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Abstract

There are several reasons for farmer depression leading sometimes to the extreme measure of committing suicide. Globalization, commercialization, modernisation, erratic climatic conditions, individual expectations, contagion and government policies are some of the reasons attributed to farmer's suicides. This study examines linkages between weather shock induced changes in agricultural productivity and farmer's suicides in India using fixed effects panel data model with 25 Indian states and 14 years (1996-2009). Estimates from single equation model show no direct effect of weather shocks on farmer suicides while a two-equation specification – one for count of farmer suicides with endogenous agricultural variable and an agricultural equation with weather shocks – yields useful insights. The results from first stage estimation as expected suggest that (low) rainfall shock and high temperature shock adversely affect crop yield per hectare, while regions with higher share of irrigated area are able to counter to some extent the adverse effects of weather shocks. The negative binomial regression model for farmer suicide includes predicted yield along with one-period lag of farmer suicides and state's suicide rates to capture the contagion effect. The results show that contagion effects are strong on farmer's suicides while predicted crop yield has negative and significant influence indicating that farmer suicides are indirectly associated with weather shocks via the changes in agricultural productivity.

Key words: *Farmer Suicide; Weather Shocks; Agricultural Productivity; Contagion Effect;*

JEL Codes: *Q540, O130, D190, O100*

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INTRODUCTION

The act of taking one's own life is the most extreme outcome of a miserable state of helplessness and despair. People experiencing suicidal thoughts and feelings suffer with tremendous emotional pain. According to the World Health Organization, nearly 8 lakh people commit suicide every year. Moreover, for every suicide committed, there are far more instances of attempted suicide. It is a phenomenon that has gripped several developing as well as developed countries and is a serious public health problem for policymakers worldwide. Factors leading to suicide are often complex and cannot be restricted to mental illness alone and can also include a host of other stressors such as substance abuse, relationship problems and financial struggles. According to the public health journal *Lancet*, suicide is the second leading cause of death among young adults in India, after road-accidents for men and maternity-related causes for women (Patel *et. al.*, 2012).

While the idea of farming may paint a picturesque image of a quaint lifestyle, the reality is far grimmer. Incidence of suicides among farmers in India has reached epidemic proportions over the last two decades and was brought to light by a vigilant press from the mid-1990s. Over the period of 1995-2014 alone, nearly 3 lakh farmers committed suicides. The reasons for these suicides have been and continue to be a subject of grave concern and intensive investigation. Research suggests that worldwide, farming is an occupation with a higher risk for suicide than other occupations for reasons like job demands, work-associated stress, and a work-home imbalance (Agerbo, 2007; Milner *et. al.*, 2013). Economic stressors appear in every step of farming – from the sowing to the harvest and culminating with fluctuating crop prices due to global market forces, and take a toll on farmers (Kennedy and King, 2014; Deshpande, 2002).

Specifically in Indian context, the role of biotechnology and crop specific farming as in Bt cotton and a higher suicide rate among those farmers has also been examined (Gruère and Sengupta, 2011; Thomas and De Tavernier, 2017; Kannuri and Jadhav, 2018). Moreover, uncertainties like weather, over which farmers have no control, directly influence farmers' livelihoods and one could suspect that higher suicide rates among Indian farmers are influenced, among other things, by the weather variability. Carleton (2017) shows a link between the annual state-wise suicide rates and cumulative exposure to temperature and rainfall and asserts that this linkage is established via an agricultural mechanism. Thus, a combination of factors like mental health, socioeconomic, psychosocial and technological are being attributed for making the life of the Indian farmer more perilous, and leading them to a desperate situation of taking their own lives.

This study explores the relationship between farmer suicides and agricultural performance in the presence of temperature and rainfall shocks across 25 states for the period 1996 to 2009. While the present study examines issues similar to those analyzed by Carleton (2017) it specifically attempts to establish agricultural channel through which the temperature and rainfall shocks affect farmer's suicides. In contrast to Carleton's focus on total suicides, the present study uses farmer's suicides as the main variable of interest. The study further differs from Carleton (2017) in terms of variables used and the empirical strategy followed.

The rest of the paper is structured as follows: The next section reviews relevant literature on the farmer distress worldwide, the situation particular to India and discusses studies linking climate change and mental health. The subsequent section describes the data used for the analysis. The paper then presents the observed trends and regional patterns in total and farmer suicides in India and discusses the empirical strategy followed and presents the econometric results. The final section provides concluding observations.

Farm Distress and Farmer Suicides

The occupation of farming has always been stressful since many of the factors affecting agricultural production are largely beyond the control of the producers. As a result, the economic as well as emotional well-being of farmers and their families is generally very closely tied to volatilities affecting agricultural productivity.

Global Evidence

The 1980s saw a devastating farm crisis in the United States of America also believed to be the worst agricultural economic crisis after the Great Depression, when markets crashed, interest rates doubled overnight, accompanied by erratic weather conditions and a terrible outbreak of depression and suicides (The Guardian, 2018). Mental health services and hotlines were installed in most major agricultural states. While the exact rate of farm suicides at present is unclear since the widely cited study of 2016, published by the Centre for Disease Control and Prevention of the U.S. Dept. of Health and Human Services was later retracted by the organization on grounds of calculation errors, many hold the belief that the current precarious condition of the US farm economy, extremely high farmer stress and declining farming income situation is a continuation of the earlier crisis and draw parallels between the present scenario and the crisis of the 1980s (Reuters, 2019).

The farming community in the UK is also in a dire situation as bad weather and the uncertainty over Brexit looms large (The Guardian, 2019). According to the Office for National Statistics, depression levels in the farmer community are on the rise and farmer suicide rates are among the highest in any occupational group (Windsor-Shellard and Gunnel, 2019). Given that British farmers majorly rely on income from exports, farmers continue to be placed on "suicide watch" amidst an atmosphere of Brexit uncertainty and food price instability.

In drought-ravaged Australia, the rate of farmer suicides in 2017 was at an all-time high in a decade after having received little rainfall in the past 7 years. Research on the factors leading towards higher rural suicide rates shows that factors such as the prevalence of mental illness do not explain discrepancies in rural suicide rates compared to urban suicide rates, because rates of mental illness have not been found to be higher in rural areas (Perceval *et. al.*, 2018; Judd et al, 2006). Instead, collective and contextual (or local) factors, such as decline in socioeconomic conditions in some rural areas, community attitudes towards mental illness and help-seeking, availability of firearms, and rural culture were found to be important as potential contributors to suicide.

Indian Context

Substantial research has been conducted to investigate farmer suicides in the Indian context. The report of the Expert Group on Agricultural Indebtedness (GoI, 2007) noted that Indian agriculture was going through a period of severe crisis, with the large number of farmer suicides across the country being one grave manifestation of such crisis.

Posani (2009) explains farmer suicides as a result of the policy shift of the 1990s and subsequent marked marginalization of farmers' interests in national policy-making discussions. Moreover, in contrast to the expected structural transformation of the economy, the sectoral distribution of GDP in India has seen a declining share of agriculture. On the other hand, the associated labour force shift has not been proportional. For instance, in 2004-05, the share of agriculture in GDP was 20.2 percent, while the workforce employed in agriculture was still 56.5 percent. This structural inconsistency points to a large and growing difference in inter-sectoral relative productivities. Further, this high burden of labour force has been falling on a slowly contracting cultivable land area. Assadi (1998) explains this as the reason for a sharp decline in the average size of the holding, leading to increasing number of small and marginal farmers and difficulties they face such as insecurity of lease, increasing costs and inadequate returns from production, and difficulties in accessing credit.

