Crop-damaging temperatures increase suicide rates in India

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More than three quarters of the world's suicides occur in developing countries, yet little is known about the drivers of suicidal behavior in poor populations. I study India, where one fifth of global suicides occur and suicide rates have doubled since 1980. Using nationally comprehensive panel data over 47 y, I demonstrate that fluctuations in climate, particularly temperature, significantly influence suicide rates. For temperatures above 20 °C, a 1 °C increase in a single day's temperature causes $\sim$70 suicides, on average. This effect occurs only during India's agricultural growing season, when heat also lowers crop yields. I find no evidence that acclimatization, rising incomes, or other unobserved drivers of adaptation are occurring. I estimate that warming over the last 30 y is responsible for 59,300 suicides in India, accounting for 6.8% of the total upward trend. These results deliver large-scale quantitative evidence linking climate and agricultural income to self-harm in a developing country.

climate | suicide | agriculture | weather impacts | India

Each year, over 130,000 lives are lost to self-harm in India (1). The causes of these deaths are poorly understood; drivers of suicidal behavior remain disputed across scientific disciplines, and nearly all evidence comes from developed country contexts (2–4). Despite lack of substantiation, public debate in India has centered around one possible cause of rapidly rising suicide rates: increasing variability of agricultural income (5, 6). Drought and heat feature prominently in these claims; climate events are argued to damage crop yields, deepening farmers' debt burdens and inducing some to commit suicide in response. With more than half of India's working population employed in agriculture, one third lying below the international poverty line, and nearly all experiencing rising temperatures due to anthropogenic climate change, these arguments appear plausible. However, the relationship between economic shocks and suicide is controversial (3, 4, 7–9), and, in India, the effect of income-damaging climate variation on suicide rates is unknown. Although the national government has recently announced a $1.3 billion climate-based crop insurance scheme motivated as suicide prevention policy (10), evidence to support such an intervention is lacking. Existing work has found that agricultural yields in India rely heavily on growing season temperature and precipitation (11, 12), but it is unclear to what extent, if any, this sensitivity to climate influences suicide rates. Previous studies of income variability affecting suicide in India are anecdotal (5) or qualitative (13–17), and none attempt to identify and synthesize quantitative relationships between climate, crops, and suicides. To fill this knowledge gap, I use a data set from India's National Crime Records Bureau (NCRB), which contains the universe of reported suicides in the country from 1967 to 2013. I pair these data with information on agricultural crop yields and high-resolution climate data to identify the effect of climatic shifts on suicide rates, and to test whether agricultural yields are a mechanism through which these effects materialize. Although my analysis is most directly applicable to India, it also contributes to building a broader understanding of the effect of climate on suicide throughout the developing world.

My empirical strategy relies on a simple thought experiment in which I observe two identical populations, alter the climate in one, and compare suicide rates in this "treatment" population to those in an unaltered "control." In the absence of such an experiment, I emulate this comparison by observing a population within India under different climate realizations over time, allowing the same population to function as both treatment and control. After accounting for secular trends, year-to-year changes in the climate are plausibly random, and amount to many ongoing approximations of my ideal experiment (18). Because this approach isolates random variation in climate, other common factors associated with both suicide and the climate are unlikely to confound the analysis. Therefore, a causal interpretation of estimated regression coefficients is reasonable, even though the climate itself was not experimentally manipulated.

I analyze the relationship between annual suicide rates, measured for each of India's 32 states and union territories, and cumulative exposure to temperature and rainfall using a regression model that accounts for time-invariant differences across states in unobservable determinants of suicide rates, such as religion or history, as well as regional time trends in suicide rates that may derive from shifting cultural norms or suicide contagion effects, among many other possible forces. Under my estimation strategy, two key empirical concerns remain. First, the functional form of the relationship between suicide rates and climate variables has minimal precedent in existing literature. I therefore use a flexible nonlinear model and show robustness of my results to alternative functional form assumptions. Second, the channels through which adverse climate conditions may affect suicide rates are not immediately discernible, yet are of central policy relevance. To this end, I distinguish between climate conditions that damage crops and those that have no

Significance

Suicide is a stark indicator of human hardship, yet the causes of these deaths remain understudied, particularly in developing countries. This analysis of India, where one fifth of the world's suicides occur, demonstrates that the climate, particularly temperature, has strong influence over a growing suicide epidemic. With 47 y of suicide records and climate data, I show that high temperatures increase suicide rates, but only during India's growing season, when heat also reduces crop yields. My results are consistent with widely cited theories of economic suicide in India. Moreover, these findings have important implications for future climate change; I estimate that warming temperature trends over the last three decades have already been responsible for over 59,000 suicides throughout India.

Author contributions: T.A.C. designed research, performed research, analyzed data, and wrote the paper.

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effect on agricultural yields. I do so by estimating differential impacts of climate during growing and nongrowing seasons, using the arrival and departure of the southwest summer monsoon to define seasonality (see *SI Appendix* for details). In additional mechanisms tests, I use spatial heterogeneity and temporal lags to assess the mediating factors between climate and suicide.

