_da is the number of draft animal tillage operations (# of operations/acre);
till_trac is the number of tractor tillage operations (# of operations/acre);
rain_two is the district-wise rainfall in the first two months after planting (mm);
D' is a vector of dummy variables for district;
ε_i is the error term equal to: $(V_i - U_i)$;
V_i is a two-sided iid random error component outside the control of the farmer; and,
U_i is a one-sided inefficiency component.

The farm-specific technical efficiency (TE_i) of the i^{th} farmer was estimated using the expectation of U_i conditional on the random variable ε_i. It follows that,

$$TE_i = Exp[-U_i] \quad (2)$$

So that, $0 \leq TE_i \leq 1$

After obtaining farm-specific technical efficiency estimates using equation (2), kernel density graphs were produced to visually represent the distribution of technical efficiency in the full sample and in each of the hubs. The one-sample Kolmogorov-Smirnov test was used to test the normality of technical efficiency score distributions in the full sample and in each hub.[29] The two-sample Kolmogorov-Smirnov test was used to test the equality of technical efficiency score distributions across the hubs.

Technical inefficiency effects are specified as:

$$\ln(U_i) = \delta_0 + \delta(c'_i) + W_i \quad (3)$$

[28] Total labor includes both hired labor and family labor
[29] Hub-specific technical efficiency scores are based on unique hub-specific frontiers against which efficiency is scored.

Where:
U_i is technical inefficiency;
δ_0, …., δ_l are the parameters to be estimated;
c'_i is a vector of farmer and household characteristics; and,
W_i is random error

The stochastic production frontier, defined by equation (1), and the technical inefficiency model, defined by equation (3), were jointly estimated by the maximum likelihood method using Frontier 4.1 in STATA (Coelli 1996). A half-normal distribution of the inefficiency variance was used in the estimation.

The degree to which technical efficiency estimates are sensitive to the model specification is an ongoing matter of debate. The two primary methods of frontier estimation are stochastic frontiers, which involve econometric methods, and Data Envelopment Analysis (DEA), which uses mathematical programming. The stochastic frontier model is sensitive to a somewhat arbitrary specification of the functional form, while DEA models do not require the specification of a function form. However, because DEA uses deterministic models, it is highly sensitive to outliers and the number of observations.[30]

In this study, because farmers were asked to recall the production information in the household survey after several months and farmers' measurement of inputs may not have been highly accurate, there is an expectation of measurement error in the household survey data. In addition, weather or other environmental factors may have played a significant role in determining output levels and there may be missing input variables in the production function. For these reasons the stochastic frontier model was selected as opposed to DEA.

There are several potential sources of bias in the estimation of technical efficiency and its determinants in this study. The specification of the functional form and the selection of the distributional form of the one-sided inefficiency term may not be the most appropriate and therefore may bias the results. The use of the Cobb-Douglas functional form imposes some restrictive properties. Of most concern are the restrictions that returns to scale take the same value across all farms and that elasticities of substitution are assumed to equal one.[31] Omitted or poorly measured input variables and unaccounted for environmental factors (such as soil quality or topography) may affect the technical efficiency scores. Finally, the use of data from only one season may misrepresent some farmers as inefficient, while their more conservative management strategy may prove them to be more efficient over a longer period of time.

Hypotheses

Many studies have shown a positive relationship between technical efficiency and socio-economic characteristics (Kalirajan (1991); Coelli and Battese (1996); Tadesse, Bedassa and Krishnamoorthy (1997); Mythili and Shanmugam (2000); and, Narala and Zala (2010)). The variables examined as potential determinants of technical efficiency in this study include categorical variables for: age of household head, years of formal education of household head, cultivable land area owned, household size, and percent of income from crops; dummy

[30] Bravo-Ureta et al., 2007
[31] Coelli, 1995

variables for: household head whose primary occupation is agriculture, household head who is upper caste, household head with monthly access to extension, household head with access to training, households where the husband holds the land title, households with a concrete floor house, households with access to piped water, households with access to a latrine, households with access to electricity, households with access to subsidized food (ration card), households with a Below the Poverty Line (BPL) Card; and, an interaction term between years of formal education of the household head and household head access to training.

Among these variables the most obvious variables to predict technical inefficiency should be years of formal education of the household head, household head access to extension, and household head access to training. All of these variables would be expected to have a negative relationship to technical inefficiency because more education, training and support would presumably enable farmers to manage their farms more efficiently. The interaction between education and training would be expected to have a negative relationship to technical inefficiency because the more educated farmers are, the more capable they would be of receiving training and implementing the material taught. More educated farmers may be more willing to attend training as well.

