RAMADAN FASTING AND AGRICULTURAL OUTPUT*

Heather Schofield†

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Abstract

Religion is an important force in many individuals' lives, with approximately 85 percent of the world's population expressing some religious belief. Yet, the literature on religion's impact on economic outcomes remains relatively sparse, driven in part by challenges around identification. This paper explores one aspect of religion's impact on economic outcomes by examining the impact of the observance of Ramadan on the economic output of farmers in India. The analysis leverages heterogeneity in cropping cycles between and within districts as well as the fact that Ramadan cycles throughout the calendar year to generate three sources of variation in the overlap between Ramadan and the labor-intensive portions of the cropping cycle. Using a difference-in-differences-in-differences approach, I find that overlap between Ramadan and the labor-intensive portions of cropping cycles results in declines in production which correspond to approximately one percent of agricultural GDP in India annually and a 20 to 40 percent decrease in productivity per fasting individual. These changes appear to be driven by changes in labor productivity and are not substantially compensated for via other potential margins of adjustment such as increased draft labor. Additional analyses suggest that productivity declines are likely to be driven primarily by reduced caloric intake rather than by other behavioral changes during Ramadan.

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†University of Pennsylvania, Perelman School of Medicine and The Wharton School. Address: Blockley Hall 1106, 423 Guardian Drive, Philadelphia Pa 19104. Phone: +1-617-233-4775. Email: hschof@wharton.upenn.edu.

1 Introduction

Religion is an important force in the lives of the majority of the world's population. Roughly 85 percent of the world's population expresses some religious belief, 54 percent state religion is very important in their lives, and nearly half of the global adult population spends time on religious activities daily (Pew Research Center, 2017, 2018). These religious beliefs have the potential for wide-ranging influences on important economic outcomes such as GDP growth, credit supply, demand, and repayment, taxation, human capital accumulation, beliefs, and norms and institutions influencing exchange and public goods (Iannaccone, 1998; Kuran, 2018; Campante and Yanagizawa-Drott, 2015; Benjamin et al., 2016; Clingingsmith et al., 2009; Beatton et al., 2019). The macroeconomic literature has also studied the relationship between religiosity and growth, typically finding a negative correlation between growth and various measures of religiosity (Barro and McCleary, 2003; McCleary and Barro, 2006). However, the directionality of this relationship is unclear; poor growth could lead to increased religious influence or religion could lead to lower growth. As Iyer (2016) notes, "it is often difficult to evaluate the effects of religion on growth separately from the effect of other factors, notably geography, other institutions, and ethnic fractionalization, which are also important growth determinants." And more broadly, despite the prevalence of religious belief and its diverse and potentially important influences, the literature on religion's impact on economic outcomes remains relatively sparse, driven in part by significant challenges around causal identification.

This paper explores one aspect of religion's impact on economic outcomes – as well as potential channels through which these effects may operate – by utilizing a natural experiment to examine the impact of the observance of Ramadan on agricultural output in India. Ramadan, a month-long religious observance centered on daylight fasting, is observed by many of the world's nearly two billion Muslims every year, including the 172 million Muslims in India (Directorate of Census Operations, 2011). The cyclical nature of the holiday, which is based on a lunar calendar combined with variation in the timing of cropping cycles, generates a natural experiment. This analysis uses a differences-in-differences-in-differences approach that leverages heterogeneity in cropping cycles within and between districts as well as the fact that Ramadan cycles throughout the calendar year to generate three sources of variation in the overlap between fasting and the labor-intensive portions of cropping cycles (sowing and harvesting). The first source of variation, generated by the fact that Ramadan cycles throughout the calendar year, is variation for a given crop-district combination over time. The second, variation among crops within a district-year, is the result of natural variation in cropping cycles for different plants. Finally, different climatic patterns across space generate variation in cropping cycles between districts, resulting in spatial variation for a given crop within a year. This identification at the level of the crop-district-year reduces many of the potential concerns around bias by controlling for time, location, or crop specific confounders that change deferentially across another dimension.

This analysis finds that overlap between Ramadan and the labor-intensive portions of the cropping cycle, sowing and harvesting, leads to economically meaningful declines in total agricultural production, both in weight and in value. A back of the envelope calculation suggests that in a typical year between 1956 and 1987, observation of Ramadan resulted in a loss of roughly one percent of agricultural GDP in India. As agricultural output represented nearly half of the Indian economy during this period, these effects are economically meaningful, accounting for a loss of 0.5 percent of overall GDP annually. Notably, despite the decline in production, two different sources of data suggest consistent labor supply among both Muslim and non-Muslims during the holiday, suggesting the holiday results in declines in labor productivity rather than labor supply. In the absence of spillovers from Muslims to non-Muslims, these estimates imply a substantial decrease in productivity of approximately 20 to 40 percent per Muslim individual during the month-long holiday.[1]

Building on these average estimates, the paper next examines heterogeneity in Ramadan's impact and demonstrates that the production declines are driven by districts with a larger concentration of Muslims. This heterogeneous effect – with little or no decline among districts with few Muslims and large declines in heavily Muslim districts – supports the conclusion that Ramadan, rather than other spurious factors, drives the production declines.

One natural question which arises in light of these estimates is whether individuals are aware of, and change behaviors in reaction to, the Ramadan fast in order to mitigate its effects. On the one hand, the substantial changes in individual productivity suggest that if individuals largely provide labor on their own farms, losses may be large for those individuals. On the other hand, if labor is dispersed across farms and Muslims and non-Muslims work on each other's farms, the effects would be correspondingly more dispersed and potentially difficult to detect. This challenge is also likely to be exacerbated by the substantial natural variation in production from year to year in agriculture.

Fine-grained data combined with the natural experiment generated by Ramadan's movement through the calendar year allow me to assess whether individuals are able to anticipate and adjust to reduced productivity driven by Ramadan. Specifically, I examine changes in other agricultural inputs such as fertilizer and draft labor (bullocks) as well as other potential margins of adjustment such as shifting to non-Muslim farm labor or fallowing land. Although it is difficult to fully rule out the possibility of small adjustments, there is no evidence of substantial changes in inputs or production processes beyond a small increase in fertilizer use when Ramadan overlaps with the sowing period.

[1] Although these declines are large, it is possible there are compensating changes in behavior and well-being which would mitigate the welfare losses. For example, increased religiosity may provide other economically productive benefits such as increased "grit" throughout the remainder of the year (Bryan et al., 2018). In addition, the microeconomic literature and related papers in psychology and sociology have typically found that religiosity is associated with a variety of positive social outcomes such as charitable giving and lower rates of youth crime, as well as greater happiness and well-being (Hoverd and Sibley, 2013; Gruber and Mullainathan, 2006; Ellison, 1991; Schulenberg et al., 1999; Hull and Bold, 1995; Lipford et al., 1993; Evans et al., 1995; Freeman and Holzer, eds, 1986). Although such changes are of economic interest, they are beyond the scope of the current paper.

This lack of adjustment does not conclusively imply that individuals are unaware of the reductions in productivity; potential adjustments such as fallowing land may be more costly than the alternative of simply accepting the period of reduced productivity and liquidity constraints or missing markets may make some adjustments infeasible or costly. However, the lack of significant changes in other inputs does suggest that the estimated changes in production reflect underlying changes in labor productivity and are not substantially ameliorated by other adjustments in agricultural inputs or production decisions.