Results

I find that temperature during India's main agricultural growing season has a strong positive effect on annual suicide rates (Fig. 1 *A* and Table 1). For days above 20 °C, a 1 °C increase in a single day's temperature during the growing season increases annual suicides by 0.008 per 100,000 people, causing an additional 67 deaths, on average across India; this amounts to a 3.5% increase in the suicide rate per SD (σ) increase in temperature exposure. In contrast, temperatures in the nongrowing season have no identifiable impact on suicide rates. This finding is robust to inclusion of state-specific trends and national-level shocks to the suicide rate (Table 1), distinct methods for averaging gridded climate data across pixels within a state (*SI Appendix*, Table S5), alternative degree day cutoff values (*SI Appendix*, Table S6), controlling for irrigation (*SI Appendix*, Table S10), and alternative definitions of the growing season (*SI Appendix*, Table S11).

The differential response of suicide to temperature in the growing and nongrowing seasons is consistent with an agricultural channel in which heat damages crops, placing economic pressure on farming households, members of which may respond to such hardship with suicide. These crop losses may also permeate throughout the economy, causing both farming and nonfarming populations to face distress as food prices rise and agricultural labor demand falls. To further test this mechanism, I use district-level yield data covering 13 Indian states from 1956 to 2000 to estimate an identical regression model to that described above, now measuring the response of crop yields to variations in the climate. I find that yields mirror suicides in their response to temperature, falling with rising growing season temperatures but reacting minimally to nongrowing season heat (Fig. 1 *E* and *F*), a result identified in many other parts of the world (12, 19, 20). For growing season days above 20 °C, annual yields fall by 1.3%/σ. This finding is robust to the same specification checks listed above for suicide (*SI Appendix*, Tables S4, S5, S7, and S11). The striking similarity between the responses of suicide and yield to temperature suggests that variations in temperature affect suicide rates through their influence over agricultural output.

India's agriculture is predominately rain-fed and dependent on the timing and duration of the monsoon, making growing season rainfall critical for crop growth (21), as well as a potential driver of suicide. As expected, growing season precipitation