Difficulty in accessing credit as well as desperate indebtedness was indeed found to be the common theme that ran through most of the reported suicides. Sadanandan (2014) argues that the increase in suicides among Indian farmers was an unanticipated consequence of the bank reforms that India undertook since the early-1990s. In particular, the entry of foreign and new generation private banks made banking in India competitive thus causing banks to view lending to the farm sector as unprofitable and unreliable. The period of financial liberalisation after 1991 is said to be a period of reversal of social and development banking with large-scale closure of commercial bank branches in rural areas and a diversion of agricultural credit away from small and marginal farmers (Ramakumar and Chavan, 2014). The resulting shrinkage in institutional credit forced farmers to borrow from informal moneylenders at exorbitant interest rates, strengthening the hold of moneylenders on rural credit and increasing farm indebtedness. Their incapability to repay this heavier debt burden could have worsened the mental health of the farmers, leading many of them to commit suicide.

This scenario was also accompanied by the fact that the neo-liberal reforms of the 1990s meant that international markets were thrown open and the Indian farmer was forced to compete in a global market. Mishra (2006) notes that during the period of 1998 to 2003, cotton export prices for the US were lower than their cost of production by more than 50 per cent on an average. With such falling international prices, the Indian farmer got much lesser return on his produce with no mechanism in place to guard him from the price volatility.

Farmers shifting to cash crop cultivation and the expensive HYV seeds were not able to recover these costs in the event of such price shocks or even crop failure. Moreover, the seeds were also usually bought from the same informal moneylender, keeping the farmer in a tight stranglehold, tied to misery. Heavy fertilizer use in such crop cultivation rendered their land less fertile, making it difficult for farmers to change their cropping patterns flexibly. Swaminathan (The Economist,

2007) explains such a course of events where "… farmers borrowed money at punitive rates, so they could sink wells and buy costly "biotech" cotton-seeds. But diesel for the pumps leapt in price, and the seeds proved ill-suited to small plots, fed mostly by rain." He remarks, "If the crops fail, a man loses hope…", thus stating that these suicides, particularly in Maharashtra, are caused mainly by home-grown factors.

Vaidyanathan (2006) observes that, indebtedness, low levels of public investment and import liberalisation are not the main causes of the agrarian crisis. He further argues that people are driven to the extreme step of suicide not merely because of irresponsible large borrowings from high cost sources but also because the increase in net incomes from loans used for productive purposes fell far below expectations. Suicide-stricken households borrow heavily for digging or deepening wells and for cultivating input-intensive high-value crops in the expectations of high yield and good prices. Thus, it is the diminishing agricultural yields and resulting diminishing incomes, which were otherwise expected to more than compensate for the high input costs and loan repayment that can drive farmers towards suicidal tendency.

The Economic Survey of India (GoI, 2018) highlights that the level of volatility of agricultural growth in India continues to be high mainly because agriculture in India even today continues to be vulnerable to the vagaries of the weather, with significant proportion of the net sown area in the country still being un-irrigated and rain-fed. Such climate volatility not only threatens agricultural productivity but also adds on to farmer distress and is likely to have far-reaching effects.

Parida *et. al.* (2018) study the effect of extreme weather events, mainly drought and flood, on farmer suicides in 17 Indian states and show that drought has significantly raised the incidence of farmer suicides across Indian states although flood has almost no direct impact on the occurrence of farmer suicides. They observe that the states of Karnataka, Maharashtra, Kerala, Andhra Pradesh and Madhya Pradesh which have seen the highest incidence of farmer suicides also feature among the states with the highest percentage of drought prone area.

Carleton (2017) establishes a link between the annual state-wise overall suicide rates and cumulative exposure to temperature and rainfall and finds that warming over the last 30 years is responsible for 59,300 suicides in India, accounting for 6.8 percent of the total upward trend. This inference is based on the estimation that for days above 20°C, a 1 °C increase in a single day's temperature during the growing season causes nearly 70 additional deaths, on average across India. In contrast, temperatures in the non-growing season are found to have no identifiable impact on suicide rates. This differential response of suicide rates to temperature in the growing and non-growing seasons is considered to indicate an agricultural channel through which effects of climatic shifts on suicides materialize, wherein heat damages crops and puts economic pressure on farming households. Additionally, the response of crop yields to variations in the climate is measured and yields are found to mirror suicides in their response to temperature, i.e. falling with rising growing season temperatures but reacting minimally to non-growing season heat, and hence the study asserts that the impact of climate change on suicide rates takes place via an agricultural mechanism.

Several concerns have been raised over the widely publicised study by Carleton (2017). The study uses state-level suicide data, which includes data for urban and rural areas combined, for each state. Plewis (2018) finds it very less plausible to suppose that there will be a causal link for non-farmers and leaves the choice of the overall suicide rate as the response variable in the modelling in Carleton (2017) open to question. Similarly, Murari *et. al.* (2018) enquire whether the rate of urban suicides can be related to climatic factors. They also flag consistency issues for suicide data before 1995. Further, given that Carleton (2017) uses six crops pooled to measure crop yield, they also disagree with the temperature threshold defined at 20°C as it does not consider crop-specific effects of temperature on yield and refute claims of a temperature-related agricultural explanation for farmer suicides. Das (2018) highlights that a link between high temperature and mortality has been established in the literature and is also observed in India. Therefore, while high temperature leading to high suicides as found in Carleton (2017) is considered plausible, the causality working through an agricultural channel is considered to be flawed. Das (2018) also calls the threshold of 20°C (or 15°C to 25°C) used by Carleton (2017) meaningless in the Indian context since for a tropical country like India, temperatures beyond 40–42°C are considered as heat-wave days and a temperature around 20°C is in fact pleasant weather in India and unlikely to trigger any extreme decision like suicide.

Numerous studies also explain the adverse effects of erratic climate on suicidal tendencies via a neurological channel. Around the world, seasonal fluctuations in suicide have been observed in many populations and extreme heat waves have been shown to cause a greater risk of suicide (Page *et. al.*, 2007). In fact, pre-existing mental illness alone has been shown to increase the risk of mortality during extreme heat events by 2 to 3 times (Bark, 1998; Bouchama *et. al.*, 2007). In addition to these studies linking climate and mental health, Ravi (2015) points out that in recent years, there have been a number of highly sensationalized suicide contagions across the world, which are typically very highly publicized suicide outbreaks. While suicide is caused by many factors, empirical evidence suggests that this phenomenon could also be seen as a contagion in India (Kapoor and Ravi, 2007; Ravi, 2015). Overall, it is difficult to attribute definitive reasons for suicides in general and farmer suicides in particular. This phenomenon is triggered by a slew of factors, which are specific to the community and culture, the framework of government institutions, economic conditions and lastly, the climatic conditions in which an individual finds oneself.

Empirical studies on farmer suicides in India have so far analyzed the nature of data and factors associated with it. Studies based on patterns and trends in the data have highlighted the limitations in measurement and compared farmer suicide rate with that across other demographic groups including women, occupations, states, rural/urban sectors (see Kaveri, 2017; Basu *et. al.*, 2016; Ravi, 2015; Nagaraj *et. al.*, 2014). In addition, the studies that analyze the role of agricultural distress are largely based on primary surveys (see Deshpande, 2002). More recently some studies have analyzed the role of weather and climate variables in total suicides or farmer suicides using countrywide secondary data (see Carleton, 2017; Parida *et. al.*, 2018). The present study attempts to fill gaps in the last strand of literature mentioned above.