Finally, the granular data used in this study allow me to assess whether these effects are likely to generalize to other contexts as well as speak to the broader literature on religion and economic activity by assessing potential behavioral changes during the holiday as possible channels for production declines. This line of inquiry begins by outlining four potential drivers of such declines: time spent on religious or social obligations, low caloric intake, sleep deprivation, and dehydration. I begin by assessing available direct evidence for these channels, examining changes in labor supply and caloric intake, and find no change in labor supply but notable declines in caloric intake. Next, I draw on evidence from relevant literatures and additional empirical tests utilizing both agricultural production data and additional data sources to assess the potential role of dehydration and sleep deprivation. Although the evidence regarding these channels is less direct, I do not find evidence of meaningful impacts. Finally, as a test comparing the potential role of caloric intake versus the three other potential channels collectively, I examine whether overlap between sowing/harvesting and the period following Ramadan also generates declines in production. Given the slow recovery from reduced caloric intake but rapid recovery from dehydration and sleep deprivation, the persistence of the effects observed in this test simultaneously provides evidence in favor of nutrition driving the declines and against these three other forces playing key roles (Keys et al., 1950; Schofield, 2018; Jéquier and Constant, 2010; Van Dongen et al., 2003). In short, while it is difficult to fully rule out all possible alternative channels in any natural experiment, these analyses provide suggestive evidence that caloric decline is likely to be the predominant driver of productivity declines during Ramadan in this context. These results also relate to an extensive literature examining the relationship between nutrition and economic productivity and provide additional evidence that nutrition may be an important driver of economic productivity (Dasgupta and Ray, 1987; Stiglitz, 1976; Deolalikar, 1988; Immink and Viteri, 1981a; Strauss, 1986; Wolgemuth et al., 1982; Banerjee et al., 2011; Schofield, 2018).

The potential importance of a nutrition-based mechanism also links this work to other economic analyses of Ramadan including Almond and Mazumder (2011), Van Ewijk (2011), and Majid (2015). However, these studies focus on the long run impact of maternal Ramadan fasting while the fetus is in-utero on human capital accumulation and economic outcomes rather than a contemporaneous effect among adults.

Finally, this paper also relates to work by Campante and Yanagizawa-Drott studying the impact of increasing the duration of the Ramadan fast on economic growth and subjective well-being at the country level (2015). The authors find that longer fasts have a negative impact on growth but a positive impact of subjective well-being, and relate this finding to the "club good" model of costly religious practices in Iannaccone (1998). While both papers focus on the economic effects of Ramadan, there are a number of key differences between them. First, in contrast to both Campante and Yanagizawa-Drott (2015) and many previous studies, I examine a context in which the holiday is observed only by a small fraction of the population, allowing for a cleaner analysis of potential channels by limiting potential spillovers. Second, the additional variation among crops and districts in my more detailed data provide for strong identification and allow me to estimate the average *overall* effect of Ramadan observance (i.e. the extensive margin of observing the holiday on average) rather than intensive margin adjustments around fasting duration. Finally, the substantial differences in income between India and many heavily Muslim countries (e.g. Saudi Arabia, Turkey, etc) suggest that, despite similarly negative economic impacts, the paths driving those outcomes and potential welfare effects could be quite different. While macro approaches typically preclude a well-identified analysis of these channels, I am able to study potential margins of adjustment and to offer insights about the relative roles of caloric changes, sleep, dehydration, and social/religious practices in causing the observed changes in output.

In short, this paper builds on an existing macroeconomics literature examining the relationship between religious practice and economic output. Although identification of the causal relationship from religious practice to economic outcomes is challenging, I provide a clear well-identified estimate of the relationship between Ramadan and economic output for a large and economically important market by utilizing large scale but fine-grained data and a natural experiment which leverages multiple sources of variation simultaneously. In addition, although this paper focuses on a single case of religious observance – Ramadan – in order to provide identification, the example is one that is common to many religions. For example, periods of fasting with a focus on prayer and community are common practice in many other global religions including Buddhism, Hinduism, and Christianity. Finally, additional analyses allow examination of potential margins of adjustment – finding surprisingly little change in anticipation of the holiday – and potential channels through which the effects operate – shedding light on the situations in which religious practices may be more or less economically costly.

The remainder of this paper is divided into five parts. Section 2 provides information on Ramadan, the setting of the study, and the data and estimation strategy used in the main analysis. Section 3 details the triple-difference approach examining the impact of Ramadan on agricultural production as well as heterogeneity in those responses. Potential changes in the production process and margins of adjustment in agricultural production in response to Ramadan are explored in Section 4. Section 5 investigates channels through which changes in productivity may occur, including nutrition, sleep, dehydration, and reduced labor supply in response to religious or social obligations.

Section 6 concludes.

2 Background

2.1 Ramadan

Ramadan is a month-long Muslim holiday observed primarily through fasting during daylight hours. Fasting includes abstinence from both food and liquids and is typically considered obligatory for practicing Muslims with the exception of children, the elderly, individuals who are ill, infirm, or traveling, and women who are pregnant or breast feeding. Muslims are also expected to abstain from smoking, sexual relations, and swearing during daylight hours throughout the holiday. In addition, there is an added emphasis on prayer, reading the Koran, and charity during this time (Blackwell, 2009; Ahmad et al., 2012). The holiday is lunar, shifting by roughly eleven days per year, and cycling through the calendar year approximately once every 30 years. Ramadan is followed by Eid, a holiday marking the end of Ramadan. During Eid, Muslims are not allowed to fast, and typically engage in a special prayer in a communal area, visit family and friends, and sometimes exchange gifts. Eid is a minimum of one day but can last up to three days (Blackwell, 2009).

2.2 Agriculture in India

Agriculture is a critical sector in the Indian economy. Although the share of GDP generated from agriculture has declined from 43 percent in 1960 to 17 percent in the last decade, agriculture still accounts for nearly half of employment in India (National Academy of Agricultural Sciences, 2013; World Bank, 2019). Driven in part by technology improvements during the Green Revolution, growth in this sector has been relatively rapid with a four-fold increase in real value over the same period (Food and Agricultural Organization , FAO; Evenson, 2003). India's primary crops are food grains such as rice, wheat, and millet as well as cash crops such as sugarcane, oilseeds, and peanuts. Additional details about the agricultural data used in this analysis are provided below.

2.3 Data

In order to examine the impact of Ramadan fasting on agricultural production this analysis draws on four main sources of data. First, data on agricultural production was obtained from the World Bank India Agriculture and Climate dataset compiled by Apurva Sanghi, Kavi Kumar, and James McKinsey. This dataset contains production and price information for 20 crops between 1956 and 1987 in 271 Indian districts covering 85 percent of the land area of India and all of the major agricultural areas, with the exception of Kerala and Assam.[2] Second, data on agricultural

[2]Additional information about this dataset is available online:
`https://ipl.econ.duke.edu/dthomas/dev_data/datafiles/india_agric_climate.htm`

production cycles was generously provided by Dave Donaldson who compiled it from the 1967 Indian Crop Calendar published by the Indian Directorate of Economics and Statistics (Donaldson, 2018). This dataset includes the typical sowing and harvesting periods for 18 of the crops included in the agricultural production data at the district level. Table A.II provides additional information about the 18 crops and their cropping cycles. Third, data on the fraction of individuals in each district who are Muslim was gathered from the 1961 Indian census.[3] Finally, rainfall and temperature data were obtained from the University of Delaware monthly rainfall and temperature series (University of Delaware, 2013). Additional data sources for the supplementary analyses of channels are also outlined in Table A.I.

2.4 Empirical Strategy

In order to assess the impact of Ramadan on economic output it is necessary to measure output as related to "exposure" to the holiday that is independent of spatial or temporal confounds. In addition, in order to increase external validity, this variation should occur in an economically important industry in which production is well measured at the same "level" as the variation in the exposure to holiday.

Agricultural production offers a number of advantages in this respect. Although many industries are relatively stable across the year (i.e. manufacturing), agricultural production has significant seasonality, both for given crops and in different locations. Specifically, crops are produced at different times of the year in different locations. For example, rice may be grown in February in one district and in June in another. Given the geographic spread of India, this variation is significant, with an average standard deviation of approximately 1.5 months in the timing of agricultural cycles for any given crop (Table A.II). In addition, different crops are produced at different times in the same location. For example, a district may grow rice in May and wheat in December. A typical district has a standard deviation of approximately 2.5 months and a range of roughly 9 months for the timing of crop cycles within the district (See Table A.III). This seasonality provides useful variation in "exposure" to Ramadan fasting both within and between districts. In addition to the variation related to heterogeneous cropping cycles, the fact that Ramadan is a lunar holiday and cycles throughout the calendar year can be exploited to provide temporal variation in exposure to Ramadan fasting for each crop-district combination.