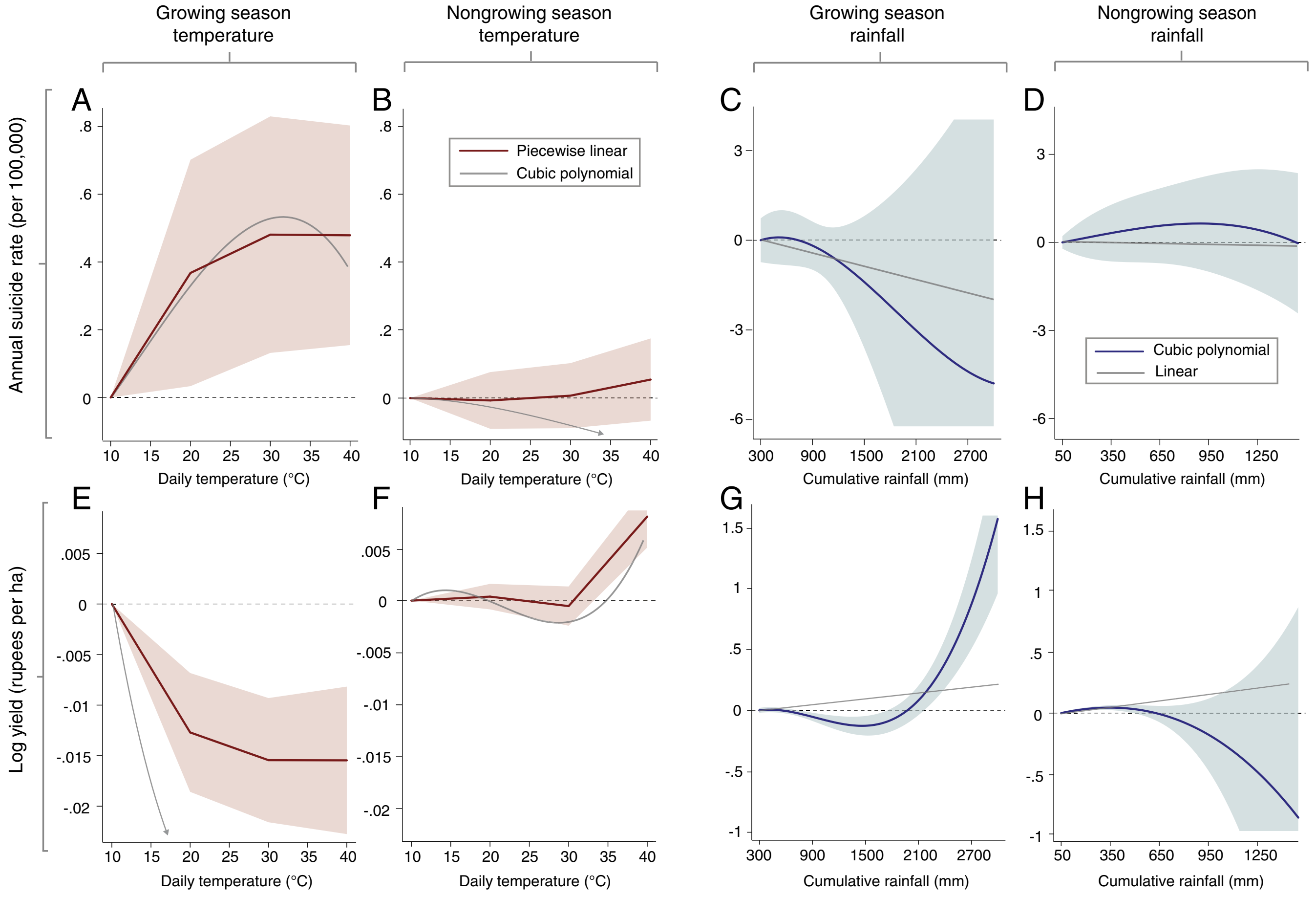

Fig. 1. Nonlinear relationships between temperature, precipitation, suicide rates, and crop yield: The response of annual suicides rates (deaths per 100,000 people) to (*A*) growing season and (*B*) nongrowing season temperatures. Response of annual suicide rates to cumulative (*C*) growing season and (*D*) nongrowing season rainfall. (*E*–*H*) Analogous relationships for log annual yield, valued in rupees per hectare. The slopes of the responses in *A*, *B*, *E*, and *F* can be interpreted as the change in the annual suicide rate or log yield caused by one day's temperature rising by 1 °C. The slopes of the responses in *C*, *D*, *G*, and *H* can be interpreted as the change in the annual suicide rate or log yield caused by one additional millimeter of rainfall. All graphs are centered at zero.

Table 1. Effect of heat exposure on suicide rates and yield values, by agricultural season

	Suicides per 100,000			100 × log yield, rupees per hectare		
Variable	State trends	Year fixed effects	State trends + year fixed effects	State trends	Year fixed effects	State trends + year fixed effects
Growing season						
Degree days below threshold, °C	0.003***	0.000	0.004***	0.013	−0.019	−0.003
	(0.001)	(0.001)	(0.001)	(0.009)	(0.018)	(0.013)
Degree days above threshold, °C	0.007***	0.009**	0.008**	−0.017***	−0.020*	−0.019*
	(0.002)	(0.004)	(0.003)	(0.006)	(0.010)	(0.010)
Nongrowing season						
Degree days below threshold, °C	−0.001	−0.009*	−0.003*	0.002	0.007	0.001
	(0.001)	(0.004)	(0.002)	(0.003)	(0.005)	(0.004)
Degree days above threshold, °C	−0.002*	0.002	0.001	0.010***	0.018***	0.010*
	(0.001)	(0.003)	(0.003)	(0.004)	(0.006)	(0.006)

Coefficients represent the effect of 1 d becoming 1 °C warmer on the annual suicide rate (suicide deaths per 100,000 people) or annual yield (log rupees per hectare), where the degree day threshold is 20 °C. All regressions include a cubic polynomial of seasonal precipitation (coefficients not shown). Suicide regressions include state fixed effects, report standard errors clustered at the state level, and are estimated with 1,434 observations. Yield regressions include district fixed effects, report standard errors clustered at the district level, and are estimated with 11,289 observations. Models with state trends include linear state-specific time trends; models with year fixed effects include annual, India-wide indicator variables. ***$P < 0.01$; **$P < 0.05$; *$P < 0.1$.

positively impacts yields, with an effect of $1.9\%/\sigma$, whereas nongrowing season rainfall (of which there is little) has no statistically distinguishable effect (Fig. 1 *G* and *H*). These yield gains again reflect the response of suicides to climate—suicide rates fall as growing season rainfall increases (Fig. 1 *C* and *D*)—although the relationship is statistically insignificant across most robustness checks (*SI Appendix*, Tables S3–S11). Despite statistical uncertainty, the yield and suicide response functions with respect to rainfall also match in the nongrowing season, where a flat relationship is estimated in both cases. Imprecision in these rainfall estimates for suicide may be due to measurement error introduced by the need to characterize monsoon rainfall at the state level, as there can be important within-state differences in monsoon arrival and withdrawal (21). The district-level agricultural data, in contrast, do not suffer from this problem. Consistent with measurement error, a less parametric estimate of rainfall's effect on suicide separately during each month of the year demonstrates that rain during all growing season months negatively influences suicide rates, but with high uncertainty (*SI Appendix*, Fig. S7). Moreover, results from an alternative empirical model measuring impacts of longer-run trends in climate demonstrate a robust and substantial negative effect of growing season rainfall on suicide rates (*SI Appendix*, Table S9). Under this approach, I find that increasing growing season rainfall by 1 cm is associated with a decrease of $\sim$0.8 deaths per 100,000, lowering the suicide rate by 7%, on average. Together, these results suggest that rainfall may mitigate suicide rates in India, plausibly through an agricultural channel.

