Testing Productivity and Farm Size Relationship in India: Evidence from India's SAT

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Abstract: *This paper presents new evidence on the relationship between farm size and productivity in India's semi-arid tropics (SAT), utilizing four decades (1975-2014) of ICRISAT data from village longitudinal study (VLS), spanning three waves. In the context of a decline in crop diversity and a surge in capital-intensive farming practices, we find a temporal evolution in the inverse farm size-productivity relationship, transitioning from being inversely significant in the first two waves (1975-84 and 2001-08) to being not significant in the third wave (2009-2014) upon controlling for household-specific characteristics, production modes. The essence of the relationship remains unaltered on controlling for supervision, and crop diversity. However, the plot level analysis suggests evolving labour and non-labour input intensity, shifts in the significance of the association with plot area, emphasizing the influence of household-specific factors on this intricate relationship.*

Keywords: Agricultural Productivity, inverse Relationship, ICRISAT, Economic sustainability, Semi-arid tropics

JEL codes: C23, O13, Q12, R29

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1. INTRODUCTION

The relationship between farm size and productivity has been a subject of enduring debate over the past century, as evidenced by seminal works such as Sen (1962), Rao (1967), Rudra (1968), Saini (1971), Rao (1975), Rudra and Sen (1980), and Chayanov (1991). This extensive discourse has given rise to three distinct strands of inquiry. The first strand accentuates the influence of unobserved factors such as soil quality (Bhalla and Roy 1988), risk considerations (Srinivasan 1972), and unobserved heterogeneity among farmers (Carter 1984; Benjamin 1995) contributing to the relative productivity differentials observed among smallholders. The second strand delves into the complex web of market imperfections, spanning land, labour, credit markets, and supervisory constraints (Feder 1985; Eswaran and Kotwal 1986). The third strand, gaining prominence in recent decades, scrutinizes the impact of measurement errors in respondent-reported land sizes and output (Lamb 2003; Barrett, Bellemare, and Hou 2010; Deininger and Byerlee 2012; Carletto et al. 2013; Paul and wa Gĩthĩnji 2018; Aragón et al. 2022).

Against this backdrop, we focus on analysing the temporal dynamics of the inverse relationship without attempting to explain it, diverging from many existing contributions in the field. Our aim is to identify factors that attenuate this relationship over time. This paper explores the dynamic relationship between farm size and productivity in India by focusing on output per acre as well profit per acre as measures of crop productivity. Leveraging comprehensive household and plot-level panel data from ICRISAT village longitudinal study (VLS) spanning the years 1975 to 2014, we present fresh empirical evidence on the evolution of the farm size-productivity relationships. Our analysis, rooted in data from India’s semi-arid tropic (SAT) region, which encapsulates nearly four decades of agricultural practices, challenges prevailing assumptions regarding the productivity advantage of smallholders. We find a temporal evolution in the inverse farm size-productivity relationship, with the relationship changing from being significantly negative in the first two waves of the survey (1975-1984 and 2001-2008, respectively) to being not significant in the third wave (2009-2014). Contrary to expectations, we find that, even after controlling for a bevy of household and plot level characteristics, smallholders do not consistently demonstrate a productivity advantage in output value and profit per acre compared to their larger counterparts across models where total operated area is considered as the measure of farm size. When categorizing farmers from 1975-1979 as first-generation and those from 2009-2014 as second-generation, the findings consistently show that smallholders held a productivity advantage in the first generation, which diminished in the second generation.

Our study contributes in the following ways. First, it positions the dynamism of the farm size-productivity relationship in the context of India's agricultural development. Second, it situates the evidence from a vulnerable agroclimatic region, namely semi-arid tropics in the context of the emerging evidence on the farm size-productivity relationship across the developing world. Third, our findings raise concerns about the sustainability of smallholder livelihoods. The persistent low net returns in rupees for smallholders accentuate apprehensions about the viability of their livelihood based on agricultural activities. Moreover, the study draws attention to the broader economic landscape by highlighting the sustainability challenges faced by marginal and small landholders in regions that are devoid of the benefits of protective irrigation owing to their semi-arid production conditions. Despite an increase in crop productivity in terms of yield per acre, the returns to agricultural inputs have not proportionally risen, especially in the face of a drastic escalation in cultivation costs over time. This intricate analysis points to a notable convergence between small and large farm holders in terms of crop economics at the per-acre level, signalling a potential loss of the historical productivity advantage of smallholders.

The subsequent sections of the article are organized to delve deeper into these insights. Section 2 provides an expansive exploration of the farm-size productivity relationship across developing countries, setting the stage for our specific study. Section 3 offers a detailed description of the panel data employed in our analysis, ensuring transparency in our methodology. Section 4 outlines our empirical strategy, while Section 5 presents descriptive statistics and fixed-effects regression results, further bolstering the robustness of our findings. Section 6 delves into policy implications arising from our study, and the concluding Section 7 synthesizes our key contributions, offering avenues for future research.

2. Recent Evidence and Regional Variations in Farm Size-Productivity Relationship

Over the past decade, there has been a resurgence of empirical studies on the farm size-productive relationship. While these studies present mixed-evidence on the sign and significance of the farm size-productivity relationship, several underlying mechanisms including role of measurement error have been identified.

Among recent shreds of evidence from Asia, Gautam and Ahmed (2019) examine the farm size-productivity relationship in Bangladesh agriculture between the period 2000 and 2008. While confirming the existence of an inverse relationship, they observe a weakening trend over time. Large farmers, propelled by faster technical change, have effectively narrowed the productivity gap with their smaller counterparts. This trend challenges the conventional understanding of the persistently disadvantaged position of large farmers. In Northern China, Sheng, Ding, and Huang (2019) contribute to the discourse by using farm-level panel data spanning from 2003 to 2013. Their findings reveal a mild U-shaped relationship between maize yield and cropped area. Importantly, their model incorporates labour and capital intensities, providing a comprehensive view of how input choices impact the intricate dynamics of the size-productivity relationship.

Several studies in the African context examine the farm size-production relationship with the diverse farm size distribution landscape in background. For example, as noted by Collier and Dercon (2014), there has been a rise in large and medium-scale farms due to governmental initiatives unlike the pattern of marginalization of land holdings as observed in India. New evidence on the farm size-productivity relationship in the continent is mixed. Paul and wa Gĩthĩnji (2018) find an inverse relationship in Ethiopia using nationally representative data. In Rwanda, Ali and Deininger (2015) find an inverse relationship as long as productivity is measured in terms of profit, but vanishing when family labour is valued at market wages, thereby underscoring the role of labour r market imperfections in shaping the observed relationship.

Recent studies also test the sensitivity of inverse relationship hypothesis to reporting biases among smallholders and larger farmers. As a case in point, Carletto, Savastano, and Zezza (2013) rejected inverse relationship in Uganda after adjusting for measurement error of farmer-reported land size. Using geographical information system (GIS) for plot level mapping, they found significant reporting errors in maize due to which the inverse relationship existed but it disappears when GPS data are used.

In the Ugandan context, Gourlay et al. (2019) found that using GPS-based measure of plot size along with sub-plot cutting, full-crop cutting, and remote sensing to estimate crop yields indicates constant returns to scale at mean as well as across the distribution. On the contrary, they find farmer-reported yields lend support to the inverse relationship. Along similar lines, Desiere and Jolliffe (2018) use yield based on crop cutting in Ethiopia to arrive at the same conclusion. Innovative explanations such as “edge effect” in Uganda context

(Bevis and Barrett 2020) have emerged that show that plot perimeter/area ratio explains most of the inverse plot size-productivity relationship.[4]

The importance of taking into account the entire distribution of farm sizes is also emerging as crucial. For example, Muyanga and Jayne (2019) examine the relationship between farm size and multiple definitions of productivity including total factor productivity (TFP) over a wide range of farm sizes in Kenya. They find a U-shaped relationship between farm size and their measures of productivity. Farms below three hectares exhibit inverse relationship; those between three and five hectares have a flat relationship; and those between five and 70 hectares have a positive relationship. They conclude that such differentials in productivity emerges from greater input use intensity and farm mechanization by large farms – which reduces labour input per hectare. U-shape relationship in Nigeria is also evident in recent studies (Omotilewa et al. 2021). Savastano and Scandizzo (2017) consider the entire distribution and productivity and find evidence of sign switches along the distribution of productivity. They find that there is 'direct-inverse-direct' relationship in Ethiopia, that is, less productive farmers exhibit an inverted U-shaped relationship while the more productive farmers show a U-shaped relationship. Their findings indicate that IR is an artefact of middle size farms having certain size and range of efficiency.

Few recent studies argue that the inverse relationship has attenuated with improvement in factor market imperfections over the period 1982-2007 (Deininger et al. 2018) and Tanzania (Wineman and Jayne 2021). Questioning partial productivity measures such as yield, Aragón et al. (2022) use microdata from Uganda to challenge the IR phenomenon on the ground that yield may pick up total factor productivity (TFP) and size dependent market distortions as well as decreasing returns to scale (DRS).