In short, the overlap between Ramadan and the labor-intensive portions of the crop cycle varies across districts, crops, and years. These sources of variation allow a differences-in-differences-in-differences (DIDID) approach to identifying the impact of Ramadan on agricultural output at the district (N = 271), crop (N = 18), year (N = 32) level.

[3]Data are taken from the 1961 census only in order to match the geographic units of the agricultural data which were reconciled to 271 consistent units over the three decades of data.

I begin by estimating Equation 1 regressing the production of crop c produced in year t in district d (q_{cdt}) on the fraction of Ramadan covered by each of the labor-intensive portions of the agricultural cycle for that crop-district-year S_{cdt} to indicate overlap with sowing and H_{cdt} to indicate overlap with harvest, as well as district-crop (θ_{cd}), district-year (γ_{dt}), crop-year (α_{ct}), crop (κ_c), district (ζ_d), and year (τ_t) fixed effects and a vector of time varying controls for rainfall and temperature relative to the cropping cycle (X_{cdt}). Further information on the time-varying controls for rainfall and temperature can be found in Section B.3. Details of the calculation of the fraction of Ramadan covered by sowing and harvesting are included in Section B.2 and example calculations are provided in Figure I. The extent of the "overlap" between Ramadan and the sowing (harvesting) seasons is measured as a fraction of Ramadan to provide a constant denominator and clearer interpretation of the coefficients of interest. Specifically, $\beta_1(\beta_2)$ multiplied by 100 corresponds to the percentage decline in total production for complete overlap between Ramadan and sowing (harvesting). Table A.IV displays the distribution of overlap between Ramadan and sowing and harvesting.

$$q_{cdt} = \beta_0 + \beta_1 S_{cdt} + \beta_2 H_{cdt} + \theta_{cd} + \gamma_{dt} + \alpha_{ct} + \kappa_c + \zeta_d + \tau_t + \beta_n X_{cdt} + \varepsilon_{ctd}. \tag{1}$$

3 Results

3.1 Agricultural Production During Ramadan

As can be seen in Table I, Column (1), total agricultural production and the value of that production decline with increased overlap between Ramadan and sowing or harvesting. Although the estimated coefficients are relatively small, they correspond to meaningful production declines. Specifically, complete overlap between Ramadan and a sowing (harvest) period would result in an overall decline in production of 2 (2.9) percent, though the sowing decline is only marginally statistically significant. The declines in value are both statistically significant, and appear to be even more substantial in economic magnitude at 3.4 percent and 4.7 percent, respectively. Notably, because only 10 percent of the population is Muslim, these overall declines in output correspond to a decline in productivity in the range of 20 to 45 percent per fasting individual when the sowing (harvesting) season fully overlaps the holiday.

In addition to examining the impact of overlap on net production by weight across all crops, Table I displays estimates of changes in the quantity and value of production of rice – the primary staple grain and the crop of greatest total economic value in India – in Columns (3) and (4). These estimates are the same order of magnitude as the percentage declines in production for all crops, indicating that the declines are observed among economically meaningful crops and are not simply driven by marginal ones.

One potential confound in this estimation strategy is that it is possible to substitute between crops. If this occurred in response to overlap with Ramadan, the estimation would pick up not only declines in the crops with overlap but increases in other crops without overlap, biasing the coefficients. Although the declines are relatively small on net, making it unlikely that farmers would substitute between crops due to overlap with the holiday, I confirm that declines are robust to aggregation at the district-year level, which would address such a substitution strategy. These results are presented in Table II. The point estimates for aggregate declines are statistically indistinguishable from the declines estimated using the crop level data. These results suggest that substitution between crops is unlikely to be driving the observed effects and biasing the crop-district-year level estimates.[4]

Further, as shown in Table A.VI, the estimated changes are also robust to omission of controls for the weather (temperature and rainfall) and to examining changes in levels rather than logs.[5]

3.2 Heterogenity in Production Declines

Despite the relatively low overall fraction of Muslims in India's population, there is substantial heterogeneity in the fraction of Muslims in each district, ranging from less than 0.1 percent to over 40 percent Muslim (Figures II and III and Table A.V provide distributional information on the fraction of the rural population that is Muslim. The sample is restricted to those districts included in the agricultural dataset). Although the geographic distribution of Muslims is non-random, the variation provides a useful heterogeneity test to confirm that the decline in production is driven by Ramadan rather than other unobserved factors. If the declines are indeed driven by Ramadan, then they should only be observed in areas in which individuals observe the holiday, or in other words, areas in which a reasonably large portion of the population is Muslim. Equation 2 tests this prediction by augmenting the previous regression with interaction terms between the overlap variables and variable(s) for the fraction of Muslims in a district M_d.[6]

$$q_{cdt} = \beta_0+\beta_1 S_{cdt}+\beta_2 H_{cdt}+\beta_3 S_{cdt}*M_d+\beta_4 H_{cdt}*M_d+\beta_5 M_d+\theta_{cd}+\gamma_{dt}+\alpha_{ct}+\kappa_c+\zeta_d+\tau_t+\beta_n X_{cdt}+\varepsilon_{ctd}. \quad (2)$$

In the non-parametric specification in Columns (1) and (2), as expected, there is no significant impact of overlap on production in below median fraction Muslim districts. However, there is a strongly negative and statistically significant impact of overlap in above median fraction Muslim districts (Table III). In Columns (3) and (4) I also estimate the net decline in production as a

[4]Another potential concern regarding anticipation of Ramadan is that individuals could shift the timing of their labor inputs in response to anticipated changes in productivity. However, given that the timing of agricultural labor for sowing and harvest is time-sensitive, this approach is likely to be infeasible or of limited efficacy. In addition, such changes would simply under-estimate the impact of the holiday, generating a lower-bound effect.

[5]Although not all crops are grown in all districts, it is relatively rare for districts to shift into or out of production of a crop. In addition, those districts which do shift in and out of production tend to have very low levels of production of that crop; the median production in these districts is just 7 percent of the median overall production.

[6]In the quadratic specification, the main effects for the fraction of Muslims term and this term squared are dropped from the estimating equation due to co-linearity with the district fixed effect.

function of the percentage of Muslims in the district using both linear and quadratic interaction terms. As in the non-parametric specification, these results are consistent with the prediction that districts with a greater proportion of Muslims experience larger declines in output, although the positive coefficient on the quadratic term suggests that the rate of decline begins to taper slightly in districts with very large Muslim populations. However, it should be noted that support in this part of the distribution is weak, so these results should be interpreted with caution. The marginal declines in production are also presented graphically in Figure IV. This heterogeneity provides additional evidence that the observed output declines are driven by Ramadan rather than other unobserved causes.

Although these declines are substantial, they are not implausibly large. For example, even relatively small changes in labor inputs – such as broadcasting seeds rather than drill planting – may impact output substantially. In addition, there are many potential pathways through which Ramadan may impact production. For example, focusing on only the single potential pathway of caloric intake as a driver of production declines, the magnitude is consistent with a back of the envelope calibration of the "expected decline" given basal metabolic rates (BMR), the estimated declines in caloric intake, and the energy requirements of farm labor (see Section B.4 for details of this calculation and Table VI for the estimated change in caloric intake during this period). This calibration of "available labor energy" predicts productivity declines of roughly 50 percent as a result of the reduction in caloric intake if no energy were mobilized from fat stores. This rough calibration does not provide evidence for or against alternative explanations for the decline. However, it does suggest that despite their substantial magnitude, the observed effects are not implausibly large, especially if multiple behavioral changes occur during this period.