Household access to concrete floors, subsidized food and BPL cards could potentially be indicators for economic status. Poorer households may be more technically inefficient, which could be the reason why they are poor; or, they may be more technically inefficient because their economic status prevents them from acquiring education, information and training. Poorer households may also be relegated to farming on marginal lands. Because differences in within-district, inter-household soil quality are not controlled for in this model, systematic inequalities in land access may bias the parameters. If access to high quality land is a function of caste or economic status, this effect should be captured in the coefficients on caste or any of the economic status indicator variables.

Household access to piped water or electricity may indicate the extent of infrastructure in the area. A higher level of infrastructure may enable higher degrees of efficiency because mechanized irrigation or mechanized production technologies would be available. Thus, piped water and electricity would be expected to have a negative relationship to technical inefficiency. Access to a latrine could be an indicator for household wealth, but it could also represent the health status of a household. Healthier households may be more efficient because of less work-time lost to illness or more energy available for management. Therefore, one would expect a negative relationship between access to a latrine and technical inefficiency.

Part IV: Estimation Results and Discussion

Summary Statistics

Summary statistics of production data and household socio-economic characteristics are presented in Tables 2 and 3 for the full sample and Appendices A and B for individual hubs. Mean yield across the full sample is 1,600.79 kg per acre. This is significantly higher than the all-India mean yield from 2009-2010 of 860.0 kg per acre.[32] Across the full sample, on average, farmers used 20.9 kg of seed per acre, 75.56 kg of active ingredient of fertilizer per acre, 77.43 grams of active ingredient of fungicide and insecticides per acre, 90.77 human days of labor per acre, 0.39 draft animal tillage operations per acre and 7.64 tractor tillage operations per acre. Ninety-one percent of the sample relied exclusively on tractors for tillage operations. Average rainfall during the first two months of the growing season (established as the month that each farmer planted their crop) was 163.36 millimeters.

Table 2: Production data (full sample)

Variable	Obs	Mean	Std. Dev.	Min	Max
Yield (kg/acre)	788	1600.79	803.40	0	3600.00
Seed (kg/acre)	788	20.90	11.84	0	60.00
AI of fertilizer (kg/acre)	788	75.56	37.41	0	395.55
AI of fung/insect. (g/acre)	788	77.43	180.26	0	3375.00
Total labor (human days/acre)	788	90.77	70.83	0	731.25
Draft Animal Tillage (# of operations/acre)	788	0.39	2.28	0	32.97
Tractor Tillage (# of operations/acre)	788	7.64	6.52	0	60.00
Rainfall first 2 months (mm)	788	163.36	71.33	35.60	405.35

The average cultivable area owned across the full sample was 3.3 acres, although there was wide variation, ranging from 0 to 200 acres. The average size of the largest rice plot was less than one acre, although again there was a wide range.[33] The average household head was 50.1 years old and had 7.26 years of formal education. Only 13 percent of household heads had monthly access to an extension worker. The average household size was 7.34 individuals. Fifty two percent of households had access to piped water, 11 percent had access to a privately owned open well and 41 percent had access to a latrine.

[32] Gov. of India 2012

[33] Plot size is controlled for in the production function as all inputs are estimated per acre.

Table 3: Socio-economic characteristics (full sample)

Variable	Obs	Mean	Std. Dev.	Min	Max
Age of HHead	788	50.10	11.55	20	90
Yrs Formal Educ of HHead	788	7.26	5.79	0	22
HHead Primary Occ. Is Agriculture	788	0.84	0.37	0	1
Caste of HHead	788	0.29	0.45	0	1
HHead is married	788	0.95	0.22	0	1
HHead Monthly Access to Extension	788	0.13	0.34	0	1
HHead Access to Training	788	0.09	0.28	0	1
Husband Holds Land Title	788	0.71	0.45	0	1
House has Concrete Floor	788	0.50	0.50	0	1
Access to Piped Water	788	0.52	0.50	0	1
Access to Latrine	788	0.41	0.49	0	1
Access to Electricity	788	0.63	0.48	0	1
Cultivable Area Owned	788	3.32	8.21	0	200
Access to Subsidized Food	788	0.81	0.39	0	1
Household Size	788	7.34	4.24	0	36
Below the Poverty Line Card	788	0.36	0.48	0	1
% of Income from Crops	788	53.27	24.78	0	100