This study in particular attempts to analyze the role of weather shocks, agricultural productivity and contagion effect on farmer suicides, using secondary data at the state-level. Thus, the attempt is to fill the gap in the literature that analyses the role of both weather shocks and agricultural productivity on farmer suicides to understand if both cause a direct impact or the weather impacts agriculture productivity which then impacts farmer suicides. While doing so we control for one technological/policy variable viz. irrigation that could ameliorate the impact of severe droughts.

Data Sources

Suicide data in India is released in reports titled Accidental Deaths and Suicides in India, published annually by the National Crime Records Bureau (NCRB), Ministry of Home Affairs, Government of India. This is data compiled from police records submitted to the NCRB from all States/Union Territories as well as Megacities and has been published in NCRB annual reports from the year 1967 onwards. While the reports of earlier years provide basic data on the number of suicides in different States in the country, they have become more detailed over the years, providing information on aspects such as the distribution of suicidal deaths by sex and age, by causes of suicide, by marital status, by educational level, by means adopted, and particularly by profession. The information on suicides by profession has been made available only since 1995.

This paper uses farmer suicides, i.e. suicides in the self-employed (farming/agriculture) category, as well as total suicides for the years 1996-2009 across 25 states of India. With respect to the selected states, rice is grown in nearly 45 percent of the net sown area in a state on average. Hence, rice yield during the kharif season is used as a proxy to represent the agricultural performance and the terms, 'yield' and 'rice yield' are used interchangeably throughout this discussion. Weather is specified as shocks based on mean temperature and rainfall during kharif season. Table 1 gives the definition of variables used in the empirical analysis along with the respective sources.

Table 1: Definitions of Variables and Data Sources

S.No.	VARIABLE	SOURCE
1.	Total farmer suicides (totalfarmersuicides)	Report on *'Accidental Deaths and Suicides in India'*, National Crime Records Bureau (NCRB)
2.	Total suicides	Report on *'Accidental Deaths and Suicides in India'*, National Crime Records Bureau (NCRB)
3.	Total Suicide Rate ($\mathrm{totalsuiciderate}$) or Suicide Mortality Rate (SMR) – defined as total number of suicides per 1,00,000 population	Report on *'Accidental Deaths and Suicides in India'*, National Crime Records Bureau (NCRB)
4.	Farmer Suicide Mortality Rate (FSMR) – calculated as total number of farmer suicides per 1,00,000 farmers	Report on *'Accidental Deaths and Suicides in India'*, National Crime Records Bureau (NCRB)
5.	Farmer Population (farmerpopulation) – calculated by interpolating/extrapolating population figures of main and marginal cultivators between 1996-2009 from census data of 2001, 2011	*'Agricultural Statistics at a Glance'*, Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Govt. of India
6.	Logarithm of Rice Yield (logyield)	Collated from agricultural statistics of various states
7.	Predicted Yield ($\widehat{\mathrm{logyield}}$)	Author's estimation of impacts of climate shocks on yield
8.	Mean Temperature	Collated from gridded data of the Indian Meteorological Department
9.	Rainfall	Collated from gridded data of the Indian Meteorological Department
10.	Net Irrigated Area	RBI Handbook of Statistics on Indian States
11.	Net Sown Area	RBI Handbook of Statistics on Indian states

(*Contd … Table 1*)

(*Contd … Table 1*)

S.No.	VARIABLE	SOURCE
12.	Temperature Shock (tempshock) – dummy variable defined as 1 when mean temperature falls in top two quintiles for a state and 0 otherwise.	Author's estimation of impact of temperature on yield
13.	Rain Shock (rainshock) – dummy variable defined as 1 when rainfall falls in bottom two quintiles for a state and 0 otherwise.	Author's estimation of impact of rainfall on yield
14.	Insufficient Irrigation (insufficient_irr) – dummy variable defined as 1 when proportion of irrigated area falls in bottom three deciles for a state and 0 otherwise.	Author's estimation of impact of proportion of irrigated area on yield

Trends and Patterns in Farmer Suicides

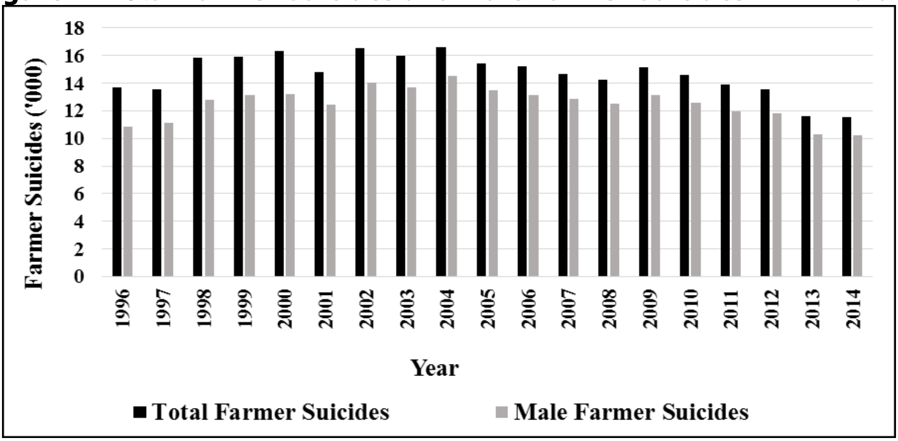
Figure 1 shows the all India pattern of the number of total and male farmer suicides between 1996 and 2014. Keeping in line with the observations made by Nagaraj *et. al.* (2014), similar trends and patterns are analysed here. During this period, about 2.13 lakh farmer suicides is reported accounting for an average of about 15 thousand per year– making every 7^{th} or 8^{th} suicide in the country every year, a farmer suicide. This figure can be expected to be an underestimation particularly because this is the count from the 25 states only. The year 1998 saw a sharp increase in farmer suicides from the previous year – a jump of about 17 percent and the number then remained nearly steady until 2002, which again saw a sharp increase of nearly 12 percent from its previous year and the peak was reached in 2004, when 16663 farmer suicides were recorded. The average number of farmer suicides per year in the four-year period from 2002-2005 was 16133 – substantially higher than the average of 15709 per year in the previous four-year period as well as the average of 14826 per year in the following four-year period.

The number of farmer suicides had declined marginally after 2004, increased again in 2009 to about 15000 and subsequently declining to about 11600 in 2014.

Gender Composition of Farmer Suicides

Farmer suicides are mainly concentrated among males with male farmer suicides accounting for nearly 84 percent of the total farmer suicides in a year (Figure 1), which means that the overall pattern of farm suicides is determined by the pattern of growth in male suicides. As Nagaraj *et. al.* (2014) explain, the overwhelming concentration of farm suicides among males could indeed be partly because of undercounting of female farm suicides in the police records on which the NCRB data are based. These records generally identify farmers by the title to land which is generally in the name of the male head of the household, hence making it very likely that suicide by female farmer may not get recorded as farmer suicide. Additionally, in an environment where the male head of a household is considered the sole breadwinner, the high proportion of male suicides is also suggested as indication that a large number of suicides are driven by economic distress.

Figure 1: Total Farmer Suicides and Male Farmer Suicides – All India



Source: National Crime Records Bureau.

Regional Patterns in Farm Suicides

There is a high degree of variation in terms of the number of farmer suicides as well as total suicides across different states in the country. Mishra (2006) observes that states like Andhra Pradesh, Goa, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Tamil Nadu, West Bengal have recorded particularly higher farmer suicides compared to other states. Similarly, Basu *et. al.* (2016) note that Kerala followed by Maharashtra, Punjab, Karnataka and Karnataka are reported to have consistently recorded high suicide mortality rate (number of suicides reported per 100,000 population). In order to explore state-level variation in farmer suicides, the 25 states are classified here into the following five geographical zones:

i. East Zone comprises of Bihar, Orissa and West Bengal;
ii. North-East Zone comprises of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura;
iii. North Zone covers Haryana, Himachal Pradesh, Jammu and Kashmir, Punjab and Uttar Pradesh;
iv. West Zone includes Goa, Gujarat, Madhya Pradesh, Maharashtra and Rajasthan; and
v. South Zone covers four states of Andhra Pradesh, Karnataka, Kerala and Tamil Nadu.