[4] This is with reference to the agronomic literature on productivity being highest around the periphery (edge) of plots.

In the Indian context, particularly in semi-arid tropics, using ICRISAT-VLS data for the period 2009-2014, Foster and Rosenzweig (2022) identify a U-shaped relationship, attributing it to labour market transaction costs and increased machine capacity. This is in contrast to study by Assunção and Braido (2007) failed to reject an inverse relationship using ICRISAT VLS data from 1975-1984

This study also uses the ICRISAT-VLS data albeit for a period spanning four decades: 1975-2014. It employs value of output per acre and profit per acre as measures of productivity and operational area as the measure of farm size. With an aim to examine the robustness of the empirical relationship between farm size and productivity, we consider myriad technological and structural changes over time. Notably, this period is characterized by an intensification of agricultural inputs or capital-intensive production (Badiani et.al, 2007). The patterns of farm mechanization and changes in labour intensity in production over the period are nevertheless different from the patterns in non-SAT agriculture. Furthermore, it examines productivity and plot size relationship and documents structural, technological, and cropping intensity changes over decades (Kumar et.al, 2020). This study underscores the need for a multifaceted and context-specific explanation of the farm size-relationship over an extended period of time, one that is congruent with the significant agricultural development of the country, this study attempts to approach to unravelling intricacies of agricultural productivity dynamics.

3. ICRISAT VLS Data: A Longitudinal Perspective

We use microdata from the comprehensive ICRISAT VLS (Village Level Survey) dataset, spanning from 1975 to 2014 to capture the dynamics of three survey waves of ICRISAT VLS: Wave-I (1975-84), Wave-II (2001-2008), and the latest Wave-III (2009-2014). The ICRISAT VLS dataset has been instrumental in offering insights into the socioeconomic changes within the Semi-Arid Tropics (SAT) regions of South Asia and Africa since its inception in 1975 (Walker and Ryan 1990).

Defined by agroclimatic characteristics such as scanty and uncertain rainfall, rainfed agriculture, and infertile, degraded soil, SAT regions have a length of growing period (LGP) of 75-180 days and a mean monthly temperature exceeding 18°C (Ryan and Spencer 2001). In the Indian context, longitudinal data have been meticulously collected from six Semi-arid tropical (SAT) villages across two Indian states since 1975 (see A.1 in Appendix). However, many new villages from different parts of India have been added to the study since 2009. In the initial five years of the study (1975-1979), a judicious sample of 40 households from each village was selected, ensuring equitable representation across labour, small, medium, and large landholding households (10 households from each farm group). For labour households, a random selection of 10 households operating less than 0.2 hectares, primarily engaged in labour-intensive activities, was conducted. To classify households based on operational landholding (above 0.2 hectares), farmers in each village were sorted in ascending order of operational land, creating three strata with an equal number of farmers in each. Subsequently, 10 households were randomly selected from each stratum, recognizing the variability in land distribution across villages.

There are important idiosyncrasies of the ICRISAT-VLS data that have been taken into consideration in preparing the data for analysis. Post-1979, the sample size experienced minor fluctuations due to factors such as household migration, split-offs of original households, and financial constraints, but it has remained stable since the last wave i.e. 2009-2014. For an in-depth understanding of sample size and sampling methodologies, ICRISAT's manuals for each survey wave provide comprehensive details (Singh et al., 1985; Rao et al., 2011a; Rao et al., 2011b). In our study, we rely on three modules from two schedules of ICRISAT’s VLS data: family composition, landholding details from the General Endowment

Schedule (GES), and cultivation input and output details from the Cultivation Schedule (CS). Notably, plot-level characteristics such as soil type and irrigation status are merged with the landholding details module. The unique identifier coding system allows us to analyse this dataset at both the household and plot levels.

However, for the period of 2001-2004, only local names of the plots are provided, and plot codes are absent, rendering unique identification challenging. Additionally, there is no segregated information on hired and family labour for this period and year 2007. Consequently, we refrain from utilizing Wave-II data for plot-level analysis and household-level labour statistics. It is crucial to note that operational land data were collected for all sampled households, while landholding and cultivation data were gathered only for those actively engaged in cropping operations at plot level. Many labour households (non-cultivator households henceforth) do not own any plot of land or they do not cultivate, because of which a small number of households in the labour sub-group are found in the landholding data. This ensures precision in our analysis, considering the variation in plot ownership and cultivation practices across different household groups.

4. THEORETICAL FRAMEWORK AND ESTIMATION STRATEGY

In the literature, farm size encompasses not only operational landholding but also household labour, capital, and other economic capacities. Productivity estimated without considering these factors is termed land productivity and is viewed as a partial measure, while productivity conditioned on them is termed farm productivity (Helfand and Taylor, 2021). Our theoretical framework posits that when only land serves as a factor of production, land productivity q is defined as:

$$\text{Land productivity} = \frac{Q}{A} = q = \varphi_u(A) \quad (1)$$

Where A is operational area of the farm, Q is the agricultural output that can be measured as either yield, output value or profit and, $\varphi_u(A)$ implies land productivity may be function of operational area A.

In ideal condition, land productivity should be unrelated to farm size i.e. $\frac{\partial \varphi_u}{\partial A} = 0$. However, empirical studies offer strong evidence to the contrary, $\frac{\partial \varphi_u}{\partial A} \neq 0$. In complex real-world agricultural systems, the relationship between land productivity and farm size is not merely bivariate. Instead, it is influenced by cropping patterns, labour and input intensities, and farmer and land characteristics. Consequently, unconditional land $\varphi_u(A)$ offers only a partial measure, accounting for a single factor of production A. To derive a more appropriate measure, we must consider other factors such as labour and input intensities, leading to conditional productivity $\varphi_c(A)$. Assuming labour intensity l, input intensity k, and operational land A as the role factors of production, the relationship is represented as:

$$\varphi_u(A) = f(l(A),\ k(A),\ \varphi_c(A)) \tag{2}$$

To estimate conditional and unconditional productivity, we used two definitions of productivity: (i) value of output per acre; and (ii) profit per acre. Plot area represents total area of the plot while operational area is the total area operated by the farm household in an agriculture year (July- June). Labour hours per acre and non-labour input cost per acre represent the intensity of labour and agriculture machinery and inputs used by households respectively. Given the availability of panel data at the household level for three survey waves, we employ a fixed-effects model at household level and plot level. The household-level model aims to capture the overall productivity dynamics within individual farm households, considering variables like labour and non-labour inputs relative to the operational area. It offers a broad perspective on how household-specific factors influence agricultural outcomes.

The household level model is shown in equation (3)

$$\ln y_{i,t} = \alpha_1 + \beta_1 \ln A_{i,t} + \theta_1 \ln l_{i,t} + \gamma_1 \ln k_{i,t} + \delta X_{i,t} + \eta T + \varepsilon_{i,t} \qquad (3)$$

Where,

$y_{i,t} = \frac{Y_{i,t}}{C_{i,t}}$, Y is value of agricultural output or profit of household *i* in year *t*

$l_{i,t} = \frac{L_{i,t}}{C_{i,t}}$, L is total labour hours in cultivation applied by household *i* in year *t*

$k_{i,t} = \frac{K_{i,t}}{C_{i,t}}$, K is value of non-labour input expenditure in cultivation by household *i* in year *t*

and A is operational area (in acres) by household *i* in year *t and C* is total cropped area by household *i* year *t. X's* are household specific controls. *T* denotes control for survey year. The coefficients $\beta_1, \theta_1, \gamma_1$ represent the elasticities with respect to operational area A, labour l, and non-labour inputs, respectively. The term δ captures the effects of household-specific controls, and η is the coefficient pertaining to controls for survey year effects. The error term ϵ accounts for unobserved and idiosyncratic factors affecting household-level production. Equation 1 estimates conditional farm productivity. When household, temporal, labour, and input intensities are omitted, it captures unconditional or land productivity. In contrast, the plot-level model delves deeper into the specific productivity of individual plots within households. By incorporating plot-specific controls, it provides insights into how variations in land management practices and input utilization at the plot level impact agricultural output. However, due to identification issues[5], we estimated plot level fixed effect model for the first and third wave. We estimated the following model with additional plot level characteristics as shown in equation (4).

$$\ln y_{i,j,t,s} = \alpha_2 + \beta_2 \ln P_{i,j,t,s} + \theta_2 \ln l_{i,j,t,s} + \gamma_2 \ln k_{i,j,t,s} + \delta X_{i,t} + \lambda W_{i,j,t} + \eta T + \varepsilon_{i,j,t,s} \qquad (4)$$

Where,

$y_{i,j,t,s} = \frac{Y_{i,j,t,s}}{C_{i,j,t,s}}$, Y is value of agricultural output and profit of household *i* in plot *j* in season *s of year t*

[5] Between 2001 and 2004, the absence of unique plot identification codes, coupled with the use of only local names for plots, hindered the consistent identification of individual plots across survey years (Rao et al., 2011a).