3.3 Summary of Results

These results demonstrate that overlap between Ramadan and sowing/harvesting has a substantial and economically meaningful negative impact on total agricultural production both in terms of quantity and value and that, consistent with Ramadan driving the declines, the impact is larger for districts with a greater percentage of Muslims.

To provide a more concrete back-of-the-envelope estimate of the aggregate losses, it is possible to weight the declines for full overlap by the expected extent of overlap. Specifically, the overlap between a crop's sowing period or harvesting period and Ramadan is approximately 0.16 in an average year (see Table A.IV). Weighting the estimated declines in value produced for full overlap of 3.4% and 4.7% (for sowing and harvesting respectively) by this average overlap generates a predicted loss of slightly less than 1% ($3.4 * .0166 + 4.7 * 0.172 = 0.86\%$) of agricultural output annually. Because agricultural output accounted for roughly half of total economic output during this period, these estimates imply a loss of 0.4 to 0.5% of GDP annually during this period due to observance of

Ramadan.

4 Margins of Adjustment

The presence of such declines in production raises a question of whether individuals are aware of these declines, and if so, whether they take steps to address them. Although the declines are economically meaningful in an aggregate sense, they may be difficult to observe at an individual level given significant year to year variability in agricultural production. To provide a sense of magnitude, a typical coefficient of variation for a set of major crops in India during this time is approximately 10 (Larson et al., 2004).[7] Notably, individual farmers and localities are likely to have much greater coefficients of variation, making this comparison even more stark.

Understanding whether these changes in inputs occur sheds light on whether individuals are aware of the declines and whether the observed changes in output are a lower bound due to compensating input adjustments. If the declines are known, there are a number of potential margins of adjustment that could be used to mitigate losses including changes in crop mix, substitution of human and animal labor, changes in fertilizer use, or shifts towards labor provided by other religions. In addition, if individuals are aware that they will not have sufficient labor to sow or harvest a crop due to Ramadan, they may choose to fallow the land (not plant) instead.

Although changes in the crop mix seem unlikely given the low percentage loss incurred in expectation and the relatively large differences in profitability of various crops, if such changes occur they could threaten the validity of the identification strategy. However, as described briefly above, I confirm that this shift between crops is not occurring by aggregating the estimation to the district-year level (Table II). The point estimates for aggregate declines are statistically indistinguishable from the declines estimated using the crop level data. These results suggest that substitution between crops is unlikely to be driving these effects and biasing the crop level estimates. Beyond changing which crops were planted, if individuals are aware that Ramadan may lead them to be unproductive and generate less output, another potential margin of adjustment would be to fallow one's fields in order to reduce costs and improve yields in the future. This margin of adjustment can be tested directly using data on acreage planted. As shown in Table IV, although the point estimates are negative, they are insignificant and economically small (changes of more than 2 percent can be ruled out). This evidence suggests that there is no significant change in the land allocated to a given crop for greater overlap with Ramadan.

Other less costly methods of substitution include changes in inputs such as draft labor (use of bullocks) or fertilizer. As shown in Table IV Column (2), there is no measurable change in the use

[7]The coefficient of variation is defined as the standard deviation divided by the mean. For example, a crop with production of 90 in year one, 100 in year two and 110 in year three would have a standard deviation of 10 and a mean of 100 resulting in a coefficient of variation of 10.

of draft labor. Despite these null results it is worth noting that the available data are aggregated to the district level and imprecise. In addition, changes in draft labor are likely to be on the intensive margin (e.g. additional hours of draft labor) rather than the extensive margin (number of bullocks available to be used) because the shock to human productivity is temporary. Hence I cannot fully rule out that small changes in inputs may occur but be undetectable given the data limitations. Although neither acreage nor draft labor appears to respond to changes in overlap, there does appear to be a small increase in fertilizer use when there is greater overlap between Ramadan and the sowing period.

Finally, if spot markets for labor are available, it may also be possible to adjust labor inputs by hiring non-Muslim individuals during the holiday period. This possibility is explored and rejected in Section 5 below.

In short, and potentially surprisingly, there is no direct evidence that individuals anticipate and respond to these effects in economically meaningful ways. While the data suggests there may be small increases in fertilizer use and additional use of draft labor is difficult to rule out given the nature of the available data, any adjustments in inputs appear likely to be relatively minor. One interpretation of this evidence is that farmers may be inattentive to the declines in production given the large year to year variation in output and the difficulty in attributing the changes to one factor in a context in which many inputs (e.g. rain) change frequently (Hanna et al., 2014). Alternatively, farm laborers and land owners may have long term repeated relationships which may make it difficult to periodically refuse to hire certain individuals in favor of other substitutable inputs. Farmers may also face very tight labor markets during the sowing and harvesting period, making it difficult or expensive to substitute workers. Finally, it is also possible that small farmers face liquidity constraints that make it prohibitively expensive to make changes to the broader input mix even if the changes in productivity are known.

5 Evidence Regarding the Forces Driving Production Declines

This section examines what behavioral changes may drive the observed declines in output during Ramadan. There are four major potential changes in behavior that could plausibly impact output in a significant manner: changes in labor supply due to religious or social obligations, declines in caloric intake, dehydration due to lack of consumption of water during the fast, or sleep deprivation due to rising early or going to bed late in order to observe the fast.

First, I directly examine possible changes in labor supply and earnings among Muslims during Ramadan using a differences-in-differences strategy on data from the National Sample Survey labor survey and the ICRISAT village level studies survey. Second, I utilize a similar identification strategy and data from the consumption module of the NSS to estimate changes in caloric intake among Muslims during Ramadan to shed light on the possibility that changes in nutrition impact production. Although direct data on a third possible channel, sleep deprivation, is limited, I explore evidence for these potential drivers of low productivity via relevant literature. Next, I augment the primary specification in the World Bank agricultural data with additional weather data to shed light on whether dehydration due to lack of fluid intake during the day while observing Ramadan drives production declines. An additional calibration exercise is also conducted using data from the literature to add evidence on this potential driver.

Finally, I conduct an omnibus test related to the timing of the changes in output. Specifically, while recovery from sleep deprivation and dehydration is rapid and any religious or social obligations associated with Ramadan should cease at the end of the holiday, caloric changes have longer term impacts on productive capacity (Belenky et al., 2003; Dinges et al., 1997; Sawka et al., 2007; Keys et al., 1950). Hence, if overlap between the period following Ramadan (leaving a gap for Eid, a holiday at the conclusion of Ramadan) and sowing or harvest period is associated with declines in production, it would provide evidence supporting the role of caloric decline in reduced production during Ramadan.

Although it is difficult to fully parse these potential channels in a natural experiment and more than one channel may contribute, collectively these tests provide suggestive evidence that changes in caloric intake may be an important driver of the observed output changes.

5.1 Time Spent on Religious and Social Activities

Relevant Literature. Time spent on religious and social activities during the Ramadan holiday is likely to vary substantially across both individuals and locations, and little information specific to India is available given the relatively low concentration of Muslims there. However, the literature does provide general information about the types of behavioral changes that Muslim individuals are likely to engage in during the holiday. The primary religious behavioral changes expected during Ramadan are an increase in the number of prayers offered, abstinence from smoking, sexual relations, and swearing during the day, and an increase in charity. While a general guideline to increase prayers and reading and recitation of the Koran exists, no specific rules are provided regarding the amount or timing of the prayer that should be completed beyond the standard prayers observed throughout the year, five times daily. Similarly, there are no specific guidelines for the amount of charity to be provided during this time.

In addition to these changes in religious practice, Muslims often spend time in social gatherings in the evenings during Ramadan. The most common set of activities following sunset is to break the fast with a small snack, to complete the fourth set of daily prayers, and then to gather with friends or family for a large evening meal (Blackwell, 2009; Ahmad et al., 2012). So, although there is an increase in religious and social activity during this time, much of the increase occurs in the evenings when individuals would not typically be working. In addition, because the prescribed changes in behavior are general and flexible, they are less likely to interfere with work requirements than observance of many other holidays. Finally, although some heavily Muslim counties see shifts in working hours during Ramadan, the smaller proportion of Muslims in India make these types of labor market changes unlikely to occur in this context.