There was significant variation in the production data and socio-economic characteristics across the three hubs. Household from Tamil Nadu achieved the highest average yield of 2,143.95 kg per acre. EUP and Bihar/West Bengal followed with 1,378.24 and 1,096.36 kg per acre, respectively. On average, farmers in Tamil Nadu used the highest application rates of seed, active ingredient of fertilizer and active ingredient of fungicide/insecticides. Average labor usage was highest in EUP with 127.6 human days per acre, followed by Bihar/West Bengal and Tamil Nadu with 111.28 and 51.02 human days per acre, respectively. The average number of draft animal tillage operations was highest in Tamil Nadu and the average number of tractor tillage operations was highest in Bihar. Average rainfall in the first two months from planting was fairly consistent across the hubs, although intra-hub variation was significant.

Estimation Results

The production frontier parameter estimates, as described in equation (1) are presented in Table 4. For the full sample, the likelihood-ratio test that the inefficiency parameter=0 reported a P-score of <.001. Therefore, we can reject the null hypothesis that the inefficiency parameter is equal to 0. Significant at the 1 percent level, fertilizer application is positively correlated with yield, while labor is negatively correlated with yield. Significant at the 5 percent level, fungicide and insecticide application and rainfall are positively correlated with yield. Significant at the 10 percent level, seed application is negatively correlated with yield.

The positive elasticity of fertilizer with regards to yield is unsurprising. Farms may underuse fertilizer because of a lack of access, high cost or lack of knowledge regarding proper use. The negative elasticity of labor with regards to yield is somewhat surprising, but may be related to labor quality. Perhaps the farms using more labor are using lower quality labor than those farms using less labor. More efficient farms may be employing highly skilled laborers and therefore will not need as much labor to complete the work that needs to be completed. The positive elasticity of fungicide and insecticide application and rainfall with regards to yield is unsurprising. Similar to fertilizer, fungicides and insecticides may be underused because of a lack of access, high cost or lack of knowledge. Rainfall is an essential input in the production systems in this study as both a direct means of irrigation and an indirect means of irrigation through recharge of surface water resources. The negative elasticity between seed application and yield may be due to the fact that higher rates of seed application result in higher plant densities. Plant crowding can have a negative effect on yield.

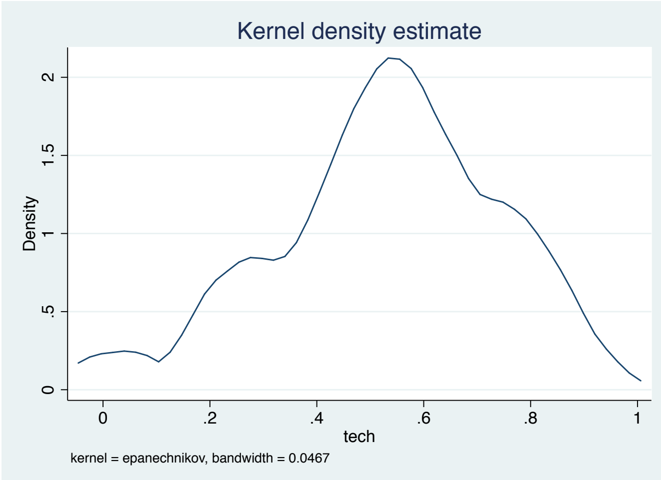
Table 4: Production Function Input Elasticity (based on the full sample)

VARIABLES	ln(Yield)
ln(Seed)	-0.0938*
	(0.0533)
ln(Fertilizer AI)	0.0639***
	(0.0217)
ln(Fung./In. AI)	0.0128**
	(0.00542)
ln(Labor)	-0.0933***
	(0.0337)
ln(Draft Animal Tillage)	-0.0309
	(0.0282)
ln(Tractor Tillage)	-0.00628
	(0.0206)
ln(Rainfall)	0.0923**
	(0.0453)
District Dummies	X
Household Controls	X
Constant	7.739***
	(0.365)
Observations	788

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Kernel density estimates of technical efficiency scores are presented in Figure 1 for the full sample and Appendix D for individual hubs. The technical efficiency scores for the full sample are based on the full sample production frontier. The technical efficiency scores for individual hubs are based on unique production frontiers for each hub against which efficiency is scored. The mean level of technical efficiency in the full sample is 52.89 percent efficiency (standard deviation of 21.00). Using the one-sample Kolmogorov-Smirnov test against a normal distribution, we are unable to reject the null hypothesis at the 1 percent level. However, at the 5 percent level the distribution of technical efficiency scores is statistically different from the normal distribution.