$l_{i,j,t,s} = \frac{L_{i,j,t,s}}{C_{i,j,t,s}}$, L is total labour hours applied in cultivation by household *i* in plot *j* in season *s* of year *t*

$k_{i,j,t,s} = \frac{K_{i,t}}{C_{i,j,t,s}}$, K is non-labour input expenditure in cultivation by household *i* in plot *j* in season *s* of year *t*

and *C* is total cropped area of plot *j of* household *i* in season *s* of year *t. X's* and *W's* are household and plot specific controls respectively. However, *P* is total area of the specific plot *j* operated by household *i* in season *s* of year *t. T* is control for year of survey. The coefficients $\beta_2, \theta_2, \gamma_2$ signify the elasticities of plot area P, labour, and non-labour inputs relative to the productivity y, respectively. The δ and λ terms account for household and plot-specific controls, respectively. The error term ϵ in this context captures unobserved and idiosyncratic determinants of plot-level production.

Plot characteristics include controls for irrigable area, irrigation source availability, bunding infrastructure, plot location, distance of plot from household (in kilometres), and soil fertility but information on irrigation status and soil type is available for all waves so we used only these two characteristics in our plot level models. Season controls for variation in Rabi and Kharif season. Household characteristics include age, gender and education of household head, and number of household members primarily engaged in cultivation and livestock. A complete description of variables is presented in Table 1.

Table 1: List of variables and description

Variable	Description
Dependent Variable: Agriculture productivity	Measured in terms of output value per acre and profit per acre in Indian rupees (at constant price base year 2012)
Log Operational area	Operational landholding by household (acres)
Log plot area	Area of the agricultural plot in acres (plots with codes A, B, C, D, etc)
Log Labour (hours/acre)	Total labour hours per acre by household (hired and family labour)
Log Labour cost (Rs. /acre)	Total labour cost per acre by household (hired labour cost and imputed value of family labour)
Log Non-labour input cost (Rs. /acre)	Total input cost (machinery and input) per acre by household
Season	Cropping season (Rabi and Kharif)
Irrigation Status	Irrigation status if the plot (Fully irrigated, More than 50% irrigated, Less than 50% irrigated and Rainfed)
Log crop diversity or intensity	Number of crops per acre grown by household in one survey year
Soil Type	Type of soil for plot
Head's gender	Gender of household head (Male, Female)
Age of head (Years)	Age of household head (years)
Years of head education	Household head's education (years)
Number of members in household whose primary work in farming	Number of members in household who are primarily engaged in farming
Number of members in household whose primary work in livestock	Number of members in household who are primarily engaged in livestock work
Family size	Number of family members in household
Head's main occupation	Main occupation of household head
Year	Agricultural survey year (July-June)

5 RESULTS AND DISCUSSION

5.1 Sample Characteristics

Table 2 provides a comprehensive overview of the demographic characteristics of the sampled households over the survey period. The age of the household head fluctuated between 44 and 50 years, with a gradual increase in the head's education by two years. Nevertheless, the sample witnessed a reduction in family size and marginalization of landholdings. The study villages exhibited a shift towards mono cropping practices, resulting in a decline in crop diversity or intensity over the period (Table 2).

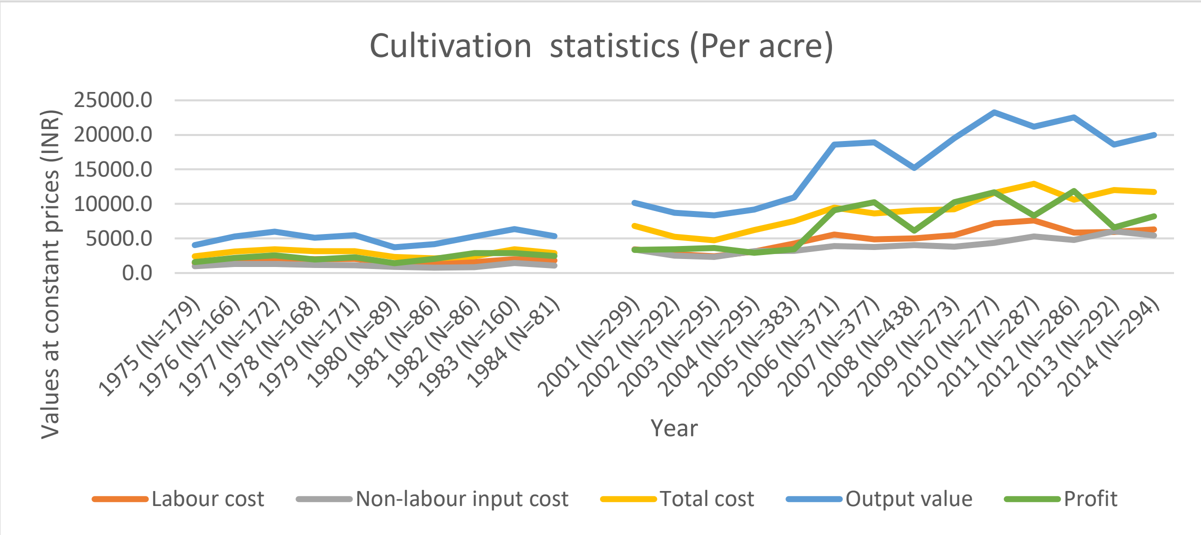
Table 2: Summary Statistics

Year	Head's Age (Years)	Head's education (Years)	Family Size	Operational Land (Acres)	Cropped area (Acres)	Number of crops per acre	Number of plots
1975 (N=179)	44.2	2.8	6.7	11.9	13.1	0.9	3.4
1976 (N=166)	44.8	2.7	6.9	14.0	15.4	0.7	3.9
1977 (N=172)	45.3	2.9	6.8	14.4	15.9	0.8	4.1
1978 (N=168)	45.9	2.9	6.8	13.3	14.2	0.7	3.7
1979 (N=171)	47.6	2.7	6.9	12.6	13.2	0.7	3.7
1980 (N=89)	49.1	2.4	6.8	12.2	12.9	0.9	3.2
1981 (N=86)	50.2	2.3	6.8	12.1	13.3	0.9	3.1
1982 (N=86)	51.1	2.3	7.0	12.0	12.7	0.9	3.2
1983 (N=160)	50.4	2.6	6.9	13.1	14.2	0.8	3.5
1984 (N=81)	51.3	2.6	6.5	12.1	12.8	0.9	3.2
2001 (N=299)	47.0	4.4	5.3	6.6	6.6	0.7	1.5
2002 (N=292)	47.9	4.4	5.3	6.9	6.9	0.7	1.6
2003 (N=295)	48.6	4.4	5.5	7.1	6.6	0.7	1.7
2004 (N=295)	48.9	4.5	5.5	7.0	6.8	0.7	1.7
2005 (N=383)	49.1	4.3	5.4	7.5	8.0	0.8	2.2
2006 (N=371)	48.6	4.5	5.2	7.6	7.6	0.7	2.3
2007 (N=377)	49.5	4.4	5.2	7.4	8.4	0.6	2.3
2008 (N=438)	48.9	4.8	5.1	7.4	6.7	0.6	2.2
2009 (N=273)	49.3	4.8	5.2	7.3	6.7	0.7	2.3
2010 (N=277)	49.1	5.2	5.0	7.0	7.0	0.7	2.3
2011 (N=287)	48.9	5.1	5.1	7.0	6.7	0.7	2.3
2012 (N=286)	49.3	5.2	5.0	7.1	7.3	0.6	2.4
2013 (N=292)	49.9	5.3	5.0	7.2	8.3	0.5	2.4
2014 (N=294)	49.8	5.4	4.9	6.7	6.5	0.6	2.3

Note: Statistics only for households operating on agricultural land (Labour households without operational land excluded).

Structural, and technological advancements (such as the introduction of genetically modified Bt seeds in cotton), and changes in the mode of production (such as intensification of non-labour inputs) led to a notable increase in both cultivation cost and production in the study villages. This change became more pronounced from Wave-II onwards. Notably, the introduction of Bt seeds, a significant factor in cotton cultivation in not only the SAT region but also rest of India (Kathage and Qaim,2012; Kranthi and Stone, 2020), contributed to an increase in both production and cultivation costs, with a higher number of pickings resulting in elevated labour costs (Figure 1). Despite these changes, the returns to total cost did not increase as expected. The ratio of profit to total cost remained less than 1 for most of the years, and variability in this ratio increased in Wave-III, leading to higher uncertainty (Figure 2).

Figure 1: Cultivation cost and output trends (Value at constant price, Base year: 2012)



The analysis of cultivation cost by farm size groups provides profound insights into the change in the mode of production between Wave-I and Wave-III. A comparison reveals a drastic increase in the intensity of both labour and non-labour inputs over time. During Wave-I, the labour group pursued a labour-intensive mode of production compared to other farm groups, with per-acre total cultivation cost also higher. However, in Wave-III, the labour group intensified non-labour inputs, surpassing labour input costs but remaining comparable to other groups (refer to Figure 3).