As has been observed in other studies, Figures 2 and 3 show that South and West zones of the country dominate in the number of total and farmer suicides, suggesting that the general socioeconomic conditions prevalent in a state do influence the incidence of suicide. The South and West zones combined have a significantly greater number of farmer suicides than that recorded in the rest of the country as shown in Figure 4 and make up nearly 80 percent of the total farmer suicides in the country in a given year. The all India trend of farmer suicides appears to be majorly driven by the farmer suicides in the South and West zones. According to Ravi (2015), while the overall number is high, the trend of total suicides is on the decline, with the share of farmer suicides in total suicides declining the fastest. It can be seen in Figure 5 that Suicide Mortality Rate (SMR), (number of suicides reported per 100,000 population) is increasing, while the share of farmer suicides in total suicides in the country is indeed declining over time (Figure 6). However, the share of farmer suicides is still much higher in South and West zones, than it is in rest of the country.

Therefore, the occurrence of suicides in general and farmer suicides in particular is not uniform across the country and the stark regional variations in farmer suicides should allow us to identify most severely afflicted states and investigate reasons as to what makes the problem particularly acute in those areas, in order to guide policy action.

Figure 2: Zone-wise Total Suicides

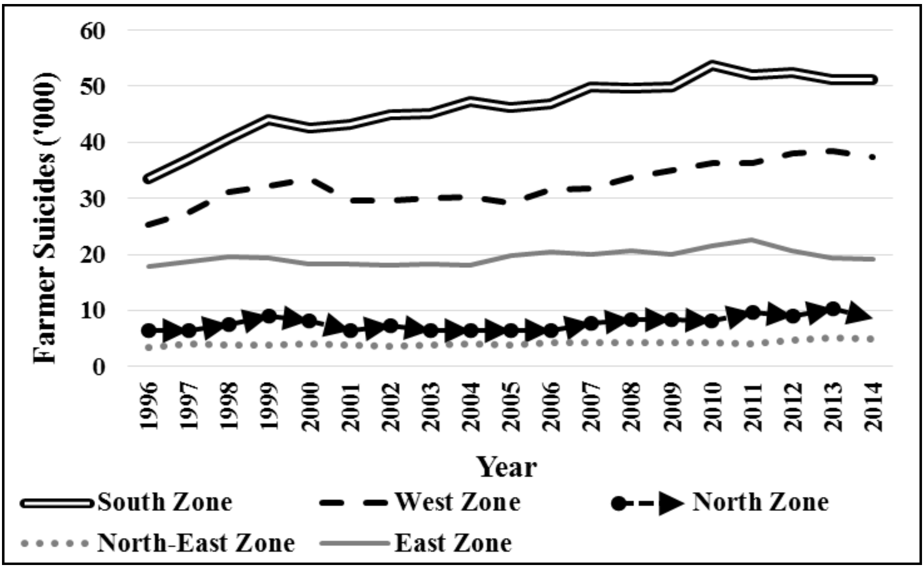


Figure 3: Zone-wise Farmer Suicides

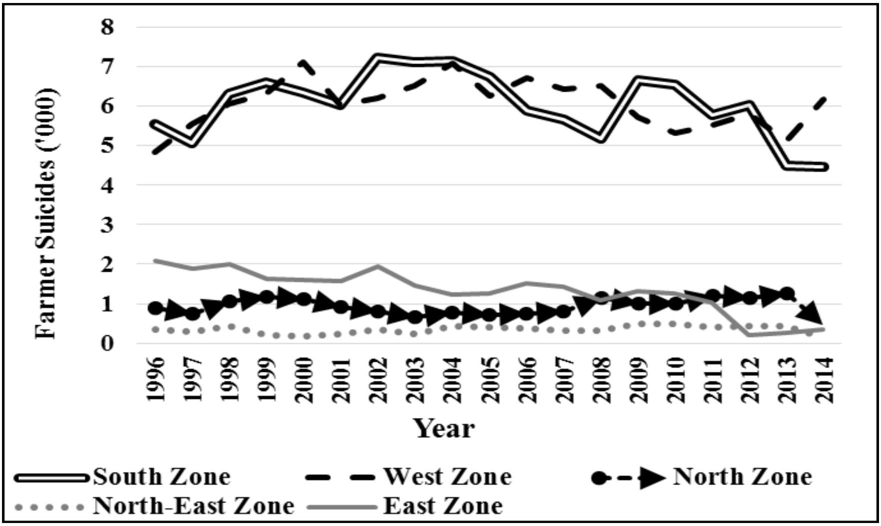
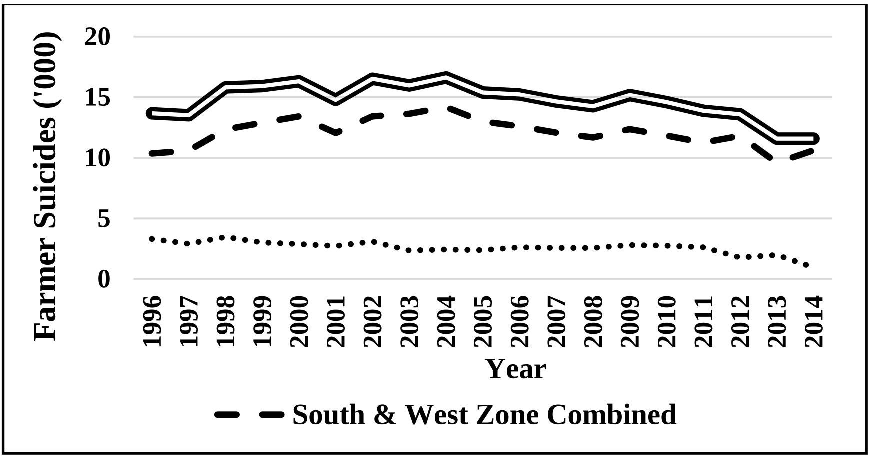
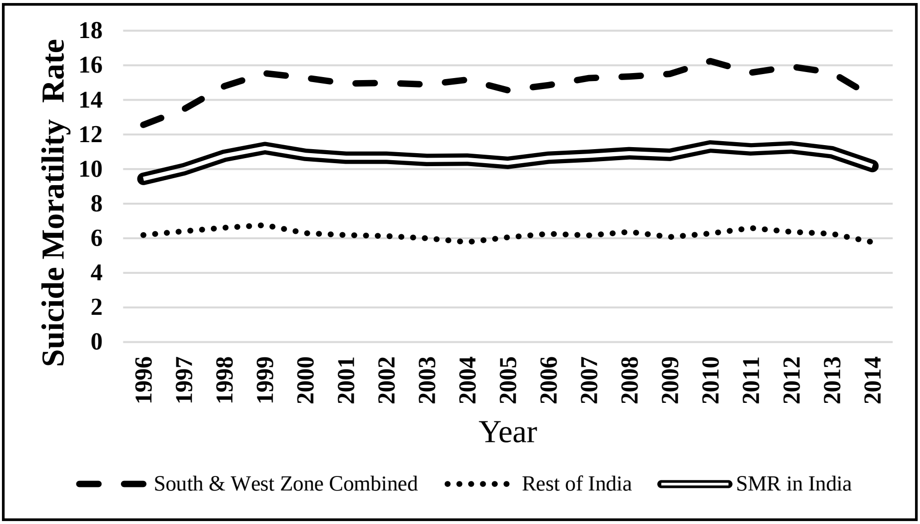