The Agricultural Mechanism. I further examine the agricultural mechanism by including lagged effects in the regression model. If suicides are affected by climate variation through negative agricultural income shocks, there may be delayed impacts: poor harvests in one year may make subsequent conditions more unbearable, as households draw on stored crops or deplete monetary savings. In contrast, if these climate variables influence suicide prevalence purely through direct channels, such as the hypothesized neurological effects of heat exposure on aggressive behavior (22, 23), delayed effects should not materialize. A model that includes lagged climate variables reveals that past growing season temperatures strongly influence suicide rates, with effects that last for $\sim$5 y (Fig. 2*A*). Similarly, high-precipitation years have a strong lagged effect in which heavy rainfall today causes lower suicide rates in 2 y to 3 y; this beneficial yield shock may enable individuals to save crops and income, making future suicides less likely (Fig. 2*B*). Interestingly, drought appears to have no effect on suicide rates, either contemporaneously or in lagged form (*SI Appendix*, Fig. S8).

Geographic heterogeneity in both suicide and crop yield impacts can be used as an additional means of assessing the channel through which climate drives suicides. I disaggregate suicide response functions by state to detect a clear geographic pattern in which southern states—which are generally hotter, have higher average suicide rates, and display steeper suicide trends over time—have much stronger responses to growing season temperature (Fig. 2*C*). I obtain similar heterogeneous responses of agricultural yields to growing season temperatures for each of the 13 states included in the crop data. Although these estimates have large uncertainty, the correlation between state yield sensitivity and state suicide sensitivity is positive, suggesting that states where agricultural yields are more damaged by high temperatures are also the states where these temperatures increase suicide rates substantially (Fig. 2*D*). Four states that have been at the center of India's public debates regarding agricultural influences on suicide (Maharashtra, Karnataka, Tamil Nadu, and Andhra Pradesh) not only have severe suicide responses to temperature, but also exhibit large negative impacts of temperature on yield.

Adaptation. As anthropogenic climate change raises temperatures throughout the world, a central question for global welfare is the extent to which populations adopt adaptive behaviors to prevent climate damages (18). I conduct four sets of tests to assess the evidence for four distinct hypotheses regarding adaptive behavior in the context of suicide in India: (*i*) locations that are hotter, on average, exhibit lower sensitivity to temperature, as populations acclimatize; (*ii*) locations that are wealthier, on average, exhibit lower sensitivity to temperature, as wealth enables investment in adaptation; (*iii*) temperature sensitivity has declined over time as incomes and access to modern agricultural technologies have risen; and (*iv*) sensitivity to longer-run gradual trends in temperature will be lower than sensitivity to short-run variations in temperature, as populations require time to adapt. My estimation strategies for testing these hypotheses are detailed in *SI Appendix*. Across all four tests, I find no evidence of any type of adaptive behavior. In hotter locations, I detect higher than average sensitivity to temperature, contradicting my first hypothesis (Fig. 3*A*). Temperature sensitivity in wealthier locations is indistinguishable from that in poor locations, failing to support my second hypothesis

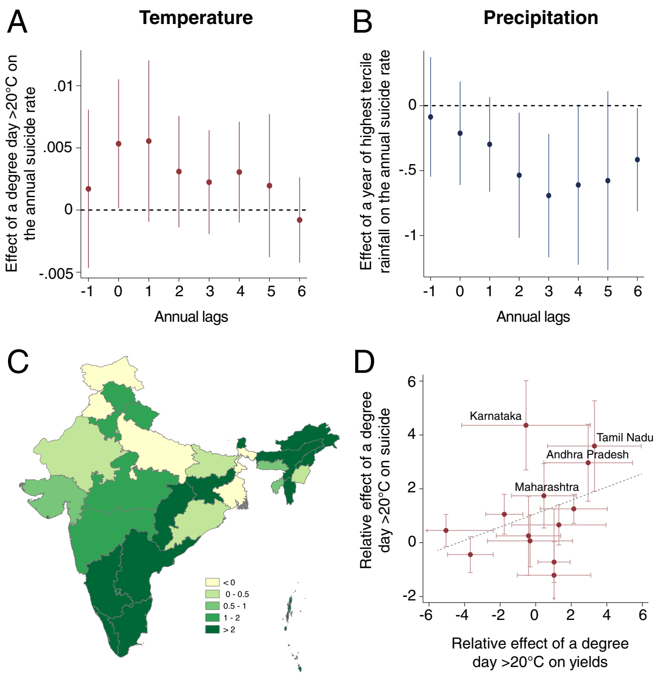

Fig. 2. Evidence for the agricultural income channel. Lagged effects of (*A*) growing season temperature and (*B*) high precipitation (years in which precipitation falls into the highest tercile of the long-run rainfall distribution) on annual suicide rates per 100,000 people suggest an economic mechanism for climate impacts. (*C*) Geographic heterogeneity in the suicide–temperature response, where states are colored by the state-specific temperature sensitivity as a fraction of the average treatment effect. Darker colors indicate more severe responses of suicide to growing season temperature; yellow indicates a negative effect. (*D*) Correlation between state-level suicide sensitivities and the additive inverse of corresponding state-level crop yield sensitivities. Temperature effects are shown as relative to the average treatment effect. Coefficients in all panels were estimated in a degree days model with a cutoff of 20 °C. Standard errors are clustered at the state level for suicide and district level for yield, and 95% CIs are shown around each point estimate.