Figure 2: Kernel Density Estimate of Full Sample Technical Efficiency Scores



The hub distributions of technical efficiency scores (based on unique hub frontiers) show significant variation. Of the three hubs, farmers in Tamil Nadu have the highest mean technical efficiency at 76.7 percent (standard deviation of 10.8). Farmers in EUP have a mean technical efficiency of 47.6 percent (standard deviation of 23.5) and farmers in Bihar/West Bengal have a mean technical efficiency of 43.4 percent (standard deviation of 22.5). Using the two-sample Kolmogorov-Smirnov test for equality of distributions, all three hubs have statistically significant different distributions when compared pair-wise to each other. Using the one-sample Kolmogorov-Smirnov test against a normal distribution for each hub, we are unable to reject the null hypothesis for each hub at the 1 percent level. None of the three hubs have a technical efficiency distribution that is statistically different from a normal distribution.

Figure 3: Kernel Density Estimates of Individual Hub Technical Efficiency Scores

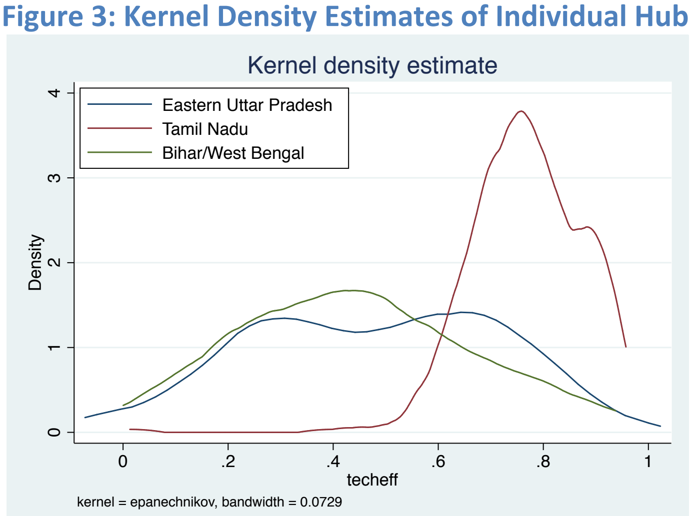


Table 5 presents the second stage estimation results for the determinants of technical inefficiency as described in equation (3). Columns (1) through (4) represent the parameters estimated from the model inputting different sub-categories of determinants of technical inefficiency. Subgroup one represents characteristics of the household head, who is also, presumably, the primary agricultural decision-maker. Subgroup two represents household assets that may be indicators of fungible capital (land title) or wealth (concrete floor). Subgroup three represents dummies for state. Subgroup four represents household characteristics including size and income characteristics. Column (5) represents the parameters estimated from the fully specified model.

Table 5: Determinants of Technical Inefficiency

	(1) HH Head Characteristics	(2) HH Assets	(3) State	(4) HH Characteristics	(5) Full Specification
VARIABLES	lnsig2u	lnsig2u	lnsig2u	lnsig2u	lnsig2u
Age HHead	-0.00234				-0.00361
	(0.00451)				(0.00602)
Education HHead	0.0315***				0.0447***
	(0.0101)				(0.0128)
Occupation HHead	-0.658***				-0.110
	(0.147)				(0.165)
Caste HHead	1.074***				0.609***
	(0.121)				(0.192)
CivStat HHead	0.0330				0.352
	(0.239)				(0.272)
Extension	-1.024***				-0.247
	(0.163)				(0.212)
Training	-0.864**				-0.392
	(0.362)				(0.449)
Educ. HHead*Training	-0.0500				-0.0655
	(0.0361)				(0.0453)
Land Title		-0.246*			0.0574
		(0.128)			(0.150)
Concrete Floor		0.807***			0.551***
		(0.122)			(0.148)
Pipe Water		-0.187			-0.576***
		(0.120)			(0.166)
Latrine		0.452***			-0.0411
		(0.126)			(0.156)
Electricity		-0.940***			-0.0453
		(0.118)			(0.177)
Cult. Area Own		0.0133			0.00263
		(0.0144)			(0.00774)
Tamil Nadu			-3.075***		-3.251***
			(0.158)		(0.261)
Bihar/W.Bengal			0.119		0.452*
			(0.141)		(0.237)
Subs. Food				-0.882***	-0.0246
				(0.140)	(0.204)
HH Size				0.0868***	-0.0114
				(0.0142)	(0.0164)
BPL Card				-0.744***	0.603***
				(0.117)	(0.172)
Inc. from Crops				-0.00195	-0.00372
				(0.00190)	(0.00261)
Constant	0.890***	0.916***	1.274***	1.127***	0.577
	(0.332)	(0.130)	(0.107)	(0.199)	(0.433)
Observations	788	788	788	788	788