The analysis of hired and family labour intensity across farm size groups indicates interesting changes over time. During Wave-I, the labour group followed a highly labour-intensive mode of production compared to other groups. Labour group households were employing both family and hired labour intensively during Wave-I; however, due to technological changes, labour intensity dropped drastically in Wave-III (Figure 4). For all farm size groups, the share of family labour hours per acre in total labour hours per acre decreased over time, with a more pronounced decline for large farm groups compared to labour and small farm groups (Figure 5).

The analysis of cultivation costs suggests that farmers in the region are not only utilizing labour intensively but also non-labour inputs, including machinery, in Wave-III compared to Wave-I. This change can be contributed to increase in number of cotton pickings after introduction of Bt cotton. In the next section, we will attempt to test the significance of the change in the mode of production across three waves using a fixed-effect model with labour and non-labour inputs (per acre) as the dependent variable.

Figure 2: Ratio of agricultural output and cultivation over time

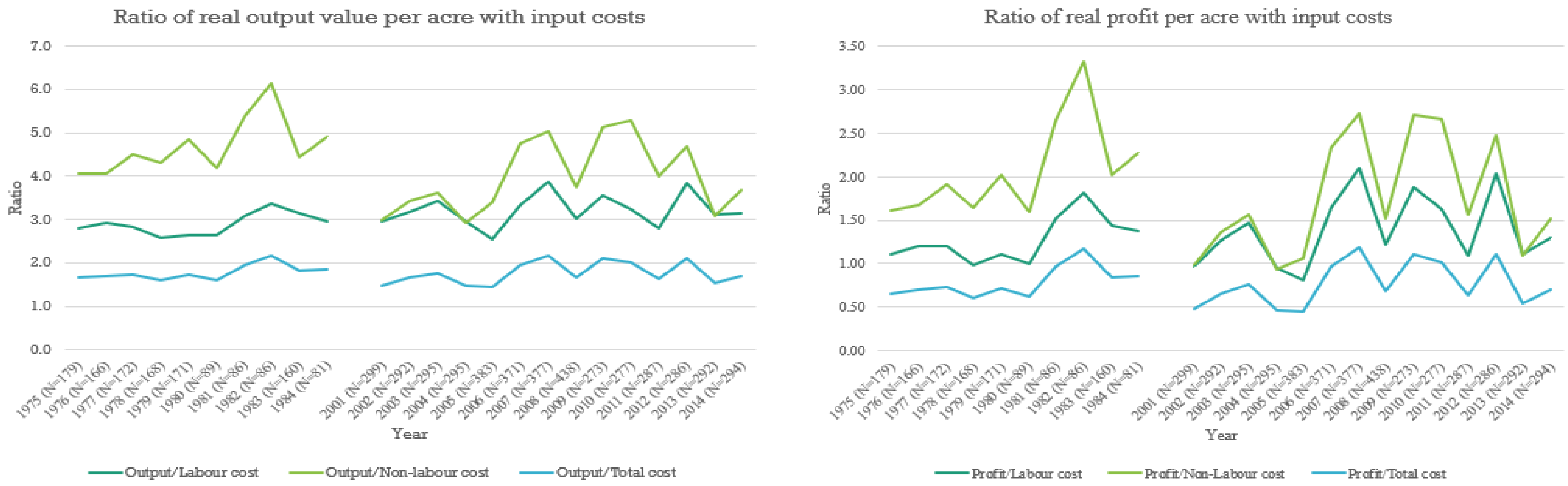
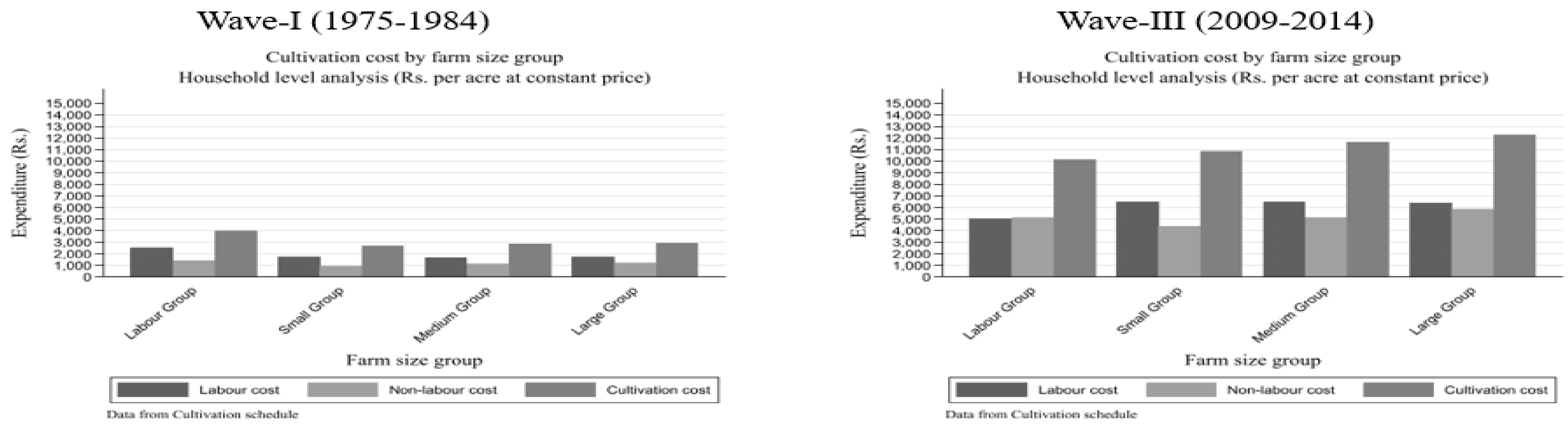
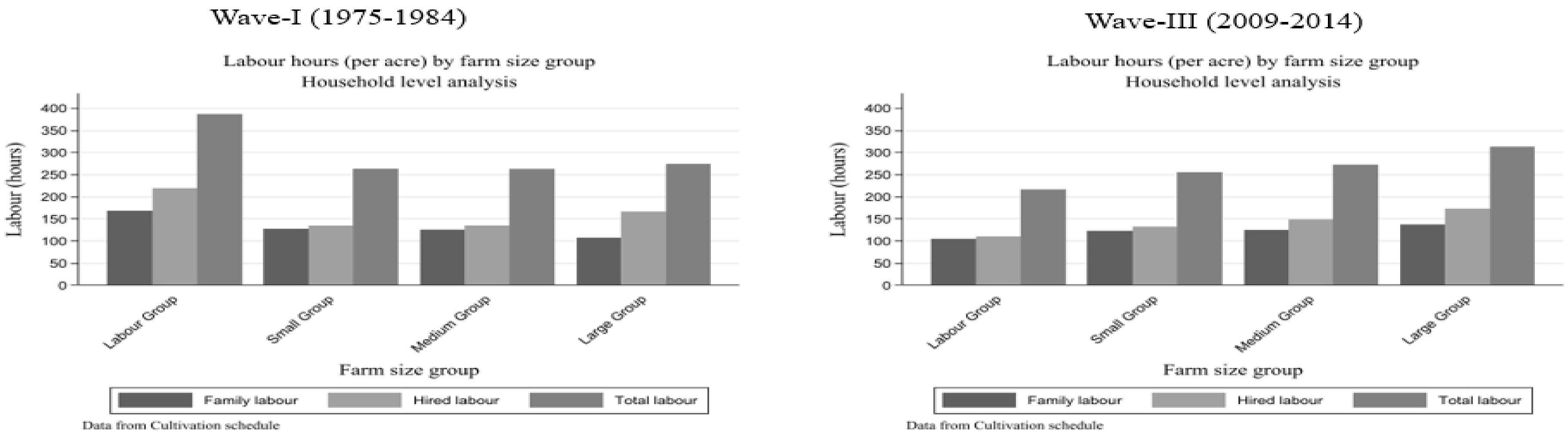


Figure 3: Cultivation cost by farm size groups



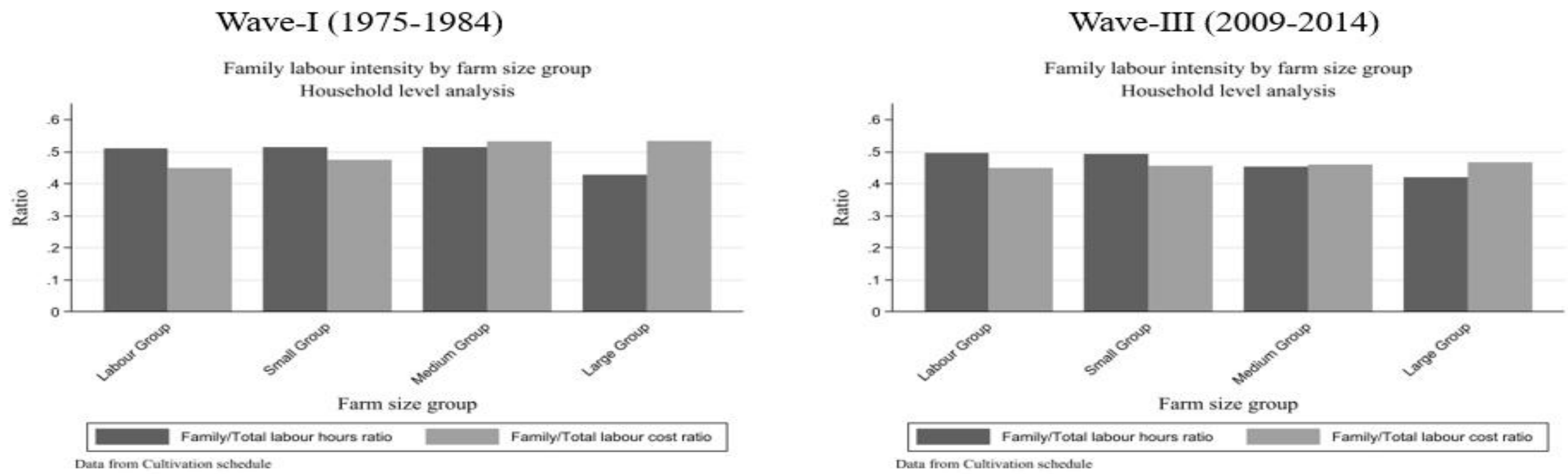
Note: Farm size group classification according to ICRISAT's sampling criteria