Figure 4: Farmer Suicides in South and West Zones versus Rest of India



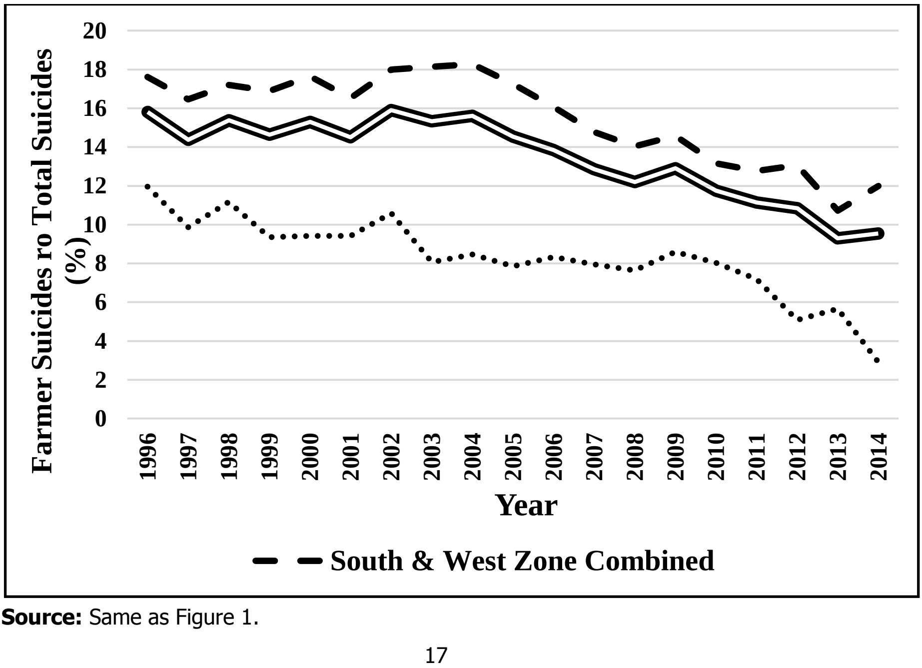
Source: Same as Figure 1.

Figure 5: Suicide Mortality Rate (1996-2014)



Source: Same as Figure 1
Note: Suicide Mortality Rate is defined as total number of suicides per 1, 00,000 population

Figure 6: Share of Farmer Suicides in Total Suicides



Source: Same as Figure 1.

Empirical Strategy and Estimates

To effectively establish agricultural channel in the relationship between farmer suicides and weather variability, a two-stage modeling specification is followed that is in line with similar approach adopted by the studies analyzing the relationship between weather variability and migration (see Feng *et. al.*, 2010; Viswanathan and Kumar, 2015). Thus, the analysis is based on two-stage least squares dummy variable model using the panel data for 25 Indian states over a period of 14 years from 1996 to 2009. Here, the first stage equation captures the effects of weather shocks and poor irrigation (modeled as an adverse shock of insufficient irrigation) on crop yield. In the second-stage of estimation, the dependent variable used is the non-negative count of number of farmer suicides. However, the dependent variable is over-dispersed, with the variance exceeding the mean, violating the assumptions of normal distribution and making the Ordinary Least Squares (OLS) estimation unsuitable. Hence, a Fixed Effects Negative Binomial regression model with direct estimation of state and time fixed effects (Allison and Waterman, 2002) is used in the second-stage to estimate the effect of predicted (climate and irrigation shock-induced) crop yield on the number of farmer suicides, while accounting for demographic factors like current farmer population and suicide rate and a one period lag of farmer suicide of the state.

Econometric Specification

More specifically, the econometric specification used for the analysis is as follows:

(1) OLS estimation using Least Squared Dummy Variable Approach:

$$\mathbf{logyield_{it}} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1}\mathbf{logyield}_{\boldsymbol{it-1}} + \boldsymbol{\beta_2}\mathbf{tempshock}_{\boldsymbol{it}} + \boldsymbol{\beta_3}\mathbf{rainshock}_{\boldsymbol{it}} + \boldsymbol{\beta_4}\mathbf{insufficient\_irr_{it}} + \boldsymbol{\varphi_{1i}} + \boldsymbol{\omega_{1t}} + \boldsymbol{\mu_{1it}}$$

(2) Negative Binomial Count Data Model with State and Time fixed effects

$$\mathbf{totalfarmersuicides_{it}} = \boldsymbol{\gamma_0} + \boldsymbol{\gamma_1}\mathbf{log\widehat{yield}}_{\boldsymbol{it}} + \boldsymbol{\gamma_2}\mathbf{totalfarmersuicides}_{\boldsymbol{it-1}} + \boldsymbol{\gamma_3}\mathbf{totalsuiciderate}_{\boldsymbol{it}} + \boldsymbol{\gamma_4}\mathbf{log\_farmerpopulation}_{\boldsymbol{it}} + \boldsymbol{\varphi}_{\mathbf{2i}} + \boldsymbol{\omega}_{\boldsymbol{2t}} + \boldsymbol{\mu}_{\mathbf{2it}}$$

The description of the variables in equations 1 and 2 is given in Table 1 above. Equation (1) is the first stage estimation for logarithm of rice yield on one year lagged (log) of rice yield, dummy variables for temperature and rainfall shocks and insufficient irrigation on yield. The lagged dependent variables would account for any time-varying omitted variable not included in the model. $\boldsymbol{\varphi}_{\mathbf{1i}}\ and\ \boldsymbol{\omega}_{\boldsymbol{1t}}$ are (time-invariant) state fixed effects and (entity-invariant) time fixed effects respectively. The state fixed affects would account for unobserved state specific characteristics that could be correlated with any of the other variables included in the model. While the time-fixed effects account for the average changes in the yield over time capturing factors that affect all the states in a similar manner for a given year and the idiosyncratic error term is $\boldsymbol{\mu}_{\mathbf{1it}}$.

Equation (2) is fixed effects negative binomial count model to estimate the effect of weather shock-led agricultural performance (yield) estimated from equation (1) on the number of farmer suicides. To account for contagion effect, previous year's number of farmer suicides for state *i*, total suicide rate of the state *i* at time *t* are included in the model. To control for the size of agricultural economy log of farmer population of state *i* at time *t* is included. $\boldsymbol{\varphi}_{\mathbf{2i}}\ and\ \boldsymbol{\omega}_{\boldsymbol{2t}}$ are (time-invariant) state fixed effects and (entity-invariant) time fixed effects respectively and $\boldsymbol{\mu}_{\mathbf{2it}}$ is idiosyncratic errors and have the same relevance as in equation 1.

Defining Weather and Irrigation Shocks

The weather shock variables are included as temperature and rainfall shocks. Based on the Economic Survey of India (GoI, 2018), these weather shocks are specified with respect to certain threshold points for temperature and rainfall below which the (log of) rice yield starts declining for a given state. Similarly, an irrigation shock is specified with respect to the point below which (log of) rice yield decline across deciles of the proportion of net sown area that is irrigated. The details are given below.