(Fig. 3*B*). Temperature sensitivity of suicide has remained remarkably stable over time, despite India's robust economic growth and dramatic improvements in agricultural yields over this period (Fig. 3*C*). Finally, the impact of gradual changes ("long differences") is, in contrast to my final hypothesis, more severe than that of short-run variations in temperature (Fig. 3*D* and *SI Appendix*, Table S9). Taken together, these tests reveal no evidence of adaptive behavior in the context of temperature damages to suicide rates in India.

Discussion

As India's suicide rate continues to rise, the causes of these deaths remain heavily debated. In this study, I find that variations in temperature during India's main growing season exert substantial influence over suicide rates. To explore the significance of this effect to total trends in India, I extend my results to calculate the share of this upward trend that is attributable to changes in India's climate over recent decades. In particular, I measure the additional number of deaths attributable to warming growing season temperatures throughout India since 1980 (see *SI Appendix* for details on this approach). I find that, by 2013, temperature trends are responsible for over 4,000 additional deaths annually across India, accounting for ∼3% of annual suicides (Fig. 4). Across all states and all years since 1980, a cumulative total of 59,300 suicides can be attributed to warming, accounting for 6.8% of the national upward trend in suicide rates over this time period.

My study has important limitations. Of primary concern is that I do not have a quasi-experiment in which agricultural incomes were randomly allocated across populations within India and suicide rates were monitored in response. Thus, although I use multiple distinct approaches aimed at pinning down the agricultural mechanism through which climate affects suicide, I do not have a direct test of the common hypothesis that climate-induced economic hardship can lead some individuals to respond with self-harm. Secondly, my empirical strategy relies on estimating the effects of year-to-year variation in temperature and precipitation on suicides within a given state; although this facilitates a causal interpretation of estimated coefficients, it does not guarantee that there are no other factors correlated with both suicide and climate within a state that could confound my estimation. However, the robustness of the effect of growing season temperature on suicide rates across many specifications (*SI Appendix*, Tables S3–S13) and subsamples (Fig. 3) makes such confounding factors extremely unlikely.

Despite these necessary shortcomings, my findings convey important lessons for current and future generations. Suicide rates are a salient indicator of human hardship. My identification of a substantial effect of climate variation on this measure of human suffering in one fifth of the global population provides empirical support for policies that aim to prevent suicides through tools that alleviate the impacts of climate on income, such as crop insurance. These findings are also critical inputs into policy decisions regarding future climate change mitigation and adaptation. As I find no evidence that adaptation has occurred over 47 y in a large and rapidly developing country, and because suicide prevalence is a valuable measure of well-being, the magnitude of effects I detect has important consequences for assessing the likely impact of future climate change on human welfare globally. India alone is predicted to experience an average temperature increase of up to 3 °C by 2050 (24). Without investments in adaptation, my findings suggest that this warming will be accompanied by a rising number of lives lost to self-harm.

Materials and Methods

Suicide and Agricultural Data. Annual suicide data are reported by the Indian NCRB at the state level beginning in 1967 for 27 of India's 29 states and 5 of its 7 union territories. Suicide records are in NCRB's "Accidental Deaths and Suicides in India" report and include the total number of state suicides per year. I calculate suicide rates as the number of total suicides per 100,000 people, with population values linearly interpolated between Indian censuses. I use agricultural data from ref. 25. These are district-level annual yield records for major crops (rice, wheat, sugar, sorghum, millet, and maize) between 1956 and 2000, compiled from Indian Ministry of Agriculture reports and other official sources. These data cover 271 districts in 13 major agricultural states, and provide log annual yield values of a production-weighted index across all crops measured in constant Indian rupees, where prices are fixed at their 1960–1965 averages. Details on these data and summary statistics are provided in *SI Appendix*.