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

In the fully specified model, many parameters with significance in their subgroup specification lose their significance. At the 1 percent significance level in the full specification: a household head with more years of education is less efficient; a household head that is upper caste is less efficient; households with concrete floors are less efficient; households with piped water are more efficient; households located in Tamil Nadu are more efficient than those not in Tamil Nadu; and, households possessing BPL cards are less efficient. The largest magnitude effect among these characteristics is being located in Tamil Nadu.

Discussion

The results from the first stage of the estimation are for the most part unsurprising. Fertilizer and fungicide/insecticide application is positively correlated with yields, which is expected given that the average farmer in the sample uses modest amounts of inputs. Rainfall is positively correlated with yields, which is again expected given that most farmers are reliant on precipitation to either directly irrigate fields or recharge irrigation water stores. Perhaps somewhat surprising is the fact that labor is negatively correlated with yields. This finding points to an overuse of labor in the sample, most likely due to high labor availability and low agricultural wage rates.

The distribution of technical efficiency scores across the three hubs highlights the different levels of efficiency in the different states. Most farmers in the sample from Tamil Nadu are operating at a high level of technical efficiency. There is a little room for yield gain given available technology and inputs. A significant increase in productivity may need to come from new technology. In EUP and Bihar/West Bengal, the potential to increase output through improvements in technical efficiency is large. In both of these hubs, the majority of farmers in the sample can achieve significant productivity growth through improved management.

The results from the second stage of the estimation highlight the determinants of technical inefficiency in the sample. Formal education of the household head is positively correlated with technical inefficiency, significant at the 1 percent level. This result is somewhat surprising given that the conventional thinking is that formal education should increase productivity. It is important to note that the magnitude of the effect is relatively small; however, a possible explanation for this effect is that farmers who are better educated are involved in other income generating pursuits outside of agriculture and perhaps have limited time to devote to agricultural management.

A similarly surprising result is the positive correlation between caste of the household head and technical inefficiency. Households whose head is upper caste are less efficient. Perhaps upper caste households own more land, and thus do not need to cultivate as intensively in order to generate sufficient income or food. Alternatively, perhaps upper caste households are not primarily agricultural households. They may have other income sources to which they dedicate more time and managerial energy.

Households with concrete floors and households with access to piped water are significant determinants of technical efficiency with, surprisingly, opposite effects. Household with concrete floors are less efficient than households without them, while households with access to piped water are more efficient than households without access. Concrete floors may serve as a proxy indicator for wealth. If this is the case, the explanation may be that households with higher income devote less time and energy to farming and thus accept lower levels of efficiency, or households with high income own more land and do not need to cultivate as intensively. However, the significant positive correlation between household access to a BPL card and inefficiency contradicts this hypothesis. This contradiction suggests that concrete floors may not be a proxy indicator for wealth, or access to a BPL card may not be a direct proxy for poverty.

Access to piped water may provide a health effect or an agricultural infrastructure effect. Households using piped water as the primary source of drinking or household water may be consuming less contaminated water or have improved sanitation and hygiene. These factors may allow them to achieve better health status than household without piped drinking water and thus be more productive. Alternatively, the piped water may be used as a source of agricultural irrigation, thereby improving irrigation efficiency.

As is evident by the comparison of mean technical efficiency scores in each of the hubs, farmers in Tamil Nadu are more efficient than farmers in the two other hubs. Because dummy variables for district were included in the first stage of the model, differences in natural resource endowments across the sample area, such as soil quality, were controlled for. Interestingly, households in Tamil Nadu appear to be poorer and lower caste than households in EUP and Bihar/West Bengal, yet they achieve both higher mean yield and a higher degree of technical efficiency. Seven percent of household heads in Tamil Nadu are upper caste, compared to 28 percent in EUP and 56 percent in Bihar/West Bengal. Fifty-three percent of households in Tamil Nadu have BPL Cards, while 31 percent and 19 percent have them in EUP and Bihar/West Bengal, respectively. Infrastructure access seems to be better in Tamil Nadu, as 100 percent of households have access to electricity, compared to 39 percent in both EUP and Bihar/West Bengal.