Figure 4: Comparison of hired and family labour utilization by farm size groups



Note: Farm size group classification according to ICRISAT's sampling criteria

Figure 5: Comparison of family labour intensity by farm size groups



Note: Farm size group classification according to ICRISAT's sampling criteria

5.2 Results

To understand the relationship between farm size and productivity, we generated a local polynomial smoothing plot of degree two. Our plots reveal an inverse relationship between farm size (operational land) and productivity[6] (output value per acre at constant price) for 99% of the observed data (Figure 6). This finding indicates that unconditional land productivity exhibited an inverse relationship during the study period from 1975 to 2014. However, since this is a measure of partial productivity, we further examined conditional productivity by estimating various specifications of the model in Equation 3.

Figure 6: Unconditional relationship between real output value per acre and farm size (acres) (1975-2014)

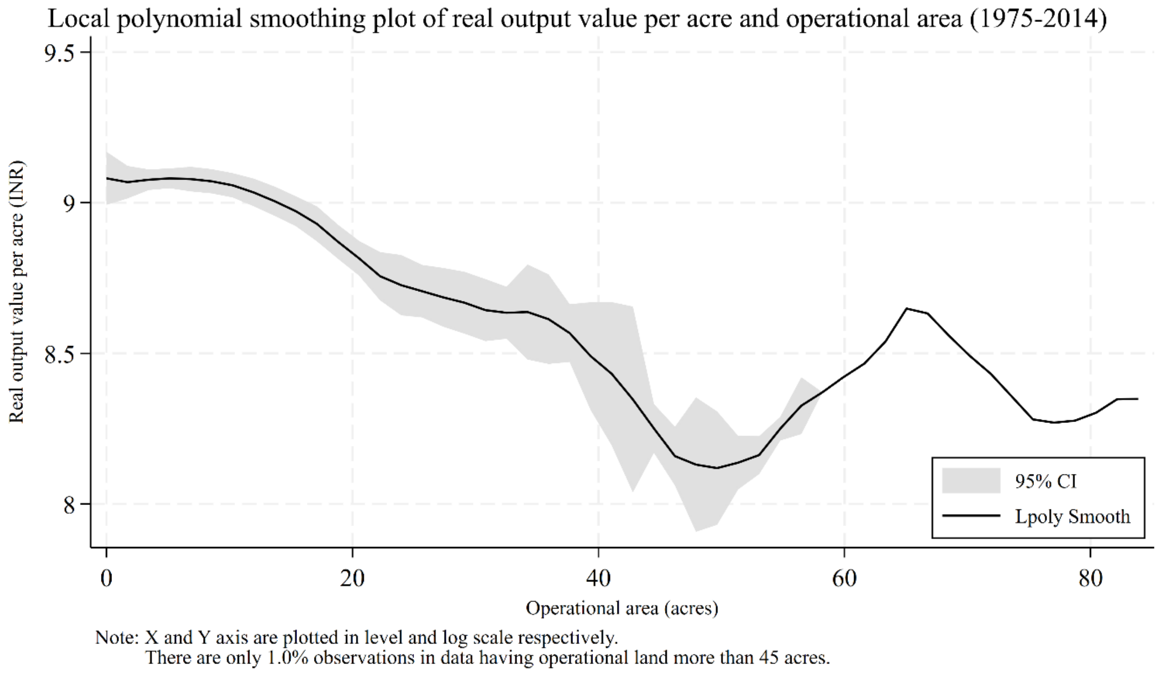


Table 3 presents fixed-effect results examining the relationship between unconditional and conditional productivity (measured by both output value and profit) and farm size over the study period. Model 1 reveals a strong inverse relationship between unconditional

[6] We obtained similar results when measuring productivity as profit per acre at constant prices. However, we did not report these findings due to space constraints.

productivity (output value per acre) and farm size. When labour and input intensities are controlled for in Model 2, the relationship weakens but remains inversely related, indicating that these factors contribute to the relationship's attenuation without fully explaining it. Introducing controls for household-specific characteristics in Model 3 results in a further weakening of the relationship. In Model 4, which incorporates year effects to consider factors such as technological advancements, changing cropping patterns, and shifts in modes of production, the previously observed inverse relationship between farm size and productivity disappears. This suggests that evolving time-related factors correlated with both productivity and farm size have influenced the observed trends. Similar patterns emerge across all models when profit per acre is used as the productivity measure.

Table 3: Farm size and productivity relationship (1975-2014)

Dependent Variable (in logs)	Output Value Model				Profit Model			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Log Operational area (acre)	-0.315***	-0.067***	-0.035*	0.003	-0.338***	-0.115***	-0.092***	-0.039
	(0.02)	(0.02)	(0.02)	(0.02)	(0.04)	(0.03)	(0.04)	(0.03)
Log Labour (hours/acre)		0.509***	0.581***	0.720***		0.412***	0.498***	0.669***
		(0.02)	(0.02)	(0.02)		(0.04)	(0.04)	(0.04)
Log Input cost (Rs. /acre)		0.365***	0.263***	0.108***		0.346***	0.219***	0.02
		(0.01)	(0.01)	(0.01)		(0.02)	(0.02)	(0.03)
Head's gender			Yes	Yes			Yes	Yes
Age of head (Years)			Yes	Yes			Yes	Yes
Years of head education			Yes	Yes			Yes	Yes
Number of members in household whose primary work in farming			Yes	Yes			Yes	Yes
Number of members in household whose primary work in livestock			Yes	Yes			Yes	Yes
Family size			Yes	Yes			Yes	Yes
Head's main occupation			Yes	Yes			Yes	Yes
Year				Yes				Yes
Constant	9.583***	3.690***	3.008***	3.406***	8.840***	3.642***	3.192***	3.611***
	(0.04)	(0.11)	(0.15)	(0.15)	(0.07)	(0.21)	(0.30)	(0.30)
N	5647	5646	5632	5632	4705	4704	4696	4696
R-sq	0.49	0.71	0.73	0.79	0.38	0.49	0.51	0.56

Note: Models 1 and 5 lack controls for labour, inputs, household characteristics, and year (unconditional). Models 2 and 6 control for labour and input intensities. Models 3 and 7 accounts for household characteristics, labour, and input intensities, while Models 4 and 8 incorporate all these controls. Dependent variables are in logarithmic scale and all costs are at constant price (Base year: 2012)

It is essential to evaluate the significance of shifts in modes of production, specifically labour-capital substitution and changes in cropping diversity, relative to farm size over time, as these factors could potentially influence the dynamics of farm size and productivity. We conducted a detailed examination to identify which factors changed over time and influenced productivity, correlating with farm size. Controlling for year-specific shocks across three survey waves, we analyzed changes in cropping diversity, labour, and input intensities relative to farm size. Table 4 presents fixed-effects regression results using the log of labour hours per acre and the value of non-labour inputs per acre as dependent variables, while controlling for farm size (operational area), household characteristics, and year. We examined each survey wave separately to discern shifts in production modes. The model for labour hours per acre reveals that small and marginal farmers initially favoured labour-intensive cultivation, but this intensity diminished over time: a 10% increase in operational area corresponded to a 2.44% decline in labour hours per acre in the first wave, further reducing to 1.47% and 1.35% in the subsequent waves. In contrast, the model for non-labour inputs per acre exhibits a different trend. While no significant relationship was observed in the first two waves, a notable relationship emerged in the third wave, indicating a 0.96% increase in non-labour input costs for every 10% rise in operational area. Overall, the findings suggest a shift in production modes over the study period, with an increasing reliance on non-labour inputs. However, marginal and small farmers continue to employ more labour hours per acre than their larger counterparts.