Empirical Evidence - No Change in Labor Supply or Earnings During Ramadan. To examine labor supply changes among Muslims in India during Ramadan, I draw on two sources of data: the second-generation ICRISAT village level studies survey – a more geographically limited and smaller but more detailed survey – and the National Sample Survey (NSS) – a large and nationally representative dataset with lumpier labor supply data (National Sample Survey Organization, 2019). In more detail, ICRISAT is a panel dataset containing monthly measures of employment and earnings. The sample was drawn from six villages chosen to be representative of the major agro-climatic zones in the semi-arid tropics of India. Households were sampled across four categories of landholdings (landless, small farmers, medium farmers, and large farmers). The National Sample Survey is a large, nationally representative, repeated cross-sectional survey containing data on employment and consumption. The employment/unemployment rounds (Schedule 10) provide information on respondents' labor supply and wages during the seven days preceding the interview as well as their religious affiliation. Households were sampled on a rolling basis such that the sample is temporally spaced within each district.

Empirical Strategy and Results. In the ICRISAT data, labor supply (or earnings) of individual i, in survey round s, and year-month t are regressed on the number of days of overlap between survey period and Ramadan (R_{ist}), an interaction between that variable and an indicator for whether the individual is Muslim (M_i), a variable for the number of days between interviews (D_{ist}) to account for survey variation, and fixed effects for individuals (λ_i) and the year-month in which the survey occurred (ψ_t) (Equation 3). "Labor days" is defined as the number of days of labor, including both paid and unpaid labor but excluding domestic work, in the past month. The wages variable is calculated as the sum of cash and in-kind wages during the month. The number of hours worked is only reported for paid labor. If the participant reports more than one paid job during the survey period, the average hours worked per day is calculated as a weighted average across all jobs reported.

$$l_{ist} = \beta_0 + \beta_1 R_{ist} + \beta_2 R_{ist} * M_i + \beta_3 D_{ist} + \lambda_i + \psi_t + \varepsilon_{ist}. \tag{3}$$

A similar specification is used with the NSS data, with adjustments to account for the fact that the data consists of multiple cross sections rather than a panel. As can be seen in Equation 4, labor supply (or earnings) of individual i, in district d, at time t (l_{idt}) is regressed on the days of overlap between the survey period and Ramadan (R_{idt}), whether the individual is Muslim (M_{idt}), the interaction of these two variables ($R_{idt} * M_{idt}$), district-year fixed effects (λ_{dt}), and month of survey fixed effects (ψ_m) to account for seasonal variation in labor supply. "Labor days" is the combination of days engaged in labor for wages and own-labor (e.g. working on one's own farm) excluding domestic work. Wages are the total (cash plus in-kind) wages received during the survey period. Earnings are considered in both levels and logs to account for unemployment and unpaid labor.

$$l_{idt} = \beta_0 + \beta_1 R_{idt} + \beta_2 M_{idt} + \beta_3 R_{idt} * M_{idt} + \lambda_{dt} + \psi_m + \varepsilon_{ist}. \tag{4}$$

Table V provides the results of these regressions. In both datasets, Muslims' labor supply and earnings during the holiday are fairly precisely estimated (a change in labor supply of less than two percent per day of overlap can be detected). Perhaps surprisingly, both earnings and labor supply remain unchanged or increase very slightly for Muslims during Ramadan. The point estimate on labor supply in the NSS is a precisely estimated zero. However, it is possible that the lumpy reporting of labor supply (at the half day level with a large fraction of individuals reporting working seven days per week) makes detecting more minor adjustments such as leaving early difficult. In the ICRISAT data, the point estimate on labor supply on the extensive margin (days worked) is small – less than one percent – but positive and marginally significant while there is no detectable effect on hours worked per day in that data. The estimated change in earnings among Muslims during Ramadan is a precisely estimated zero in the ICRISAT data and an increase of approximately one percent in the NSS data, though the increase is only marginally statistically significant in logs (and not statistically significant in levels).

Possible explanations for the observed slight increase is labor supply are either an attempt to compensate for reduced productivity and/or to accrue funds for charity, which Muslims are expected to provide during Ramadan. Regardless of the cause, these results suggest that changes in labor supply driven by religious or social obligations are unlikely to drive the observed declines in production when Ramadan overlaps with important parts of the agricultural cycle and may (weakly) work against such declines.

5.2 Nutrition

Caloric Intake and Body Mass Index in India. The Indian Planning Commission's recommended caloric intake has typically been 2,100 calories per adult in urban areas and 2,400 calories per adult in rural areas (Sharma, 1999). Caloric intake in India has, however, remained significantly below these levels for many years and, of note, has been declining over time despite strong economic growth (Deaton and Drèze, 2009). In addition, the distribution of calories in India is quite skewed, such that mean caloric intakes are substantially higher than median caloric intakes. The low caloric intakes lead to correspondingly low body mass indices (BMI), with over half of the population below the WHO cutoff for underweight (BMI < 18.5) in 1971, the median year in this study. Roughly one-third of the population remains underweight at present (Deaton and Drèze, 2009; World Health Organization, 2013).

Although Muslims fast during daylight hours during Ramadan, it is possible that there could be substitution of food consumption across time to the evenings and mornings, limiting or eliminating declines in caloric intake. Hence, I directly estimate the change in caloric intake in order to shed light on the plausibility of this channel.

Data. This analysis utilizes the consumer expenditure portion of the 60th, 62nd, and 64th rounds of India's National Sample Survey (NSS, Schedule 1). The dataset provides retrospective data on household level consumption data for nearly 150 food items over the past month or the past week. These rounds cover a period substantially later than that covered by the agricultural data. Although use of earlier rounds would be ideal, it is not possible as only the more recent rounds include precise survey dates that are required to calculate overlap between the survey period and Ramadan. Per capita caloric intake is calculated for the 36,000 households living in rural areas and engaged in agricultural labor. The conversion from the quantity of food consumed to caloric content is completed using the conversion tables provided by the NSS.

Results - Changes in Caloric Intake. I estimate caloric declines among Muslim households during Ramadan according to the following equation:

$$C_{idt} = \beta_0 + \beta_{1r} R_i + \beta_2 F_{it} + \beta_{3r} R_i * F_{it} + \beta_4 E_{it} + \beta_{5r} R_i * E_{it} + \gamma_{dt} + \psi_m + \varepsilon_{ist}. \tag{5}$$

C_{idt} is calories per capita per day in household i, in district d, in year t. R_i is a vector of binary variables for the household's religion. F_{it} is an indicator variable denoting full overlap of the survey period and Ramadan. E_{it} is an indicator for overlap between the survey period and Eid, and γ_{dt} and ψ_m are district-year and month of survey fixed effects, respectively. The sample is limited to rural households whose primary occupation is agricultural work and which have either no overlap or complete (29 day) overlap between the survey period and Ramadan for ease of interpretation.

Although imprecisely estimated, the results suggest a fairly substantial decline in caloric intake among rural Muslim households during Ramadan (See Table VI). The decline appears to be approximately 600 calories per person per day, an estimate consistent with not eating a midday meal. Notably, neither protein nor fat consumption changes significantly during this time suggesting that the dietary mix does become slightly "richer", despite the decline in calories.[8] This decline is substantial relative to total caloric consumption, which is approximately 2200 calories per capita per

[8]Results available upon request.

day despite the fact that most individuals in this population engage in heavy physical labor. The results are robust to and strengthened by a variety of methods of topcoding used to address implausibly high consumption levels. Although imprecise enough that the evidence is not definitive, these results are consistent with previous literature suggesting that calories have the potential to influence productivity (see Section B.1) and further suggest that reduced caloric intake has the potential to play a role in the decrease in agricultural production during Ramadan. These results are explored further via the omnibus test in Section 5.5.