Climate Data. Climate data are generally available at higher spatial and temporal resolution than social outcome data. Although suicides and yields are only measured annually, if the relationship between these outcomes and temperature is nonlinear, daily climate data are required, as annual averages obscure such nonlinearities (26). For daily temperature data, I use the National Center for Environmental Prediction gridded daily reanalysis product, which provides observations in a grid of $\sim 1^\circ \times 1^\circ$. These data include daily mean temperature for each grid over my sample period. To convert daily temperature into annual observations without losing intraannual variability in daily weather, I use the agronomic concept of degree days (details in *SI Appendix*). I aggregate grid-level degree day values to state-level observations using an area-weighted average (see *SI Appendix*, Table S5 for robustness checks using weights based on population and area planted with crops). When these state-level degree day values are summed over days within a year, regressing an annual outcome on cumulative degree days imposes a piecewise linear relationship in daily temperature, in which the outcome response has zero slope for all temperatures less than T^*. Although a body of literature identifies biologically determined cutoffs T^*

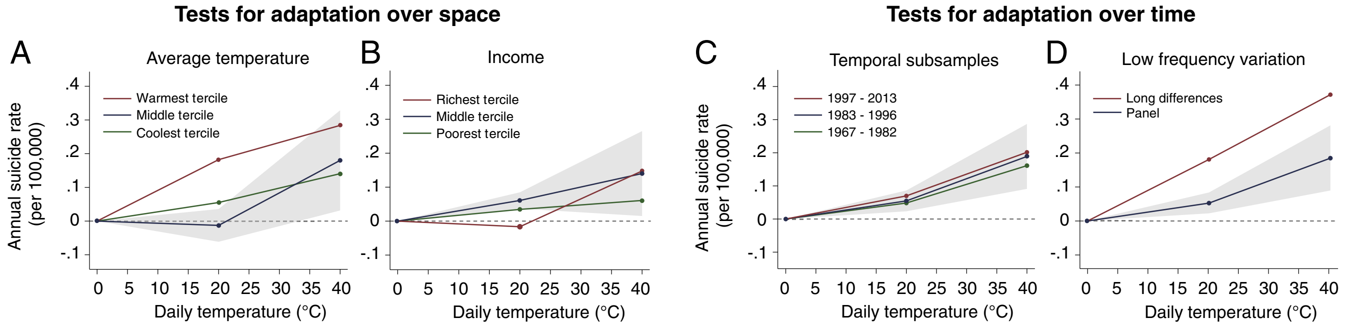

Fig. 3. Four tests of adaptation in the suicide–temperature relationship. Shown is heterogeneity in the suicide response to growing season degree days above 20 °C, (*A*) by terciles of long-run average growing season degree days, (*B*) by GDP per capita in 2010, (*C*) by periods within the sample, and (*D*) across two different estimation strategies ("long differences" estimates the effect of long-run climate trends, and "panel" estimates the effect of year-to-year variation). Shaded areas indicate the 95% CI around (*A* and *B*) the middle tercile response function, (*C*) the period 1983 to 1996, and (*D*) the panel method.

for yields of a variety of major crops, there is no empirical support to draw on in selecting T^* for suicides. Thus, although I use $T^* = 20\,^{\circ}\mathrm{C}$ throughout this study, I show robustness for a range of plausible cutoffs based on the distribution of my temperature data, and, in Fig. 1, I estimate a flexible piecewise linear function using four different degree day cutoffs to impose minimal structure on the response function.

Because reanalysis models are less reliable for precipitation data, and because nonlinearities in precipitation that can't be captured with a polynomial appear to be less consistently important both in the violent crime literature (27) and in the agriculture literature (19), I use the University of Delaware monthly cumulative precipitation data to complement daily temperature observations (28). These data are gridded at a $0.5^{\circ} \times 0.5^{\circ}$ resolution, with observations of total monthly rainfall spatially interpolated between weather stations. I again aggregate grids up to states using area-based weights, after calculating polynomial values at the grid level first.

Regression Estimation. To identify the impact of temperature and precipitation on suicide rates, I estimate a multivariate panel regression using ordinary least squares, in which the identifying assumption is the exogeneity of within-state, annual variation in cumulative degree days and precipitation. My primary estimation approach uses a flexible piecewise linear specification with respect to temperature and a cubic polynomial function of precipitation. To isolate the impact of economically meaningful climate variation, I separately identify the temperature and precipitation response functions by agricultural seasons (see *SI Appendix* for details). My empirical model takes the general form

$$suicide\_rate_{it} = \sum_{s=1}^{2}\sum_{k=1}^{\kappa}\beta_{ks}\sum_{d\in s}DD^{k}_{idt} + \sum_{s=1}^{2} g_s\left(\sum_{m\in s}P_{imt}\right) + \delta_i + \eta_t + \tau_i t + \varepsilon_{it}, \qquad [1]$$

where $suicide\_rate_{it}$ is the number of suicides per 100,000 people in state i in year t, s indicates season (growing and nongrowing), and $k = 1, \ldots, \kappa$ indicates a set of degree day cutoffs that constrain the piecewise linear response. In my most flexible model, I let $\kappa = 7$ with degree day intervals of 5 °C, and, in my simplest model, I let $\kappa = 2$ and estimate a standard degree day model with just one kink point and two piecewise linear segments. DD^{k}_{idt} is the degree days in bin k (e.g., degree days between 10 °C and 20 °C) on day d in year t in state i, and P_{imt} is cumulative precipitation during month m in year t in state i. I estimate $g(\cdot)$ as a cubic polynomial. State fixed effects δ_i account for time-invariant unobservables at the state level, year fixed effects η_t account for India-wide time-varying unobservables, and state-specific time trends $\tau_i t$ control for geographically differentiated trends in suicide driven by time-varying unobservables. Robustness to different temporal adjustments is shown in *SI Appendix*, Table S8.