Part V: Conclusion

This study has used plot-level data from rice production in the 2009 Kharif season in four states in India to estimate the technical efficiency of production and it's determinants. In the full-sample production function, fertilizer, fungicide/insecticides and rainfall are positively correlated with yield, while labor is negatively correlated with yield (significant at least at the 5 percent level). Years of formal education, upper caste status, concrete floor ownership and BPL card ownership are positively correlated with technical inefficiency, while access to piped water and location in Tamil Nadu are negatively correlated with technical inefficiency (significant at least at the 5 percent level). The mean level of technical efficiency across the full sample (generated using a full-sample frontier) is 52.89 percent.

The underlying purpose of this study was to better understand where public investments in India should be directed in order to increase technical efficiency of rice farmers. There are several key conclusions from the study that inform this purpose. The following conclusions are those the author feels are best supported by the results of this study and are not intended to be a conclusive discussion of policy options for increasing technical efficiency in rice production in India.

The positive effect that fertilizer and fungicide/insecticide have on yield suggests that some farmers in the sample are not using adequate amounts of fertilizer or pesticides. The appropriate policy response would be to implement policies or programs that encourage increased use of fertilizer and pesticides. The data used in this study do not allow conclusions to be made as to why farmers are not using higher quantities of fertilizer and pesticides. Potential barriers to increased use may be: prohibitive cost of these chemical inputs, lack of access to credit to purchase the inputs, lack of access to these inputs in markets, and a lack of knowledge regarding which products to use or how to most effectively use them. Further research is needed to fully understand the conditions surrounding fertilizer and pesticide use.

The negative effect that access to piped water has on technical inefficiency suggests that increased access to water infrastructure will improve farmer's technical efficiency levels. Water infrastructure may be used to support household water use, thereby improving household sanitation and hygiene and decreasing the effort required to collect household water. In addition, water infrastructure may be used to expand the potential for agricultural irrigation activities and increase agricultural water use efficiency. Further research may be needed to identify the mechanism behind the efficiency effect from access to piped water. Once the mechanism is understood, policy makers should prioritize increasing the water infrastructure supporting that mechanism.

The state-specific technical efficiency distributions (based on unique state-specific production frontiers) provide useful insight for state-level policy. Technical efficiency in Tamil Nadu is tightly clustered around the mean with most farmers producing at a level close to the frontier. In EUP and Bihar/West Bengal, the majority of farmers are operating at efficiency levels further from the frontier and the variances are higher. These distinctions suggest different policy goals. Farmers in Tamil Nadu are operating close to the technical frontier, thus policy makers should prioritize introducing and encouraging the adoption of new technologies that will shift the production frontier outwards. With their current high levels of technical efficiency, farmers in Tamil Nadu will only be able to achieve significant output gains through the use of new technologies. Farmers in EUP and Bihar/West Bengal are operating at mean levels of technical efficiency that are further from the frontier. Thus, there is potential to achieve output gains given current input levels and existing technologies. In order to make more effective use of current inputs, policy makers in EUP and Bihar/West Bengal should prioritize improving production management and increasing technical efficiency.

This study is just one attempt to evaluate and analyze the level of technical efficiency in Indian rice production at a static point in time. Population growth in India is spurring rising staple food demand and climate change is increasingly affecting growing conditions and agricultural resources. Given these population needs and resource pressures, it will be increasingly necessary for Indian agriculture to operate as efficiently as possible. Additionally, a widespread improvement in the technical efficiency of agricultural production could promote income growth and poverty reduction. Continued monitoring and analysis of technical efficiency in Indian rice production is necessary to both assess changing agricultural contexts and evaluate and inform productive policy actions.

Appendices

Appendix A: Production Data by State

EUP

Variable	Obs	Mean	Std. Dev.	Min	Max
Yield (kg/acre)	206	1378.24	906.49	0.00	3600.00
Seed (kg/acre)	206	16.75	5.67	3.00	30.00
AI of fertilizer (kg/acre)	206	65.79	24.51	0.00	140.42
AI of fung/insect. (g/acre)	206	36.77	108.38	0.00	680.00
Total labor (human days/acre)	206	127.60	100.56	0.00	731.25
Draft Animal Tillage (# of operations/acre)	206	0.06	0.43	0.00	4.38
Tractor Tillage (# of operations/acre)	206	7.54	8.34	0.21	60.00
Rainfall first 2 months (mm)	206	149.27	68.09	35.60	370.20