5.3 Sleep

Little direct evidence on the level of sleep experienced by the Indian population exists. And, unfortunately, the data that does exist is recent (limiting overlap with the period for which agricultural data are available), more focused on urban and elderly populations, and is not of sufficient scale to allow any direct tests of Ramadan's impact on sleep among Muslim populations during Ramadan in India. Hence, no direct tests of this relationship can be conducted in this precise context. However, below I provide evidence on the plausibility of this relationship by drawing on the relevant literature regarding sleep's impact on physical and cognitive performance. In addition, the omnibus test examining overlap between the period following Ramadan and the sowing and harvesting seasons, which is described in greater detail below, also sheds indirect light on whether sleep is likely to play a substantial role in the observed production declines.

Literature - The Impact of Sleep on Cognitive and Physical Function. A limited literature on the impact of Ramadan on sleep habits does exist. However, it focuses on countries such as Saudi Arabia which are nearly exclusively Muslim (Bahammam (2006) provides a review). Because the holiday is celebrated so widely in these countries, the habits of the country as a whole often shift during the month of Ramadan. For example, stores often both open and close later than usual. However, because the median district in this study is only seven percent Muslim, these equilibrium shifts are unlikely to occur in India. In addition, within this literature, changes in sleep patterns appear to vary widely across countries (Bahammam, 2006). Hence, the direct literature on changes in sleep patterns during Ramadan is unlikely to aid in understanding the likely impact of possible changes in sleep patterns on agricultural production in India. Instead, I focus on the more extensive and relevant literature surrounding the physiological relationship between chronic partial sleep deprivation, defined as 2 to 7 hours of sleep per night for periods of days to months, and physical and cognitive performance to understand the likely effect of changes in sleep patterns during the holiday.

The effects of sleep deprivation on performance appear to be heavily cognitive and occur primarily when sleep drops below six to seven hours per night (Goel et al., 2009; Durmer, 2005). When sleep drops below this level, the largest and most consistent effects center on changes in mood with increased sleepiness and negative affect (Alhola and Polo-Kantola, 2007; Durmer, 2005). In addition, in sleep labs and high-income countries chronic sleep deprivation of less than 6 hours per night is likely to lead to reduced vigilance, poorer memory consolidation, and slowed reaction time and learning (Blagrove et al., 1995; Rogers, 2003; Ferrara and De Gennaro, 2001; Van Dongen et al., 2003). These effects on mood and cognitive function typically tend to have a relatively linear relationship with the cumulative deprivation in the early stages and then often level off over a longer time horizon (multiple weeks) as individuals acclimatize to the new regimen (Ferrara and De Gennaro, 2001).

Despite cognitive declines associated with less than six hours of sleep per night, the evidence to date suggests that reduced sleep has little impact on physical performance until the deprivation becomes relatively extreme (Guezennec et al., 1994; Sinnerton and Reilly, 1992). As VanHelder and Radomski (1989) note, "Sleep deprivation of 30 to 72 hours does not affect cardiovascular and respiratory response to exercise of varying intensity, or the aerobic and anaerobic performance capability of individuals." Some studies do show declines in time to exhaustion after extended periods of sleep deprivation (Reilly and Piercy, 1994; VanHelder and Radomski, 1989; Vardar et al., 2007). However, results are mixed and the conditions of deprivation are much greater than those likely to be experienced during Ramadan.

Finally, a recent randomized trial on sleep in India suggests that modest changes in nighttime sleep (30 minutes per night over the course of one month) have no impact on physical performance (measured by an index of performance on an exercise cycle and daily steps) or on cognitive function (as measured both via direct laboratory measures of cognitive function and performance in a data entry job) at the levels of sleep and sleep quality experienced in this population (Bessone et al., 2020).

In short, although direct evidence is limited, making it difficult to draw strong conclusions, the literature relating sleep to cognitive and physical outcomes suggests that changes in sleep patterns during Ramadan are unlikely to be a significant driver of changes in production in this context. Physical capabilities are quite resistant to decreased sleep, even when the physical requirements are substantial as in military combat training. And although extended sleep deprivation is clearly associated with declines in specific areas of cognitive function, the sleep deprivation in these studies tends to be both more extreme than is likely to be experienced during Ramadan and its impact tends to be limited to specific domains of cognitive function (e.g. memory, reaction time) that are unlikely to be strongly related to agricultural production. Finally, the most relevant evidence – drawn from an RCT in India with an increase in sleep of 30 minutes per night over one month – suggests that modest changes in night sleep do not impact overall physical performance.

5.4 Dehydration

In addition to fasting, observant Muslims also refrain from drinking water during daylight hours during Ramadan. This restriction may cause individuals to become dehydrated, especially those individuals engaged in hard labor in hot climates. To examine whether dehydration may be a driver of the observed declines in output during this period, I draw on three sources of evidence: 1) a review of relevant literature, 2) an empirical test examining the impact of weather conditions which increase the rate of perspiration on output (controlling for the impact of those conditions on plant growth), and 3) the omnibus test conducted below which examines declines in production associated with overlap between sowing/harvesting and the period following Ramadan. Because recovery from dehydration is rapid, dehydration is unlikely to drive longer term impacts on production following the Ramadan holiday.

Literature - The Impact of Dehydration on Cognitive and Physical Function. The human body is remarkably efficient at regulating hydration via changes in plasma osmolarity (water-electrolyte balance) which drives re-absorption as needed (Jéquier and Constant, 2010). However, with extended exercise and lack of fluid replacement, dehydration does begin to negatively impact measures of aerobic performance once two percent of body weight has been lost. These declines become more consistent around three to four percent loss in body weight; however, even at these levels results are mixed (Casa et al., 2005; Sawka et al., 2007). There is generally no detectable impact of dehydration on strength and anaerobic performance until at least five percent of body weight is lost from water loss (Casa, 1999a,b; Greiwe et al., 1998; Sawka et al., 2007). There is also more limited evidence that dehydration beyond two percent of body weight may cause declines in cognitive function in areas such as short term memory consolidation (Grandjean and Grandjean, 2007).

Given that these findings suggest that dehydration's likely impact depends on its extent, it is necessary to estimate the expected body weight losses due to dehydration for fasting farmers in India. While, to the best of my knowledge, no direct evidence on body water loss rates among farmers in India exists, it is possible to benchmark expected losses relative to sports activities in which sweat rates have been measured based on caloric requirements and environmental factors.[9] This calibration, outlined in Section B.5, finds that expected water losses by the end of the day are around the two percent threshold at which aerobic effects become detectable. Given that these losses are cumulative throughout the day, and the mean losses at the day's end just reach the threshold

[9] Although no direct evidence on the extent of dehydration during fasting in India is available, related research does exist. The closest existing study examined 10 female farmers in Ghana working while fasting in similarly challenging environmental conditions – 7 to 8 hours of labor per day in temperatures exceeding 30 degrees Celsius in the shade with over 80 percent relative humidity. These women lost an average of 3.8 percent of their body weight by the time they broke their fast in the evening (Prentice et al., 1984).

for detectable impacts on physical performance, it is likely that most farmers are not significantly impacted by dehydration during this time. However, as some individuals are likely to reach this threshold, I conduct an additional test to shed further light on the magnitude of such potential effects.