Table A.1 in Appendix reports the estimated coefficient of the regression of log of rice yield on four dummy variables for five quintiles of the temperature's distribution with the middle quintile as the reference category (referred as neutral or normal weather). The quintiles for temperature are formed separately for each state while the regression estimates are based on all the states. The estimated coefficient shows that for top two quintiles (or 4th and 5th) log of rice yield declines as the estimated coefficient is negative and statistically significant and this is illustrated further in Figure A.2 of the appendix. Thus, the dummy variable for extreme temperatures, $\boldsymbol{tempshock}_{\mathbf{it}}$ = 1 if mean rice temperature in state *i*, in year *t* falls in the top 40 percentile of its distribution, and 0 otherwise.

Similarly, Table A.2 and Figure A.2 show that for low rainfall that is, when rainfall values are in the bottom two quintiles then log of rice yield are significantly lower compared to the top three quintiles. Hence, the dummy variable for extreme rainfall, $\boldsymbol{rainshock}_{\mathbf{it}}$ = 1 if rice rainfall in state *i*, in year *t*, falls in the bottom 40 percentile of its distribution, and 0 otherwise.

Finally, for irrigation shock, log of rice yield is regressed on decile-wise dummy variable created on the basis of irrigated area share in total net sown area regression, with the fifth decile taken as the reference category . Here it is observed that log of rice yield coefficient is negative and significant for the bottom three deciles (Table A.3 and Figure A.3). That is, when the irrigated proportion of net sown area falls in bottom 30 percentile, the irrigation is insufficient and significantly decreases yield. Hence, a state *i* is defined to be insufficiently irrigated if, in any year *t*, only up to 30 percentile of its net sown area is irrigated. Accordingly, $\boldsymbol{insufficient\_irr}_{\mathbf{it}}$ = 1 when net irrigated area as proportion of net sown area lies in its bottom 30 percentile, and 0 otherwise.

The descriptive statistics of various variables are presented in Table 2. The summary statistics show that mean number of farmer suicides (611.8) is far lower than the variance (786236). This indicates over-dispersion and provides basis for using negative binomial regression model for the estimation of equation (2) above.

Table 2: Descriptive Statistics

Variable	Mean	St. Dev	Minimum	Max
CHARACTERISTICS OF SUICIDE VARIABLES				
Total farmer suicides	611.083	886.657	0	4453
Lagged farmer suicides of previous year	611.385	891.66	0	4453
Total suicide rate	10.761	8.219	.4	48.2
CHARACTERISTICS OF YIELD VARIABLES				
Log (yield)	7.484	0.4	5.652	8.3
Lagged Log (yield) of previous year	7.481	0.403	5.652	8.3
CHARACTERISTICS OF CLIMATE VARIABLES				
Temperature in the 60th percentile	27.129	1.518	22.995	29.378
Temperature shock	0.386	0.487	0	1
Rainfall in the 40th percentile	1154.753	718.634	279.62	2994
Rain shock	0.383	0.487	0	1
CHARACTERISTICS OF IRRIGATION VARIABLES				
Irrigated proportion in the 30th percentile	0.338	0.228	0.051	0.95
Insufficient Irrigation	0.277	0.448	0	1
DEMOGRAPHIC CHARACTERISTICS				
Log (farmer population)	14.957	1.783	11.062	17.464

Source: Authors' own estimates.

Empirical Estimates

Tables 3a and 3b provide the empirical estimates based on equations (1) and (2), respectively. Results reported in Table 3a show that the weather shock (be it high temperatures or low rainfall during the *kharif* season) on an average has an adverse effect on the rate of growth of rice yield. After controlling for adverse weather shocks a lower share of irrigated area has further adverse impact on the yield. In other words the impact of an adverse weather shock on relative rate of change in rice yield during growing season could be countered to some extent if more of net sown area is irrigated. A temperature shock causes a decline in yield of around 8 percent, keeping all things constant, and a rain shock decreases yield roughly by 5.5 percent, with insufficient irrigation lowering yield by nearly 6 percent. The one-period lag of yield is also statistically significant with expected sign indicating that if the previous period in a particular state has had higher yield, it continues to have a positive association with growth rate in rice yield in the current period.

In equation (2) rice yield could be potentially endogenous so that predicted yield from first stage equation (1) is used as an instrument to estimate its impact on the number of farmer suicides. Results for the negative binomial regression model for count of farmer suicides are reported in Table 3b. The predicted yield is statistically significant at 5 percent level of significance with a negative coefficient value of -0.97. This implies that for a 1 per cent decline in rice yield the farmer suicide increases by 0.4 (=exp(-0.97)) per cent. This implies that the agricultural productivity channel has an important role in decreasing the farmer suicides.

The contagion effect in the model is captured by three different variables: previous year’s number of farmer suicides, suicide mortality rate of the state and state specific fixed effects (coefficient estimates not reported here). It is observed that all these coefficients are statistically significant at 1 percent level with positive sign highlighting the contagion effect. The fixed effect coefficients have similar magnitude for the southern and western states and are higher in magnitude compared to other states of India, emphasizing the fact that in 1996 the southern and western regions of the country reported on an average higher farmer suicides compared to the remaining parts of India. After controlling for other variables, the state’s farmer population was not statistically significant.

Tables A.4 in the Appendix reports the results based on single-equation specification that assesses the direct impact of weather shocks on farmer's suicides. Table A.5 reports results based on alternative estimation approach (i.e., Poisson regression model for count of farmer suicides, or OLS model with farmer suicide rate) of the second stage in the two-equation specification. As could be seen from the reported estimates, neither specification gives satisfactory results.

Table 3a: Linear Regression Estimates for Logarithm of Rice Yield

VARIABLES	Log(Rice Yield)
Temperature shock	-0.0777***
	(0.0253)
Rainfall shock	-0.0540***
	(0.0178)
Insufficient Irrigation	-0.0617***
	(0.0221)
One Year Lagged log(rice yield)	0.2303**
	(0.1022)
Intercept	6.1324***
	(0.7918)
Number of observations	325
R-squared	0.8351
Time fixed effects	Yes
State fixed effects	Yes

Note: Standard errors are in parentheses, **** p<0.01, ** p<0.05, * p<0.1* *Temperature shock =1 if temperature >60th percentile* (base: temperature falling in 60th percentile), *Rain shock =1 if rainfall < 40th percentile* (base: rainfall greater than 40th percentile), *Insufficient Irrigation =1 if irrigated proportion < 30th percentile* (base: irrigated proportion greater than 30th percentile)

Table 3b: Negative Binomial Regression Estimates for Count of Farmer Suicides

VARIABLES	Count of farmer suicides
	Coefficients
Predicted log(yield)	-0.9669**
	(0.4014)
One Year Lag of Farmer suicide count	0.0003***
	(0.0001)
Total suicide rate	0.0381***
	(0.0129)
Log(farmer population)	-0.0230
	(0.6498)
Constant	14.2768
	(11.4874)
Observations	325
Pseudo R-squared	0.2039
Time fixed effects	Yes
State fixed effects	Yes

Note: (1) Standard errors are in parentheses, **** p<0.01, ** p<0.05, * p<0.1*;

(2) The estimated value of the over-dispersion parameter is 0.1957 and the likelihood ratio test for this parameter to be zero is 6503.87*** significant at 1 percent level of significance.

CONCLUSIONS

This study analyses the trend and pattern of farmer suicides and also in comparison with total suicides across 25 states of India for the period 1996 to 2009. The main aim of the analysis though was to demonstrate that farmer suicides are primarily linked to loss in agricultural productivity which in turn is affected by weather shocks and low penetration of irrigation networks.