TAMIL NADU

Variable	Obs	Mean	Std. Dev.	Min	Max
Yield (kg/acre)	324	2143.95	455.23	23.33	3500.00
Seed (kg/acre)	324	32.72	6.56	24.00	60.00
AI of fertilizer (kg/acre)	324	84.19	31.60	2.00	175.75
AI of fung/insect. (g/acre)	324	138.70	110.00	0.00	449.00
Total labor (human days/acre)	324	51.02	15.83	15.00	111.00
Draft Animal Tillage (# of operations/acre)	324	0.52	2.30	0.00	15.15
Tractor Tillage (# of operations/acre)	324	7.07	3.94	0.00	20.00
Rainfall first 2 months (mm)	324	169.51	65.39	76.35	385.20

BIHAR/WEST BENGAL

Variable	Obs	Mean	Std. Dev.	Min	Max
Yield (kg/acre)	258	1096.36	627.32	0.00	2953.00
Seed (kg/acre)	258	9.36	5.15	0.00	27.00
AI of fertilizer (kg/acre)	258	72.52	48.71	0.00	395.55
AI of fung/insect. (g/acre)	258	32.95	258.62	0.00	3375.00
Total labor (human days/acre)	258	111.28	58.98	7.56	406.59
Draft Animal Tillage (# of operations/acre)	258	0.50	3.00	0.00	32.97
Tractor Tillage (# of operations/acre)	258	8.44	7.37	0.00	35.09
Rainfall first 2 months (mm)	258	166.90	79.31	48.85	405.35

Appendix B: Socio-Economic Characteristics by State

EUP:

Variable	Obs	Mean	Std. Dev.	Min	Max
Age of HHead	206	49.98	13.48	20.00	90.00
Yrs Formal Educ of HHead	206	7.08	5.66	0.00	22.00
HHead Primary Occ. Is Agriculture	206	0.88	0.33	0.00	1.00
Caste of HHead	206	0.28	0.45	0.00	1.00
HHead is married	206	0.94	0.24	0.00	1.00
HHead Monthly Access to Extension	206	0.06	0.23	0.00	1.00
HHead Access to Training	206	0.10	0.30	0.00	1.00
Husband Holds Land Title	206	0.92	0.28	0.00	1.00
House has Concrete Floor	206	0.68	0.47	0.00	1.00
Access to Piped Water	206	0.27	0.44	0.00	1.00
Access to Latrine	206	0.30	0.46	0.00	1.00
Access to Electricity	206	0.39	0.49	0.00	1.00
Cultivable Area Owned	206	2.57	3.78	0.00	25.00
Access to Subsidized Food	206	0.44	0.50	0.00	1.00
Household Size	206	8.86	4.74	0.00	36.00
Below the Poverty Line Card	206	0.31	0.46	0.00	1.00
% of Income from Crops	206	53.23	30.38	0.00	100.00

TAMIL NADU:

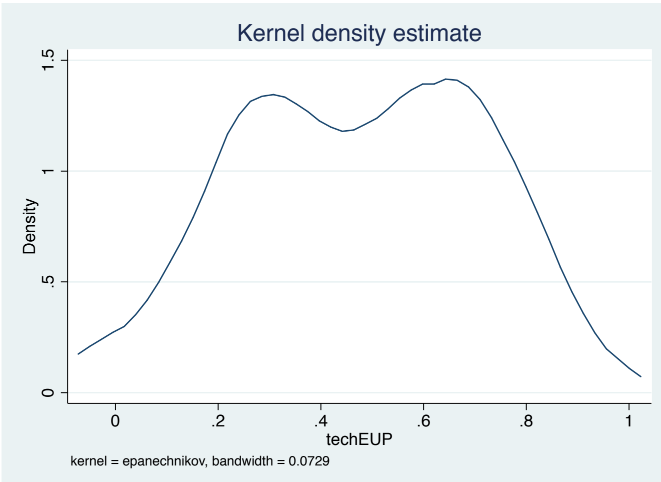
Variable	Obs	Mean	Std. Dev.	Min	Max
Age of HHead	324	50.37	7.63	24.00	75.00
Yrs Formal Educ of HHead	324	6.40	5.56	0.00	16.00
HHead Primary Occ. Is Agriculture	324	0.94	0.23	0.00	1.00
Caste of HHead	324	0.07	0.26	0.00	1.00
HHead is married	324	0.97	0.16	0.00	1.00
HHead Monthly Access to Extension	324	0.19	0.39	0.00	1.00
HHead Access to Training	324	0.08	0.27	0.00	1.00
Husband Holds Land Title	324	0.73	0.45	0.00	1.00
House has Concrete Floor	324	0.38	0.49	0.00	1.00
Access to Piped Water	324	0.44	0.50	0.00	1.00
Access to Latrine	324	0.43	0.50	0.00	1.00
Access to Electricity	324	1.00	0.00	1.00	1.00
Cultivable Area Owned	324	3.73	11.94	0.01	200.00
Access to Subsidized Food	324	1.00	0.00	1.00	1.00
Household Size	324	5.61	2.21	1.00	14.00
Below the Poverty Line Card	324	0.53	0.50	0.00	1.00
% of Income from Crops	324	53.54	16.06	10.00	100.00