Empirical Evidence – No Decrease in Production with Higher Perspiration Rates. In order to provide additional evidence on this potential pathway, I utilize the fact that atmospheric conditions can significantly impact the rate of perspiration and water loss. Specifically, evaporative potential (PET) is a measure of the propensity of water to evaporate into the atmosphere.[10] If dehydration were a significant factor in production, then as evaporative potential increased body water loss would also increase, and production would decline. However, evaporative potential is also likely to influence agricultural production directly. Hence, this test augments the previous specification not only with a main effect for the average PET over the sowing and harvesting seasons to account for direct effects on output, but also with interactions between high PET (HPET) during the relevant season – defined as districts in the top quartile of PET measurements for that season – and overlap between the seasons and Ramadan (Equation 6).

$$q_{cdt} = \beta_0 + \beta_1 S_{cdt} + \beta_2 H_{cdt} + \beta_3 HPET^S_{cdt} + \beta_4 HPET^H_{cdt} + \beta_5 S_{cdt} * HPET^S_{cdt} + \beta_6 H_{cdt} * HPET^H_{cdt} + \theta_{cd} + \gamma_{dt} + \alpha_{ct} + \kappa_c + \zeta_d + \tau_t + \beta_n X_{cdt} + \varepsilon_{ctd}. \tag{6}$$

The results of these regressions do not suggest a significant role for dehydration in driving production declines (Table VII). If dehydration were reducing output, the interactions between high evaporative potential and sowing or harvesting would be negative. However, the coefficients are mixed – with different signs between sowing and harvesting seasons – and none are significant. Further, the addition of these terms does not eliminate the negative effect of overlap between sowing/harvesting and Ramadan observed in the earlier regressions as would be expected if dehydration were the key factor in production declines. Rather, these terms remain negative and significant.

5.5 Omnibus Test - Persistence of Production Declines Following Ramadan.

A distinctive feature of low caloric intake is that recovery from this state takes time, often requiring weeks or even months to fully regain physical performance in extreme cases of deprivation (e.g., Keys et al. (1950)). This lag between increased caloric intake and improved physical performance suggests that the reduced caloric intake during the holiday would be expected to have an impact

[10]Data on PET were obtained from the British Atmospheric Data Center (BADC) and Climatic Research Unit (CRU) Databases.

beyond Ramadan itself.

In contrast, recovery from sleep deficits and dehydration is rapid. And as discussed in greater detail above, sleep deficits primarily influence cognitive rather than physical function. However, a number of researchers have documented that a single night of greater than eight hours of sleep reverses cognitive deficits from extended (24-48 hours) periods of total sleep deprivation (Drummond et al., 2006; Kendall et al., 2006; Brendel et al., 1990). Similarly, Belenky et al. (2003) cannot distinguish measures of attention and reaction time between groups which had either five, seven, or nine hours of sleep per night for one week after a three-day recovery period with eight hours of sleep per night. Dinges et al. (1997) also demonstrate that two nights of ten hours of sleep is sufficient to overcome deficits accumulated over seven nights with five or fewer hours of sleep. Similarly, for recovery from dehydration, Sawka et al. (2007) survey a variety of sources and note that normal body water and performance can typically be restored within 8 to 24 hours even after fairly extensive dehydration.

These rapid recovery periods from sleep deprivation and dehydration suggest that if reduced production during Ramadan were due to sleep deprivation, dehydration, or changes in labor supply related to religious obligations that these deficits should disappear within a few days after the conclusion of the holiday. In contrast, if the reduced production is the result of lower caloric intake during the month, there should continue to be residual effects which reduce production in the weeks following the holiday. Hence, examining the impact of overlap between the sowing and harvesting seasons and the weeks following Eid (a short holiday immediately following Ramadan) serves as a useful test to distinguish between nutritional deficits and other behavioral changes during the holiday as likely causes of the reduced production.

This test is conducted using an empirical approach similar to the previous analyses, in which the fraction of Ramadan covered by the sowing and harvesting seasons is replaced with the fraction of the weeks following the holiday covered by the sowing and harvesting seasons. However, because the Eid holiday could potentially confound the results and there is a short recovery period for dehydration and sleep deprivation, I calculate overlap with the first and second week following Eid rather than following Ramadan. The estimating equation, Equation 7, is displayed below. P_{cdt}^{XN} denotes the overlap between season X (where $X = \{S$ for sowing, H for harvesting$\}$) and week N (where $N = \{1, 2\}$). All other variables are as defined previously.

$$q_{cdt} = \beta_0 + \beta_{XN} P_{cdt}^{XN} + \theta_{cd} + \gamma_{dt} + \alpha_{ct} + \kappa_c + \zeta_d + \tau_t + \beta_n X_{cdt} + \varepsilon_{ctd}. \tag{7}$$

Although the standard errors are larger and the point estimates slightly smaller on average, the results of overlap for the first week post-Eid are quite similar to the results during the holiday itself for both sowing and harvest (Table VIII). This effect is robust to longer (4 day) specifications for Eid (Columns (3) and (4)). While the point estimates remain similar for the second week post-Eid for sowing, the effects attenuate by the second week following Eid for harvest, as might be expected given the relatively brief period of deprivation.

In short, while not conclusive, these results are consistent with the loss in productivity being driven by reduced caloric intake but inconsistent with diminished productivity being driven by dehydration, sleep deficits, or time spent on religious activities. This omnibus test is also consistent with the tests presented previously which show: (i) no significant change in labor supply during the holiday, (ii) and no increase in the extent of declines as individuals become increasingly dehydrated, and (iii) the decline in caloric intake during this period among Muslim households. Hence, while fully isolating the channels through which these effects operate is not likely to be possible, there is strong suggestive evidence that nutrition is likely to be a key channel in this context.

6 Conclusion

Eighty-five percent of the world's population adheres to a religion. For many of these individuals, religion plays a central role in their lives, including their economic outcomes via a wide variety of channels. Although religion's potential influence on economic outcomes has been discussed for many years and a literature has begun to develop, the challenges inherent in identifying causal impacts of religious practice on economic output has limited the evidence available on this relationship.

This study begins to close that gap by utilizing a natural experiment to provide one of the few causal estimates of the impact of common religious practice on economic output in a broadly relevant context. Specifically, the study takes place in the agricultural sector of India, a sector which is central to the welfare of the country (as well as many other developing countries) and accounts for half of all employment. This analysis takes a differences-in-differences-in-difference approach utilizing variation in the timing of cropping cycles between and within districts as well as Ramadan's lunar calendar to provide causal identification. I find declines in total agricultural production between 2 and 3 percent in quantity and 3 and 5 percent in value when Ramadan and labor-intensive parts of the agricultural cycle fully coincide, or an average decrease of approximately 1 percent of India's agricultural GDP (0.5 percent in overall GDP) annually during this period. Reassuringly for the identification strategy, there are no declines in production in districts with few Muslims, but large declines in districts with many Muslims. Although the overall declines are relatively small in percentage terms, they are economically meaningful and correspond to much greater declines in productivity – roughly 20 to 40 percent per Muslim individual – given the low fraction of Muslims in the population.

Interestingly, despite the meaningful changes in output I do not observe any major changes in agricultural production processes or inputs such as fertilizer, draft labor, or land in reaction to Ramadan. Although this lack of adaptation may appear puzzling, there are a number of plausible reasons why adjustments may not occur. First, the declines in output may simply be difficult to detect if a mix of Muslim and non-Muslim labor is used on many farms and the production process in agriculture (which was primarily rain fed during this time) is noisy. In addition, many of the possible margins of adjustment may be costly or difficult to undertake for small farmers who are frequently liquidity constrained and likely to face a tight labor market during peak seasons. Further work of this type to understand why markets adjust, or fail to adjust, to such declines in productivity due to religious practice would be quite valuable. In particular, understanding whether adjustments are particularly difficult among the poor, who are more likely to face missing markets or liquidity constraints that prevent adaptation to such costs, would improve our understanding of the distribution of the costs associated with various religious practices.

In order to begin to generate evidence on the drivers of declines in output, the final portion of the paper analyses four potential channels through which Ramadan may influence output: reduced labor supply due to religious or social obligations, reduced caloric intake, sleep deprivation, and dehydration. Although fully parsing these channels is difficult in a natural experiment, the literature and empirical tests are generally consistent with caloric declines as a meaningful driver as well as inconsistent with large productivity declines through several other potentially impactful channels explored.

While this paper focuses on the impact of Ramadan, practices from other religions are likely to have similar impacts. For example, fasting is a practice common to many religions including Hinduism, Christianity, and many other religions. Of course, the exact magnitudes of such effects are unlikely to be directly comparable across either religions or geographies within a religion. However, future research to improve our understanding of the range in the magnitude of these effects and the features of religious practices which generate such effects would broaden our understanding of religion's role in economic production and growth.