Table 4: Structural change in the mode of production

	Labour (hours/acre)			Input cost (Rs. /acre)		
Dependent Variable (in logs)	Wave-I (1975-1984)	Wave-II (2001-2008)	Wave-III (2009-2014)	Wave-I (1975-1984)	Wave-II (2001-2008)	Wave-III (2009-2014)
Log Operational area (acre)	-0.244***	-0.147***	-0.135***	0.035	0.028	0.096**
	(0.02)	(0.03)	(0.03)	(0.05)	(0.04)	(0.04)
Log Labour (hours/acre)				0.956***	0.871***	0.743***
				(0.06)	(0.03)	(0.03)
Log Input cost (Rs. /acre)	0.217***	0.339***	0.440***			
	(0.01)	(0.01)	(0.02)			
Head's gender	Yes	Yes	Yes	Yes	Yes	Yes
Age of head (Years)	Yes	Yes	Yes	Yes	Yes	Yes
Years of head education	Yes	Yes	Yes	Yes	Yes	Yes
Number of members in household whose primary work in farming	Yes	Yes	Yes	Yes	Yes	Yes
Number of members in household whose primary work in livestock	Yes	Yes	Yes	Yes	Yes	Yes
Family size	Yes	Yes	Yes	Yes	Yes	Yes
Head's main occupation	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Constant	3.205***	3.342***	1.855***	1.309	2.843***	4.391***
	(0.55)	(0.26)	(0.35)	(1.16)	(0.43)	(0.44)
N	1351	2691	1669	1351	2691	1669
R-sq	0.84	0.78	0.78	0.78	0.78	0.77

Note: Dependent variables are in logarithmic scale and all costs are at constant price (Base year: 2012)

Input and labour intensity may correlate with farm size if there is a differentiation in crop diversity associated with farm size. To ascertain whether changes in the relationship between labour and input intensities and farm size are attributable to crop diversity, technological shifts in labour substitution, or both, we further examine the relationship between crop diversity (number of different crops per acre) and farm size over time.

Table 5 presents results on the significance of changes in crop diversity over time. At the household level, our findings indicate a notable decline in crop diversity across all survey waves, and this decline is correlated with farm size. Importantly, the decline in crop diversity is more pronounced among larger farmers, likely due to the promotion of mono-cropping practices. Given the direct correlation between labour intensity and crop diversity, we conclude that changes in crop diversity, labour, and input intensities over time are correlated with farm size, potentially weakening the inverse relationship and altering it in the third wave.

Table 5: Household level crop diversity over time

Dependent Variable:	Log Crop diversity		
	Wave-I	Wave-II	Wave-III
Year	-0.021***	-0.011**	-0.038***
	(0.01)	(0.01)	(0.01)
Log Operational area (acre)	-0.534***	-0.348***	-0.482***
	(0.03)	(0.03)	(0.03)
Log Labour (hours/acre)	0.129***	0.246***	0.314***
	(0.03)	(0.02)	(0.03)
Log Input cost (Rs. /acre)	0.055***	0.017	-0.028
	(0.02)	(0.01)	(0.02)
Head's gender	Yes	Yes	Yes
Age of head (Years)	Yes	Yes	Yes
Years of head education	Yes	Yes	Yes
Number of members in household whose primary work in farming	Yes	Yes	Yes
Number of members in household whose primary work in livestock	Yes	Yes	Yes
Family size	Yes	Yes	Yes
Head's main occupation	Yes	Yes	Yes
Year	Yes	Yes	Yes

Constant	-0.198	-1.465***	0.15
	(0.62)	(0.27)	(0.37)
N	1351	2691	1669
R-sq	0.83	0.70	0.77

Note: Dependent variables are in logarithmic scale and all costs are at constant price (Base year: 2012)

We investigate the evolving relationship between farm productivity and size over time, considering changes in crop diversity, labour, and input levels linked to farm size. Table 6 presents intriguing findings on the dynamics of the farm size and productivity relationship. During the first wave, both models (with and without inputs) demonstrate an inverse relationship between farm size and productivity in the output value and profit models. The results of output value model without inputs are consistent with Assunção and Braido (2007) on same dataset for first wave. However, this relationship weakens over time, with significant coefficients of -0.313 and -0.123 during the first and second waves, respectively. The coefficient becomes non-significant at -0.067 in the third wave for the output value model without controlling for labour and non-labour inputs. Similar trends are observed in the profit models without controlling for inputs. However, when controlling for labour and non-labour inputs intensity, the strength of the inverse relationship diminishes for both output value and profit models in each wave. Coefficients of the output model with input controls are significantly negative during the first wave but become non-significant with positive values in the second and third waves. The profit model with input controls presents similar results. Labour and non-labour inputs per acre are significantly associated with productivity measures, suggesting that the shift in the mode of production contributes to the weakening of the inverse farm size and productivity relationship.

Table 6: Dynamic Farm Size Productivity Relation at Household Level

	Wave-I (1975-1984)				Wave-II (2001-2008)				Wave-III (2009-2014)			
Dependent Variable (in logs)	Output Value Model		Profit Model		Output Value Model		Profit Model		Output Value Model		Profit Model	
	Without inputs	With Inputs	Without inputs	With Inputs	Without inputs	With Inputs	Without inputs	With Inputs	Without inputs	With Inputs	Without inputs	With Inputs
Log Operational area (acre)	-0.313***	-0.085***	-0.321***	-0.159**	-0.123***	0.035	-0.139**	-0.016	-0.067	0.032	-0.035	0.086
	(0.03)	(0.03)	(0.06)	(0.06)	(0.04)	(0.03)	(0.07)	(0.07)	(0.06)	(0.05)	(0.11)	(0.11)
Log Labour (hours/acre)		0.671***		0.617***		0.726***		0.625***		0.765***		0.803***
		(0.04)		(0.09)		(0.03)		(0.06)		(0.04)		(0.10)
Log Input cost (Rs. /acre)		0.075***		-0.106**		0.164***		0.127***		-0.080***		-0.217***
		(0.02)		(0.04)		(0.02)		(0.04)		(0.03)		(0.07)
Head's gender	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Age of head (Years)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Years of head education	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of members in household whose primary work in farming	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of members in household whose primary work in livestock	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Family size	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Head's main occupation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	7.697***	3.867***	4.642***	1.892*	10.010***	4.272***	9.672***	4.830***	9.802***	6.116***	10.845***	7.842***
	(0.85)	(0.75)	(1.01)	(1.10)	(0.41)	(0.36)	(0.66)	(0.70)	(0.52)	(0.50)	(0.95)	(1.08)
N	1344	1344	1196	1196	2642	2641	2163	2162	1647	1647	1338	1338
R-sq	0.73	0.8	0.52	0.54	0.62	0.76	0.52	0.58	0.6	0.71	0.51	0.54

Note: Dependent variables are in logarithmic scale and all costs are at constant price (Base year: 2012)

In literature some studies suggested that neglect of controlling for supervision (Feder, 1985) and crop intensity/diversity (Wassie et al., 2019) may results in inverse farm size and productivity relationship. To address potential confounders, such as supervision and crop diversity, Table A.4 introduces controls for supervision cost (measured by the number of different plots, which require higher labour supervision costs) and crop diversity (measured by the number of different crops per acre). The results indicate that, even with these controls, there is no significant difference in the nature of the farm size and productivity relationship. This suggests that supervision and crop diversity controls are insufficient to explain the nature of the farm size and productivity relationship.

Table 7 reports the generational dynamics of the farm size-productivity relationship by specifically examining two distinct time periods: Generation-I, spanning from 1975 to 1979, and Generation-II, covering the years 2009 to 2014. As we mentioned in table 2, there were large fluctuations in sample size between 1980-84 and 2001-2008 due to split-offs, migration and termination of study in some villages during 1980-84 because of financial constraints at ICRISAT. Also, during 2001-2008, sample size varies a lot due to similar reasons. To discard the effect of fluctuation of sample size on farm size and productivity relationship over time, we used data between 1975-79 from first wave and 2009-2014 from third wave that have more than 90% and 85% household in all years of wave respectively. There is large gap between both periods so we named them as two generation of farmers: 1975-79 as Generation 1 and 2009-14 as Generation 2 This approach is particularly insightful given the considerable fluctuations in sample size observed across different waves of data collection.

The results from the regression analysis demonstrate a notable consistency in the sign and significance of coefficients as compared to table 6. Despite potential concerns arising from variations in sample size during the first wave, the key finding is that these fluctuations do not introduce a discernible effect on the farm size and productivity relationship. The sign and significance of coefficients pertaining to operational area (farm size) and other relevant variables remain stable across both periods. This stability lends support to the robustness of the observed relationships, suggesting that changes in sample size during the first wave do not compromise the overall reliability and validity of the findings. Consequently, the findings imply that the identified dynamics in farm size and productivity are not contingent on sample size variations, reinforcing the credibility of the observed patterns over time.

