Extended Abstract

Paper/Poster Title	**Resource Efficiency Estimation and Digital Recommendation: Sustainable Pathway to Improve Paddy Farmers' Productivity**

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Abstract	***200 words max***

The study assesses the resource use efficiency of smallholder paddy farmers with/without considering undesirable outputs through the mobile-based application. Further, the study performs an impact assessment of digital recommendations on farmers' paddy yield improvement. A mobile app-based questionnaire was used to collect data from 153 paddy farmers of eastern India. The study employed Data Envelopment Analysis (DEA) to identify the farmers' resource use efficiency with/without undesirable output. We found lower farm eco-efficiency scores with undesirable output in the model compared to the case of not considering the undesirable output analysis. Results also showed that farmers are over-utilizing fertilizers, farming machinery, and labor in farming, which needs to be reduced to the recommended optimal level. Finally, by using the Propensity Score Matching (PSM), we observed that the farmers achieved better paddy yield, i.e., an additional 0.6t/ha paddy, due to the adaptation of mobile-based recommendations. Subsequently, we used probit modeling to estimate the critical factors for adopting mobile-based services. Results show that farmers' education level, farm experience, social capital, and market information play a significant role in mobile-app-based recommendation adoption. This study supports that farmers need to be suggested to use digital advisory services, and state/central policies may be aligned towards strengthening farmers' capacities for applying digital services in the farming system.

Keywords	Eco-efficiency estimation, Mobile application based input recommendation, paddy yield improvement, Slack-Based Data Envelopment Analysis, Propensity Score Matching Approach
JEL Code	Q1, Q12, Q15, Q16

Introduction

100 – 250 words

Nearly 870 million people across developing countries, where rice is responsible for food security, are estimated to suffer chronic undernourishment (Muthayya et al., 2014). Therefore, to maintain food security, rice/paddy yield needs to be doubled by 2050 (Ray et al., 2013). Farmers often overuse inputs like seeds, irrigation water, chemical fertilizer, and biocides (insecticides, fungicides, and herbicides) to maximize the rice yield (Mobtaker et al., 2010). The increased amount of input used to improve the grain yield also enhances greenhouse gas emissions and minimizes profit (Erdal et al., 2007). Therefore, using agricultural inputs at an optimum rate is crucial for maximizing paddy production's profit and long-term sustainability (Yuan & Peng, 2017).

Past studies used Data Envelopment Analysis (DEA) found that the resource use efficiency of farmers involved in different crop production and recognized key inputs for efficiency improvement (Houshyar et al., 2017). However, rarely any study provides insight into the role

of digital platforms in input use recommendations for achieving better eco-efficiency and monitor whether farmers' yields improved afterward or not. Hence, the study aims to estimate paddy producers' resource-use eco-efficiency by using a digital platform and measure the impact of digital recommendation adoption on paddy yield in the study area.

Methodology *100 – 250 words*

In this research, we propose a DEA-based model to estimate efficiency as a function of land size, land rent, human labor, machines, and fertilizers. We have not considered irrigation costs because agriculture in the study area is primarily rainfed (Baruah et al., 2004). Additionally, we have taken undesirable outputs in the form of GHG emissions to obtain a more accurate measure of efficiency, i.e., eco-efficiency. The Directional Distance Function (DDF) has been paired with DEA to estimate the impact of undesirable outcomes on farm efficiency.

After identifying the inefficient farmers based on slack-based DEA analysis, the study provided input recommendations to all of them. However, not all the farmers adopted the provided input recommendations. The research used probit regression analysis to identify the determinants of mobile-app-based recommendation adoption. Finally, the study divided the farmers into two groups, i.e., recommendation adopters and non-adopters. Finally, we used a Propensity Score Matching (PSM) approach to estimate the impact of the adoption of input recommendations on farmers' paddy yield than non-adopters of the recommendations.

Results *100 – 250 words*

DEA efficiency scores were evaluated with and without considering undesirable outputs for comparison. Results show that the technical efficiency of 119 out of 153 farmers decreased after including GHG emissions as an undesirable output. Only the remaining 34 farmers had been able to manage their farm inputs in a better way and produced comparatively lower levels of GHG emissions. The slacks in output variables represent the scope for potential improvement. We found that the average agricultural labor cost could be reduced by INR 218. Similarly, the cost of fertilizers, farming machinery, and labor (adult man) should be reduced by approximately INR 1259, INR 1862, and INR 929, respectively. However, there is little scope for reduction in the area under paddy cultivation, which is helpful. If individual farmers optimize the input slacks correctly, there is a potential scope of improvement in the yield by nearly 12 quintals on average, and a reduction of 1397 kg of CO2eq released during cultivation. The probit estimates show that farmers' education level, group membership, market information, Kisan Credit Card, asset ownership, age, and household size regulates the mobile app-based recommendation adoption of the farmers. Finally, the PSM results indicate that mobile-app-based recommendation adopters achieve an additional 0.6t/ha paddy yield than the non-adopters.

Discussion and Conclusion *100 – 250 words*

The study concluded that eco-efficiency (undesirable output) is lower than paddy growers' efficiency. The study showed that the mobile app helps farmers provide optimal inputs (Fertilizer, irrigation, insecticides, pesticides, etc.) and use recommendations at the right time. An optimum and timely supply of inputs helps improve plant nutrition and growth, resulting in greater production per unit area. Findings concluded that farmers using mobile advisory services achieved better yields than non-users. The non-government organizations, civil societies, research institutions, and private players can also help the farmers in capacity development for the better use of farm-based digital advisory services along with the government for the holistic development of the farming community.