Eq. **1** identifies $\hat{\beta}_{ks}$, the season-specific estimated change in the annual suicide rate caused by 1 d in bin k becoming 1 °C warmer. This annual response to a daily forcing variable is described in detail in ref. 26. The polynomial response function for precipitation generates marginal effects of one additional millimeter of rainfall, again estimated seasonally. Due to likely correlation between errors within states, I cluster standard errors at the state level. This strategy assumes that spatial correlation across states in any time period is zero, but flexibly accounts for within-state, across-time correlation. I estimate a nearly identical specification as shown in Eq. **1** for agricultural yields. However, with district-level data, I include district fixed effects and state-specific time trends, and I cluster standard errors at the district level.

Adaptation. Fig. 3 shows results from four sets of tests for evidence of adaptation. The exact specifications for all regression models are shown in *SI Appendix*. All models use a variant of Eq. **1** in which $\kappa = 2$, the degree day

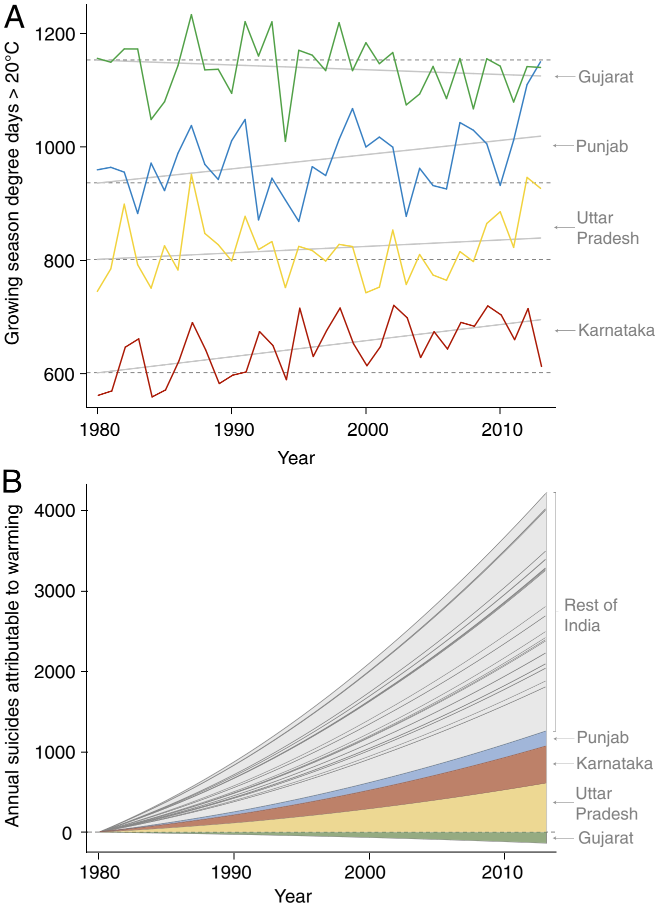

Fig. 4. Attribution of suicides to warming trends in growing season temperatures since 1980: (*A*) trends in degree days above 20 °C during India's main growing season for four example states and (*B*) the total number of deaths annually that can be attributed to warming trends, using the estimated marginal effects of degree days on suicide rates.

cutoff is set to 20 °C, and state-specific linear trends are included. In Fig. 3 *A* and *B*, I estimate Eq. **1**, but add an interaction term between degree days in the growing season and an indicator for the tercile of average growing season degree days that state i falls into (Fig. 3*A*) or an indicator for the tercile of average gross domestic product (GDP) per capita that state i falls into (Fig. 3*B*). These distributions are defined over all states and all years in the sample. In Fig. 3*C*, I split the 47 y in my sample into three temporal subsamples, and estimate the coefficient on an interaction between growing season degree days and an indicator for each of these three subsamples. In Fig. 3*D*, I estimate a "panel of long differences" empirical model in addition to the standard panel regression in Eq. **1** (29). To do so, I collapse my data to four observations for each state, where each observation measures the 10-y change in suicide rates and climate variables for each decade, and where these changes are "smoothed" by taking 5-y averages at the end points. I then estimate the effect of changes in average degree days and precipitation on changes in average suicide rates.

Attribution of Climate Trends. To compute estimates of the effect of warming temperature trends since 1980, I follow the approach outlined in refs. 18 and 30. I first estimate a state-specific linear trend in growing season degree days above 20 °C for the years 1980–2013. I then generate a detrended degree days residual that is normalized to temperature in 1980 and predict suicide rates using actual and detrended growing season degree days. In so doing, I use the coefficient estimates from the model in Table 1 which includes both state trends and year fixed effects (column 3). The elevated risk of suicide attributable to the trend, relative to the detrended counterfactual, is the difference between these two predictions. Multiplying by the population in each state and each year recovers the total additional number of suicides. Fig. 4*B* displays these additional deaths in each year; integrating over states and years gives the cumulative effect of temperature trends for all of India over the entire period since 1980 (see *SI Appendix* for details).