Table 7: Generational dynamics in Farm Size Productivity Relation at household level

	Generation-I (1975-1979)				Generation-II (2009-2014)			
Dependent Variable (in logs)	Output Value Model		Profit Model		Output Value Model		Profit Model	
	Without inputs	With Inputs	Without inputs	With Inputs	Without inputs	With Inputs	Without inputs	With Inputs
Log Operational area (acre)	-0.332***	-0.101**	-0.325***	-0.229**	-0.067	0.032	-0.035	0.086
	(0.05)	(0.05)	(0.10)	(0.10)	(0.06)	(0.05)	(0.11)	(0.11)
Log Labour (hours/acre)		0.597***		0.428***		0.765***		0.803***
		(0.06)		(0.13)		(0.04)		(0.10)
Log Input cost (Rs. /acre)		0.100***		-0.111*		-0.080***		-0.217***
		(0.03)		(0.06)		(0.03)		(0.07)
Head's gender	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Age of head (Years)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Years of head education	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of members in household whose primary work in farming	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of members in household whose primary work in livestock	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Family size	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Head's main occupation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	8.162***	4.056***	2.766*	1.307	9.802***	6.116***	10.845***	7.842***
	(1.02)	(0.93)	(1.61)	(1.77)	(0.52)	(0.50)	(0.95)	(1.08)
N	844	844	737	737	1647	1647	1338	1338
R-sq	0.77	0.83	0.57	0.58	0.6	0.71	0.51	0.54

Note: Dependent variables are in logarithmic scale and all costs are at constant price (Base year: 2012)

In the current context, we have established the evolving nature of the inverse farm size and productivity relationship at the household level, noting its gradual weakening over time and eventual insignificance in the third wave. To add further nuance, we extended our analysis to the plot level, employing equation (4) to explore the dynamics between productivity and plot size. The fixed-effect models presented in Table 8 depict a negative and statistically significant coefficient for log plot area in models without inputs during Wave-I, suggesting an initial inverse relationship between plot size and productivity. However, this significance diminishes upon the inclusion of control variables such as labour hours per acre and input costs per acre.

In Wave-III, although there is an inverse relationship in models without labour and input costs, it is not statistically significant. However, the sign of the relationship does not change when control variables are incorporated, indicating that intra-household factors do not account for variations at the plot level in wave-III. The shift in the relationship between Wave-I and Wave-III, as revealed by the fixed-effect models in Table 8, signifies a notable transformation in the dynamics of the farm size-productivity relationship at the plot level over time. The attenuation during Wave-I implies that the initially observed negative association is mitigated when considering intra-household managerial factors and mode of production. Nevertheless, by Wave-III, this significance diminishes even in the absence of inputs, suggesting a further weakening of the observed relationship.

Table 8: Dynamic Farm Size Productivity Relation at plot level

	Wave-I				Wave-III			
Dependent Variable (in logs)	Output Value Model		Profit Model		Output Value Model		Profit Model	
	Without inputs	With Inputs	Without inputs	With Inputs	Without inputs	With Inputs	Without inputs	With Inputs
Log Plot Area (acre)	-0.171***	0.029	-0.259***	-0.091	-0.103	-0.13	0.305	0.244
	(0.05)	(0.04)	(0.08)	(0.08)	(0.17)	(0.13)	(0.30)	(0.29)
Log Operational area (acre)	0.014	0.059***	-0.003	0.021	-0.118***	0.01	-0.104**	-0.005
	(0.02)	(0.01)	(0.03)	(0.03)	(0.02)	(0.02)	(0.04)	(0.04)
Log Labour (hours/acre)		0.827***		0.756***		0.559***		0.376***
		(0.02)		(0.04)		(0.02)		(0.05)
Log Input cost (Rs. /acre)		0.061***		-0.026		0.287***		0.280***
		(0.01)		(0.02)		(0.02)		(0.04)
Season	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Irrigation status	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil type	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Head's gender	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Age of head (Years)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Years of head education	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of members in household whose primary work in farming	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of members in household whose primary work in livestock	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Family size	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Head's main occupation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	7.692***	2.617***	6.373***	1.964**	10.034***	4.708***	9.254***	4.849***
	(1.07)	(0.88)	(0.99)	(0.97)	(0.51)	(0.41)	(0.85)	(0.85)
N	5581	5577	4484	4480	3913	3911	2987	2985
R-sq	0.71	0.81	0.60	0.64	0.55	0.73	0.50	0.55

Note: Dependent variables are in logarithmic scale and all costs are at constant price (Base year: 2012)

It is intriguing to explore the relationship between labour and input intensity and plot size while accounting for household fixed effects by controlling for farm size. However, several factors could contribute to changes in this relationship, such as shifts in agricultural practices, technological advancements, alterations in socio-economic conditions, and variations in labour and input intensity across different plot sizes. The absence of a significant relationship in Wave-III, even without controlling for inputs, suggests evolving intra-household managerial practices or other unobserved factors affecting farm productivity. Table 9 reveals that, during Wave-I, farmers engaged in more labour and input-intensive cultivation on smaller plots compared to larger ones, with this intensity being greater among smaller farmers than larger ones. Thus, during Wave-I, variations in cultivation and managerial practices explained the inverse relationship at the plot level; however, this relationship diminished over time, resulting in the disappearance of the inverse relationship.

Table 9: Labour and input intensity at plot level

	Labour(hours/acre)		Input (INR/acre)	
Dependent Variable (in logs)	Wave-I	Wave-III	Wave-I	Wave-III
Log Plot Area (acre)	-0.209***	-0.054	-0.180***	0.184
	(0.04)	(0.14)	(0.07)	(0.17)
Log Operational area (acre)	-0.032***	-0.075***	-0.194***	-0.081***
	(0.01)	(0.02)	(0.02)	(0.02)
Season	Yes	Yes	Yes	Yes
Irrigation status	Yes	Yes	Yes	Yes
Soil type	Yes	Yes	Yes	Yes
Head's gender	Yes	Yes	Yes	Yes
Age of head (Years)	Yes	Yes	Yes	Yes
Years of head education	Yes	Yes	Yes	Yes
Number of members in household whose primary work in farming	Yes	Yes	Yes	Yes
Number of members in household whose primary work in livestock	Yes	Yes	Yes	Yes
Family size	Yes	Yes	Yes	Yes
Head's main occupation	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Constant	4.148***	5.117***	5.027***	6.993***
	(0.80)	(0.43)	(1.39)	(0.52)
N	5872	4056	5865	4053
R-sq	0.74	0.61	0.74	0.69

Note: Dependent variables are in logarithmic scale and all costs are at constant price (Base year: 2012)

6. DISCUSSION

The farm size-productivity question holds paramount academic and policy significance for various compelling reasons. In light of the fact that nearly 90% of the world's agricultural land, including that in India, is operated by smallholders and family farms, the inquiry becomes pivotal for the livelihoods of the predominant smallholder and family farm sectors (Wiggins, Kirsten, and Llambí 2010; Lowder, Skoet, and Raney 2016). This is particularly crucial as the total operated area is decreasing, and the average size of land holdings has dwindled to as small as one hectare (2.47 acres) according to the Agricultural Census 2015-16. The viability of smallholder farming, which constitutes a significant portion of agricultural activity, becomes a disconcerting concern.

Furthermore, recognizing the importance of smallholder agriculture in poverty reduction and economic development, especially in countries like India and China where three-fourths of smallholders are concentrated (Lipton 2009), is pivotal. A deeper understanding of the productivity advantages of smallholders could provide valuable insights into agricultural development pathways (Loayza and Raddatz 2010) and the role of agriculture in overall economic development. This context gains additional significance when considering issues such as farmers' suicides and widespread agrarian distress, which are intricately linked to the decline in farm sizes (Government of India 2007; Mishra and Reddy 2011).

The implications of understanding the relationship between farm size and productivity extend to land reforms policies, particularly in assessing the optimality of the scale of agricultural production for profitability and sustainable agriculture. The resurgence of interest in the farm-size productivity relationship informs policies like land consolidation in China and the emergence of large farms (mega-farms) in land-abundant countries such as Brazil.

Addressing issues related to the displacement of millions of farmworkers and creating avenues for gainful employment becomes crucial in any attempt to collectivize farms or establish institutions that increase scale.

Moreover, variations in farm size distribution and productivity implications across countries highlight the need for policies aimed at rectifying resource misallocation. Lastly, productivity differentials across farm sizes concerning cropping systems and agroecological zones underscore the importance of assessing the scale neutrality of agricultural productivity-enhancing mechanisms. In sum, unravelling the intricate dynamics of the farm size-productivity relationship has far-reaching implications for shaping effective and equitable agricultural policies that address the diverse challenges faced by smallholders and family farms globally.

7. **CONCLUSIONS**

In summary, our research offers pivotal insights into the relationship between farm size and productivity spanning the years 1975 to 2014. Contrary to expectations and despite notable structural and technological shifts, returns on total cost have consistently fallen below 1 throughout most of this period. A pronounced uptick in the variability of this ratio was evident in wave-III, pointing to heightened uncertainty. The agricultural sector has experienced a marked shift towards capital-intensive production methods, underscored by a significant escalation in cultivation costs. Initially, small and marginal farmers predominantly adopted labour-intensive cultivation practices; however, this pattern has gradually diminished over time. Concurrently, larger farms have increasingly turned to non-labour inputs, particularly evident in wave-III, indicating a pivotal shift in production paradigms. Moreover, the prevalence of mono cropping has intensified, resulting in a notable reduction in crop diversity, a trend most pronounced among larger farming entities.