Unlike some of the recent studies (Carleton, 2017), the two-step specification of the econometric model has enabled us to show that the higher farmer suicides are not directly associated with adverse weather shocks but it operates only via lowered agricultural productivity. The results of the first stage equation show that agricultural productivity (as captured using rice yield) is adversely affected by higher temperatures, lower rainfall and lower share of irrigated area. The negative binomial regression model as the second stage equation has the predicted yield from first stage as a regressor along with suicide contagion variables. Both these equations use state and time fixed effects to control for any other time-invariant and entity-invariant variables respectively. Single equation estimation did not give statistically significant estimates for weather shocks or weather variables on farmer suicides, so no direct effect of weather on farmer suicides could be established.

The insights from this study show that farmer suicides are inversely associated with agricultural productivity as captured by rice yield per hectare after controlling for contagion effect and farmer population. Furthermore, the contagion effect seems to be rather dominant at the state level and operates through three different components. First, the time invariant state fixed effects coefficients are similar in magnitude for the southern and western states indicating that to start with these states had higher number of farmer suicides compared to the northern, central and eastern states. The suicide rate and the previous year's farmer suicide numbers are the other two time varying variables that contribute to explaining the variation in state level farmer suicide numbers.

One of the shortcomings of this study is the use of rice yield as the agricultural variable, so further extension would be to identify a measure that will enable the use of commercial crops which are usually shown to be capital intensive and as a result are shown to cause large distress when there is a crop failure. Unlike other studies (see for example Viswanathan and Kumar, 2015) we find that in the agricultural equation, the weather variables were statistically significant only as discrete shocks and not as continuous variables. This could be because the earlier studies used either district level data or state-level data over a longer period of time. An extension of the present analysis could use a multi-level modelling approach with agricultural yield equation estimated using district level data and farmer suicide equation estimated with state level data . Model specification with continuous weather variables would enable hind-casting of avoidable farmer suicides if temperature and rainfall variability were lower after controlling for other covariates. With respect to the two-stage econometric modelling approach followed, bootstrapping techniques have to be used to correct for any sample selection bias and standard errors.

Alarmingly high numbers of suicides become a public health challenge. So ideally, the policy should have different strategies to address the covariate shock arising from cropping pattern, weather, infrastructure and other services (irrigation, roads, and extension services), economic factors like price volatility and credit. The idiosyncratic shocks arising from farmer specific characteristics should have a separate intervention strategy.

A primary measure of well-being of a region or community is assessed by mortality rates and extending it further a key measure of development indicator would be reduced mortality assessed across age groups as in infant or child mortality or improvement in life expectancy at birth. In this context reducing suicides as they are clearly preventable mortality, gains a lot of significance. When such deaths are associated with a particular occupation then it is also relatively easier to target that group and prevent the proximate reasons that make them take the drastic step. The state level analysis presented here shows that addressing the productivity aspect of distress could clearly reduce farmer suicide mortality. Moreover, falling agricultural productivity worsened by the occurrence of weather shocks is found to increase these suicides. However, the magnitude at which weather/climate variability is acting through an agricultural mechanism and aggravating this phenomenon must be thoroughly examined. Nevertheless, there is also an urgent need to initiate policy action to minimise the additional pressure that weather/climate variability puts on farmers, given the projections of extreme weather conditions and heat waves particularly in this part of the world.

A firming up of the findings of the contagion effect of the farmer suicides in particular and the regional aspect of suicide pattern in general, shows that geographical targeting would be relatively easy. The worrying fact is that the more developed states show proneness for such unnatural deaths. This could pose some challenges since the cause for suicides could arise from inability to meet aspirations particularly where there is a visible improvement in economic prosperity but with larger inequality. If this inequality manifests itself through the occupational structure or source of income then it has to be probed further and addressed. The more developed states also show a far lower share of agriculture in the state's domestic product compared to the poorer states while the employment share in agriculture continues to remain high. The silver lining is that such states will also have the financial, professional and technological resources to absorb the surplus labour from agriculture and to make agriculture more viable. Thus, reducing these types of mortality will in general contribute to overall well-being of the population.

Since 2009 there has been a decline in farmer suicides but as the IndiaSpend (2018) article highlights the suicides among agricultural labourers are increasing. This would require further analysis from primary survey and focus group discussions to understand if land inequality and landlessness among those associated with agriculture make them more vulnerable. Further, physical and mental health may be worse among people who are under distress when agriculture sector is not performing well. The richer states could also bring in a higher inequality in access to good health care. In these states, heath care will be available with good quality but largely in private sector which could be unaffordable or when accessed make poorer people debt ridden which would further make the poor vulnerable. One hopes that deeper penetration of Ayushman Bharat program that also covers mental health issues will facilitate access to better health care and help in reducing suicide mortality. Policymakers must continue to focus on providing crucial healthcare and counselling services to farmers and those associated with agriculture.

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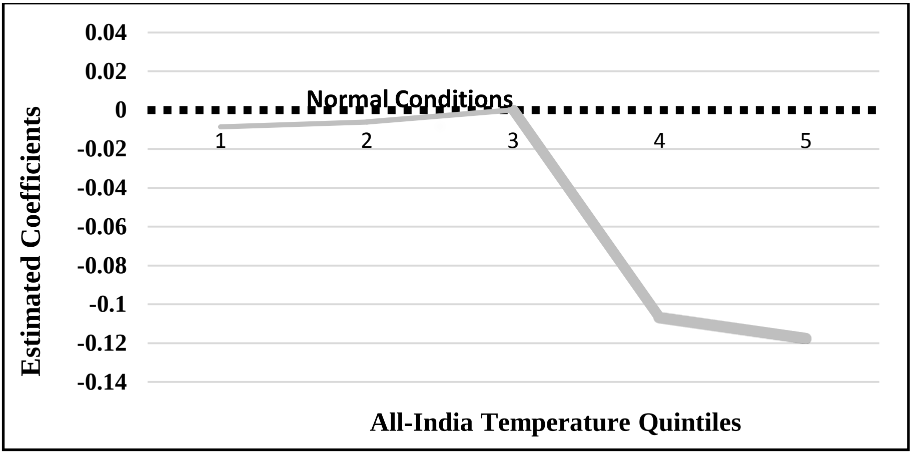
APPENDIX

Table A.1: Estimation of log of Rice Yield on Temperature Quintiles

VARIABLES	Log(yield)
Temperature Quintiles, Base: 3rd Quintile	
Quintile 1	-0.0086
	(0.0385)
Quintile 2	-0.0062
	(0.0358)
Quintile 4	-0.1070**
	(0.0415)
Quintile 5	-0.1176**
	(0.0458)
Intercept	7.7050***
	(0.0879)
Observations	350
R-squared	0.7521
Time fixed effects	Yes
State fixed effects	Yes

Note: Standard errors are in parentheses, **** p<0.01, ** p<0.05, * p<0.1*

Figure A.1: Plot of Estimated Coefficients of Rice Yield-Temperature Quintiles Regression