BIHAR/WEST BENGAL:

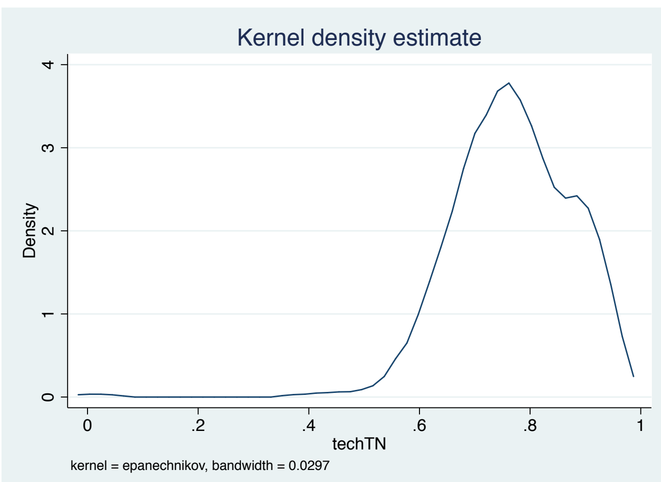
Variable	Obs	Mean	Std. Dev.	Min	Max
Age of HHead	258	49.86	13.80	22.00	88.00
Yrs Formal Educ of HHead	258	8.49	5.98	0.00	20.00
HHead Primary Occ. Is Agriculture	258	0.68	0.47	0.00	1.00
Caste of HHead	258	0.57	0.50	0.00	1.00
HHead is married	258	0.93	0.26	0.00	1.00
HHead Monthly Access to Extension	258	0.12	0.32	0.00	1.00
HHead Access to Training	258	0.09	0.28	0.00	1.00
Husband Holds Land Title	258	0.52	0.50	0.00	1.00
House has Concrete Floor	258	0.49	0.50	0.00	1.00
Access to Piped Water	258	0.82	0.39	0.00	1.00
Access to Latrine	258	0.48	0.50	0.00	1.00
Access to Electricity	258	0.37	0.48	0.00	1.00
Cultivable Area Owned	258	3.40	3.89	0.00	29.63
Access to Subsidized Food	258	0.86	0.34	0.00	1.00
Household Size	258	8.29	4.95	0.00	26.00
Below the Poverty Line Card	258	0.19	0.39	0.00	1.00
% of Income from Crops	258	52.97	28.62	5.00	100.00

Appendix C: Kernel Density Estimates of Technical Efficiency Scores by State (based on unique state-specific production frontiers)

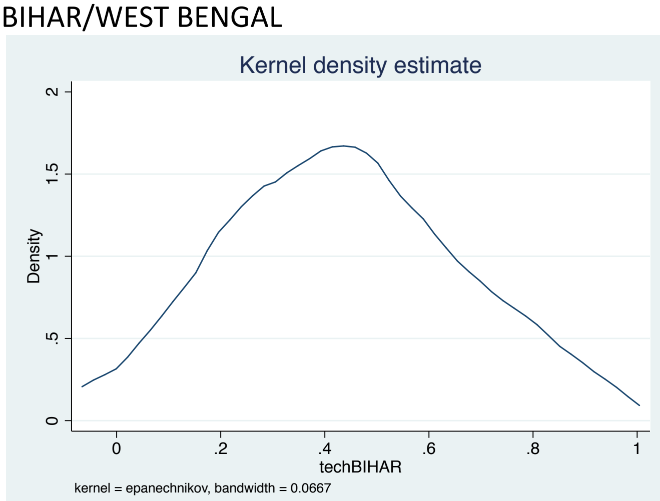
EUP



TAMIL NADU



BIHAR/WEST BENGAL



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