Our theoretical framework initially identifies an inverse relationship between farm size and productivity during waves I and II, which transitions to independence in wave-III, albeit with a weakening trend over time.

Further analysis emphasizes the multifaceted factors influencing this relationship. While labour and input intensities serve as initial contributors to the inverse relationship, they do not provide a comprehensive explanation. A deeper examination reveals a temporal shift in production strategies, marked by an increasing dependence on non-labour inputs. Intriguingly, larger farms exhibit a decrease in crop diversity, whereas smaller farms persistently still adopting labour-intensive approaches. This dynamic underscore the pivotal role of crop diversity and production techniques in shaping the interplay between farm size and productivity.

Additionally, our comparative analysis spanning two distinct periods, labeled Generation-I (1975-1979) and Generation-II (2009-2014), confirms the consistent nature of the observed relationships, bolstering the validity of our findings.

Significantly, our results spotlight the waning influence of both plot size and farm size (operational area) on productivity in wave-III, particularly when accounting for household-specific attributes. This trend hints at broader technological advancements and favourable market dynamics for large holders. Yet, even with controls for supervision and crop diversity, the intricate dynamics of the farm size-productivity nexus remain incompletely understood.

Lastly, an intra-household examination at the plot level uncovers further complexities. Initially, smaller plots exhibited higher labour and input intensity, a trend that attenuated over time. By wave-III, the correlation between plot size and productivity lost statistical significance, suggesting evolving managerial strategies or underlying unobserved variables.

The study underscores the need for further exploration into the impacts of rising wage rates on large-scale mechanized farms and the nuanced nature of factor-bias in technical change. Despite smallholders being indistinguishable from large farms in terms of crop economics at the per-acre level, the relatively higher intensity of family labour for smallholders poses concerns for sustainability. Despite improvement of productivity over time, return to total cost are still low even after technological advancements. After introduction to Bt cotton and other advance technology, profit level has increased but variability in returns over time also has increased that is concerning for sustainability aspect. The econometric evidence aside, the low absolute levels of smallholders continue to be concern (see Table A.3 in Appendix). Whenever there were poor monsoon years for the farmers, the profits from cultivation were depressed across farm groups but the small and marginal groups faced most precarity. It is in this context, that imperfections in crop and weather insurance markets deserves serious attention. Particularly in India's SAT, low productivity and high risk has serious welfare implications, and there is a need to strengthen insurance markets for the same (Gaurav and Mishra 2015).

Policy implications emanate from our findings, especially in the context of current agricultural development strategies and efforts to address the agrarian crisis. If smallholders are losing their productivity advantage over large farms, policy emphasis may shift towards collectivizing farms and operating at larger scales. The study contributes to ongoing debates on unfinished land reforms and production modes at scale, informing discussions on group farming or Farmer Producer Organizations (FPOs) for raising aggregate productivity.

However, it is crucial to note that the weakening of the inverse relationship over time and the rejection of the Inverse Relationship (IR) in agriculture in wave-III do not imply the converse – that large farmers are inherently more productive. This complexity underscores the interconnectedness between agriculture productivity and structural transformation, informing policies on the role of agriculture in broader development agendas.

Despite the valuable insights gained, the study acknowledges limitations, including measurement issues in yield and endogeneity in farm size. These limitations prompt avenues for further research and refinement in measurement methodologies within the emerging literature.

In conclusion, our rigorous analysis of the farm size-productivity relationship in India, covering the period from 1975 to 2014, offers insights that transcend traditional perspectives. Our study elucidates the complex interplay between farm size and productivity, highlighting the diverse factors that influence this dynamic over time. Despite marked structural and technological changes, the expected increase in returns on total cost has remained largely unattained, with the profit-to-total cost ratio consistently falling below 1 throughout the study duration. Notably, the amplified variability observed in this ratio during wave-III underscores a heightened period of uncertainty, warranting further scrutiny of these evolving patterns.

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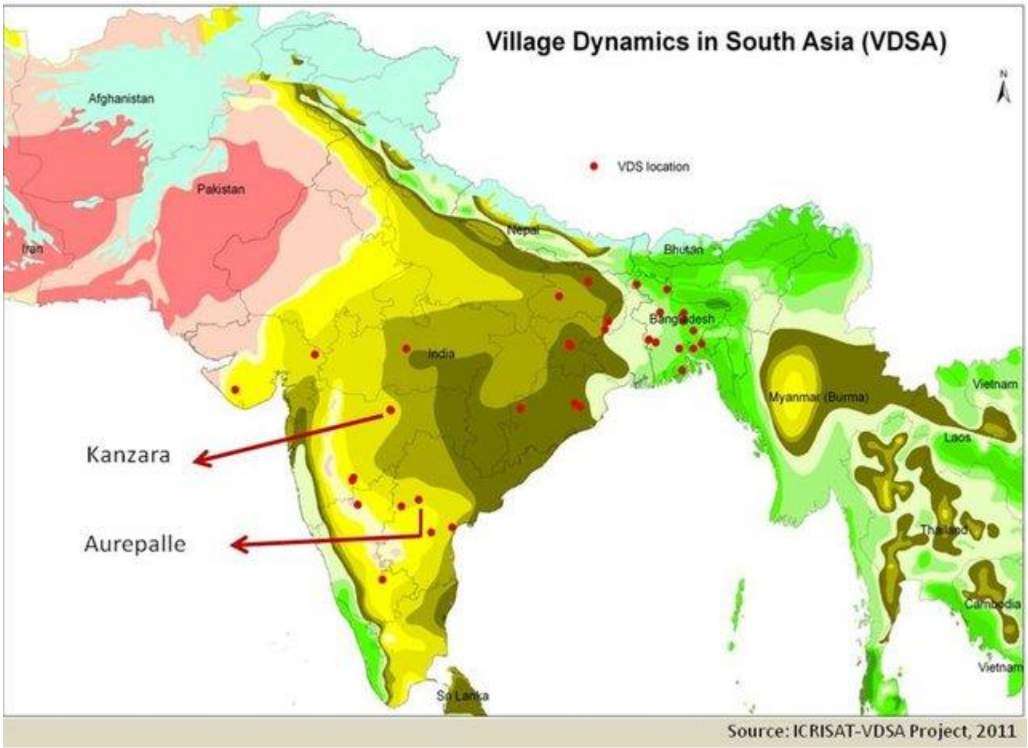
Appendix

A.1 Study villages by ICRISAT from SAT India



A.2 Study villages and their location

Country	State	District	Village
India	Andhra Pradesh	Mahbubnagar	**Aurepalle**, **Dokur**
	Maharashtra	Akola	**Kanzara**, **Kinkhed**
		Solapur	**Kalman**, **Shirapur**

A.3 Average annual profit by farm group (Household level)

Group	Wave-I	Wave-II	Wave-III
Labour	11293.9	20894.2	18298.1
Small	11737.1	21879.7	37813.7
Medium	20633.7	47271.0	84476.9
Large	62364.3	80416.2	127942.8

A.4 Dynamic Farm Size Productivity Relation with controls for supervision and crop diversity at the household level

	Wave-I (1975-1984)				Wave-II (2001-2008)				Wave-III (2009-2014)			
Dependent Variable (in logs)	Output Value Model		Profit Model		Output Value Model		Profit Model		Output Value Model		Profit Model	
	Without inputs	With Inputs	Without inputs	With Inputs	Without inputs	With Inputs	Without inputs	With Inputs	Without inputs	With Inputs	Without inputs	With Inputs
Log Operational area (acre)	-0.289***	-0.096**	-0.287***	-0.158*	-0.144***	-0.05	-0.280***	-0.205**	-0.02	-0.03	0.08	0.11
	(0.05)	(0.04)	(0.09)	(0.09)	(0.05)	(0.04)	(0.09)	(0.08)	(0.08)	(0.07)	(0.16)	(0.16)
Log Labour (hours/acre)		0.674***		0.636***		0.741***		0.647***		0.813***		0.829***
		(0.04)		(0.09)		(0.03)		(0.07)		(0.04)		(0.10)
Log Input cost (Rs. /acre)		0.077***		-0.106**		0.166***		0.130***		-0.089***		-0.225***
		(0.02)		(0.04)		(0.02)		(0.04)		(0.03)		(0.07)
Number of crops (per acre)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of plots	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Head's gender	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Age of head (Years)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Years of head education	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of members in household whose primary work in farming	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of members in household whose primary work in livestock	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Family size	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Head's main occupation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	7.505***	3.948***	4.855***	2.145*	9.797***	4.254***	9.583***	4.833***	9.608***	6.165***	10.548***	7.841***
	(0.85)	(0.76)	(1.03)	(1.10)	(0.41)	(0.36)	(0.66)	(0.70)	(0.53)	(0.50)	(0.96)	(1.08)
N	1344	1344	1196	1196	2642	2641	2163	2162	1647	1647	1338	1338
R-sq	0.74	0.8	0.52	0.55	0.63	0.76	0.52	0.58	0.6	0.71	0.51	0.54

Note: Dependent variables are in logarithmic scale and all costs are at constant price (Base year: 2012)