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1. Patel V, et al. (2012) Suicide mortality in India: A nationally representative survey. *Lancet* 379:2343–2351.
2. Mann JJ, et al. (2005) Suicide prevention strategies: A systematic review. *JAMA* 294:2064–2074.
3. Stack S (2000) Suicide: A 15-year review of the sociological literature part I: Cultural and economic factors. *Suicide Life Threat Behav* 30:145–162.
4. Rehkopf DH, Buka SL (2005) The association between suicide and the socio-economic characteristics of geographical areas: A systematic review. *Psychol Med* 36:145–157.
5. Patel R (2007) *Stuffed and Starved: Markets, Power and the Hidden Battle for the World Food System* (Black Inc, Carlton, VIC, Australia).
6. Sengupta S (September 19, 2006) On India's farms, a plague of suicide. *New York Times*, Section A, p 1.
7. Durkheim E (1897) *Suicide: A Study in Sociology*; trans Spaulding JA, Simpson G (1951) (Free, Glencoe, IL).
8. Hamermesh DS, Soss NM (1974) An economic theory of suicide. *J Polit Economy* 82: 83–98.
9. Becker GS, Posner RA (2004) *Suicide: An Economic Approach* (Univ Chicago, Chicago).
10. Agence-France Presse (January 13, 2016) Thousands of farmer suicides prompt India to set up 1.3bn crop insurance scheme, *Guardian*, Section South and Central Asia.
11. Auffhammer M, Ramanathan V, Vincent JR (2006) Integrated model shows that atmospheric brown clouds and greenhouse gases have reduced rice harvests in India. *Proc Natl Acad Sci USA* 103:19668–19672.
12. Auffhammer M, Ramanathan V, Vincent JR (2012) Climate change, the monsoon, and rice yield in India. *Clim Change* 111:411–424.
13. Mohanty BB (2005) 'We are like the living dead': Farmer suicides in Maharashtra, western India. *J Peasant Stud* 32:243–276.
14. Herring RJ (2008) Whose numbers count? Probing discrepant evidence on transgenic cotton in the Warangal district of India. *Int J Mult Res Approaches* 2:145–159.
15. Deshpande R (2002) Suicide by farmers in Karnataka: Agrarian distress and possible alleviatory steps. *Econ Polit Wkly* 37:2601–2610.
16. Rao V, Gopalappa D (2004) Agricultural growth and farmer distress: Tentative perspectives from Karnataka. *Econ Polit Wkly* 39:5591–5598.
17. Sarma E (2004) Is rural economy breaking down? Farmers' suicides in Andhra Pradesh. *Econ Polit Wkly* 39:3087–3089.
18. Carleton TA, Hsiang SM (2016) Social and economic impacts of climate. *Science* 353:aad9837.
19. Schlenker W, Roberts MJ (2009) Nonlinear temperature effects indicate severe damages to US crop yields under climate change. *Proc Natl Acad Sci USA* 106:15594–15598.
20. Schlenker W, Lobell DB (2010) Robust negative impacts of climate change on African agriculture. *Environ Res Lett* 5:014010.
21. Burgess R, Deschênes O, Donaldson D, Greenstone M (2014) Weather, climate change and death in India, Working paper (London School of Economics, London). Available at www.lse.ac.uk/economics/people/facultyPersonalPages/facultyFiles/RobinBurgess/WeatherClimateChangeAndDeathInIndia.pdf.
22. Seo D, Patrick CJ, Kennealy PJ (2008) Role of serotonin and dopamine system interactions in the neurobiology of impulsive aggression and its comorbidity with other clinical disorders. *Aggress Violent Behav* 13:383–395.
23. Ray RS, et al. (2011) Impaired respiratory and body temperature control upon acute serotonergic neuron inhibition. *Science* 333:637–642.
24. Hijioka Y, et al. (2014) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge Univ Press, Cambridge, UK), pp 1327–1370.
25. Duflo E, Pande R (2007) Dams. *Q J Econ* 122:601–646.
26. Hsiang S (2016) Climate econometrics. *Annu Rev Resour Econ* 8:43–75.
27. Burke M, Hsiang SM, Miguel E (2015) Climate and conflict. *Annu Rev Econ* 7:577–617.
28. Matsuura K, Willmott CJ (2015) Terrestrial Air Temperature: 1900–2014 Gridded Monthly Time Series. Available at climate.geog.udel.edu/~climate/html_pages/Global2014/README.GlobalTsT2014.html. Accessed December 14, 2016.
29. Burke M, Emerick K (2016) Adaptation to climate change: Evidence from US agriculture. *Am Econ J Econ Policy* 8:106–140.
30. Lobell DB, Schlenker W, Costa-Roberts J (2011) Climate trends and global crop production since 1980. *Science* 333:616–620.