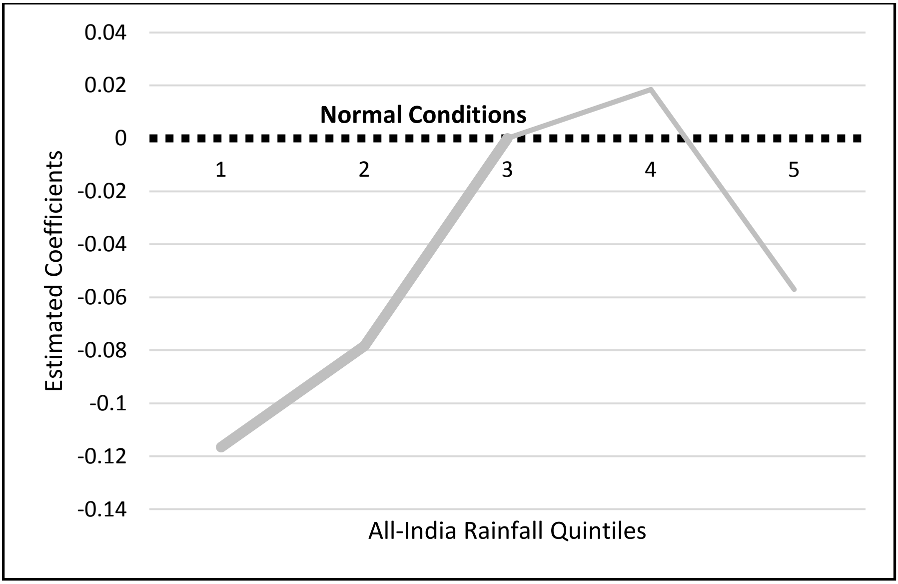
Note: (1) The estimated coefficients are close to zero for first three categories of the temperature quintiles and thereafter the magnitude declines. This indicates that rice yield is adversely affected by high temperatures that cross the threshold of an average value of 27 deg. C in the kharif season. (2) The estimated coefficient for the 4th and 5th quintile temperature categories are statistically significant as shown in Table A.1

Table A.2: Estimation of log of Rice Yield on Rainfall Quintiles

VARIABLES	Log(rice yield)
Rainfall quintiles; Base: 3rd quintile	
Quintile 1	-0.1166***
	(0.0326)
Quintile 2	-0.0783*
	(0.0415)
Quintile 4	0.0184
	(0.0271)
Quintile 5	-0.0570
	(0.0390)
Intercept	7.7216***
	(0.0829)
Observations	350
R-squared	0.7560
Time fixed effects	Yes
State fixed effects	Yes

Note: Standard errors are in parentheses, **** p<0.01, ** p<0.05, * p<0.1*

Figure A.2: Plot of Estimated Coefficients of Rice Yield-Rainfall Quintiles Regression



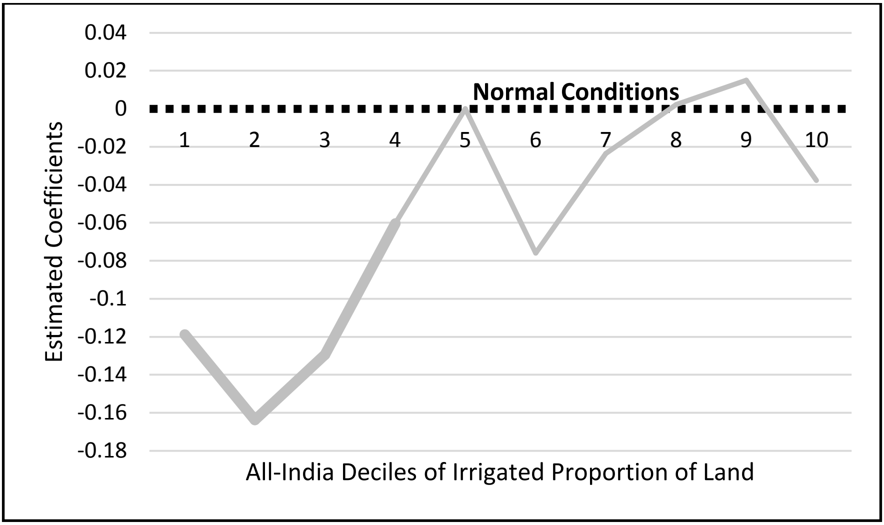
Note: The estimated coefficients are negative and statistically significant for the bottom two rainfall quintiles while it is of higher magnitude and similar values at the higher end of the quintiles. Though high rainfall as in the 5th quintile also shows a decline in rice yield but it is not statistically significant and hence not considered as a separate category in the regression analysis in equation (1).

Table A.3: Estimation of log of Rice Yield on Deciles of Share of Irrigated Area

VARIABLES	Log(rice yield)
Deciles of irrigated proportion of net sown area; Base: 5th decile	
Decile 1	-0.1188**
	(0.0601)
Decile 2	-0.1638***
	(0.0532)
Decile 3	-0.1294**
	(0.0611)
Decile 4	-0.0604
	(0.0497)
Decile 6	-0.0759
	(0.0554)
Decile 7	-0.0236
	(0.0560)
Decile 8	0.0022
	(0.0485)
Decile 9	0.0150
	(0.0601)
Decile 10	-0.0377
	(0.0589)
Intercept	7.7964***
	(0.0951)
Number of Observations	350
R-squared	0.7573
Time fixed effects	Yes
State fixed effects	Yes

Note: Standard errors are in parentheses, **** p<0.01, ** p<0.05, * p<0.1*

Figure A.3: Plot of Estimated Coefficients of Rice Yield-Deciles for Share of Irrigated Area Regression



Note: The estimated coefficients are significant and negative for the bottom three deciles of the Irrigated share of net sown area. Hence the bottom three deciles are combined into a category for the regression model in equation 1.

Table A.4: Estimates of Single Equation Specification: Negative Binomial, Poisson and OLS Models

VARIABLES	NBRM	PRM	OLS
	Count of farmer suicides	Count of farmer suicides	FSMR
Lagged farmer suicides of previous year	0.0003*** (0.0001)	0.0003*** (0.0000)	
Lagged FSMR of previous year			0.063 (0.097)
Temperature shock	-0.030 (0.072)	-0.097*** (0.008)	0.00008 (0.000)
Rain shock	0.069 (0.063)	0.022*** (0.006)	0.001 (0.001)
Insufficient Irrigation	0.278*** (0.072)	0.061*** (0.006)	0.001** (0.001)
Total suicide rate	0.037*** (0.013)	0.045*** (0.002)	0.001** (0.000)
Log(farmer population)	0.096 (0.640)	-0.079 (0.070)	0.001 (0.006)
Constant	4.531 (10.816)	7.683*** (1.171)	-0.025 (0.098)
Observations	325	325	325
Pseudo R-squared/ R-squared	0.206	0.972	0.893
Time fixed effects	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes

Note: (1) Standard errors are in parentheses, **** p<0.01, ** p<0.05, * p<0.1;* (2) NBRM: Negative Binomial Regression Model; PRM-Poisson Regression Model; OLS: Ordinary Least Square; FSMR: Farmer Suicide Mortality Rate- Number of farmer suicides per 100,000 farmers

Table A.5: Estimates of Two-Equation Specification: Poisson and OLS Models

VARIABLES	POISSON RM	OLS
	Total farmer suicides	**FSMR**
Lagged farmer suicides of previous year	0.0003*** (0.0000)	
Lagged FSMR of previous year		0.0698 (0.0989)
Total suicide rate	0.0499*** (0.0017)	0.0006** (0.0002)
Log(farmer population)	-0.1945*** (0.0710)	0.0018 (0.0057)
Predicted log(yield)	0.0002 (0.0385)	-0.0050 (0.0032)
Constant	9.5678*** (1.3037)	0.0073 (0.1018)
Observations	325	325
Pseudo R-squared/ R-squared	0.9718	0.8899
Time fixed effects	Yes	Yes
State fixed effects	Yes	Yes

Note: (1) Standard errors are in parentheses, **** p<0.01, ** p<0.05, * p<0.1*

(2) Step1 equation is the same as Equation (1) described in the earlier section on empirical strategy and Step 2 is the estimated results for Poisson Regression model for Count of Farmer Suicides and OLS Regression Model for Farmer Suicide Mortality Rate (FSMR), defined as number of farmer suicides per 100,000 farmers

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