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7 Tables and Figures

Table I: Effect of Overlap Between Ramadan and Cropping Cycles on Output

	All Crops		Rice Only	
	(1)	(2)	(3)	(4)
	ln(quantity)	ln(value)	ln(quantity)	ln(value)
Overlap sowing	-0.020*	-0.034***	-0.041**	-0.016
	(0.010)	(0.011)	(0.018)	(0.019)
Overlap harvest	-0.029***	-0.047***	-0.043***	-0.043**
	(0.009)	(0.009)	(0.016)	(0.017)
Observations	103104	103088	7741	7741
Mean of DV	1.517	1.837	3.910	3.998

Notes: This table tests for changes in agricultural output in each district-crop-year as a function of overlap between Ramadan and the sowing and harvesting season for that crop-district-year.

- Overlap is defined as the fraction of Ramadan covered by the sowing (harvesting) season such that multiplying coefficients by 100 produces the decline associated with complete overlap between Ramadan and the season. A more detailed description of calculation of the overlap variables is included in Section B.2.
- The dependent variables are: Columns (1) and (3), log production in thousands of tons, and Columns (2) and (4), log value of production (in 1,000,000 Rs deflated to 1973). Columns (1) and (2) include all 18 crops whereas Columns (3) and (4) are limited to rice only. Rice is both the most commonly consumed staple grain and the most economically important crop in India.
- Columns (1) and (2) include district-crop, district-year, crop-year, district, year, and crop fixed effects. Columns (3) and (4) include fixed effects for district and year. All regressions include time varying controls for average rainfall and temperature during the sowing and harvesting seasons, two-month leads to each season, and a two-month lag following the sowing season.
- Robust standard errors clustered by district-year are in brackets.
- * p<0.1, ** p<0.05, *** p<0.01.

Table II: Effect of Overlap Between Ramadan and Cropping Cycles on Output, District-year Aggregation

	(1) ln(quantity)	(2) ln(value)
Overlap sowing	-0.060***	-0.035
	(0.020)	(0.022)
Overlap harvest	-0.039**	-0.066***
	(0.019)	(0.023)
Observations	8636	8636
Mean of DV	5.807	5.960

Notes: This table tests for changes in agricultural output in each district-year as a function of overlap between Ramadan and the sowing and harvesting seasons for that district-year.

- Overlap at the district-year level is defined as the weighted sum of the overlap between Ramadan and each of the 18 crops, where the weights are the average fraction of production that the crop accounts for in all years excluding the current year. A more detailed description of the calculation of the overlap variables for each crop is included in Section B.2.
- The dependent variables are log production in thousands of tons in Column (1) and log value of production (in 1,000,000 Rs deflated to 1973) in Column (2).
- Regressions include district and year fixed effects as well as a vector of time-varying controls for monthly rainfall and temperature during both the current and leading agricultural year (to account for long crop cycles).
- * p<0.1, ** p<0.05, *** p<0.01.

Table III: Heterogeneity in Production Declines by Fraction Muslim

	Median Split		Quadratic	
	(1)	(2)	(3)	(4)
	ln(quantity)	ln(value)	ln(quantity)	ln(value)
Overlap sowing	0.019	0.002	0.021	-0.003
	(0.014)	(0.014)	(0.014)	(0.014)
Overlap sowing*Above p50 Muslim	-0.076***	-0.070***		
	(0.017)	(0.017)		
Overlap harvest	-0.003	-0.016	0.007	-0.007
	(0.011)	(0.012)	(0.012)	(0.013)
Overlap harvest*Above p50 Muslim	-0.050***	-0.061***		
	(0.014)	(0.015)		
Overlap sowing* Fraction Muslim			-0.969***	-0.791***
			(0.173)	(0.178)
Overlap sowing* Fraction Muslim squared			2.471***	2.196***
			(0.416)	(0.427)
Overlap harvest* Fraction Muslim			-0.941***	-1.001***
			(0.175)	(0.181)
Overlap harvest* Fraction Muslim squared			2.692***	2.742***
			(0.400)	(0.428)
Observations	103104	103088	103104	103088
Mean of DV	1.517	1.837	1.517	1.837

Notes: This table tests for changes in agricultural production in each district-crop-year as a function of the fraction of Ramadan covered by the sowing (harvesting) season and the interaction of that variable with various indicators for the fraction of Muslims in the district.

- Columns (1) and (2) interact the overlap variable with an indicator for an above median fraction of Muslims in the district. Columns (3) and (4) interact the overlap variable with a continuous variable for the fraction Muslim as well as this variable squared.
- Quantities (Cols. (1) and (3)) are in log thousands of tons and values (Cols. (2) and (4)) are in log 1,000,000 Rs deflated to 1973.
- The net decline in production and in productivity per Muslim individual at each fraction Muslim based in the estimates in Columns (3) and (4) are plotted in Figure IV.
- Regressions include district-crop, district-year, crop-year, crop, year, and district fixed effects as well as time varying controls for average rainfall and temperature during the sowing and harvesting seasons, two month leads to each season, and a two month lag following the sowing season.
- Robust standard errors clustered by district-year are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table IV: Potential Margins of Adjustment

	(1) Area	(2) Bullocks	(3) ln(fertilizer)
Overlap sowing	-0.110	3366.856	0.070***
	(0.195)	(2179.638)	(0.026)
Overlap harvest	-0.018	1839.502	-0.049
	(0.169)	(2244.222)	(0.031)
Observations	136960	8640	8434
Mean of DV	28.657	216713.335	7.932

Notes: This table reports on potential adjustments to agricultural inputs in response to overlap between Ramadan and the sowing or harvesting season.

- Area is measured at the level of the crop-district-year while draft animal labor (bullocks) and fertilizer use are captured at the level of the district-year. Hence, Column (1) utilizes the same estimation strategy and controls as the regressions in Table I while Columns (2) and (3) utilize the estimation strategy and controls in Table II.
- Area planted is measured in 10,000HA. Bullocks measures the number of castrated (male) cattle over the age of 3 years which are used in rural areas for work only. Fertilizer captures the natural logarithm of the sum of all fertilizers measured (nitrogen, phosphorus and potassium) in the dataset.
- Robust standard errors clustered by district-year are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table V: Labor Market Outcomes During Ramadan

	ICRISAT Agricultural Laborers			**NSS Agricultural Laborers**		
	(1) Labor days	(2) Average work hours	(3) ln(total earnings)	(4) Labor days	(5) Total earnings	(6) ln(total earnings)
Muslim*Overlap	0.155*	-0.003	0.002	-0.013	2.986	0.011*
Ramadan	(0.089)	(0.011)	(0.006)	(0.010)	(2.083)	(0.006)
Muslim				0.058**	51.685***	0.184***
				(0.024)	(6.859)	(0.024)
Overlap Ramadan	-0.039	-0.002	-0.004***	0.003	-0.171	-0.001
	(0.035)	(0.001)	(0.001)	(0.004)	(0.535)	(0.003)
Observations	31432	19417	19287	395505	395510	123007
Individuals	1146	910	914	395505	395510	123007
Mean of DV	21.752	7.131	6.816	6.007	135.623	5.727

Notes: This table provides a test of whether reduced labor supply by Muslims reduced agricultural production during Ramadan. Given the coarse nature of the labor supply variable in the NSS, the table also examines wages.

- Data in Columns (1)-(3) includes ICRISAT respondents for whom agricultural work is their primary occupation.
- The ICRISAT survey elicits information on labor supply, hours, and wages of the respondent during the preceding month. The number of days of overlap between Ramadan and the survey period is calculated as the number of days of Ramadan falling within the 30 days preceding the survey date. Labor supply is defined as the number of days paid and unpaid labor excluding domestic work in the past month. Wages include both cash and in-kind payments. Average hours worked is only reported for paid labor. If the participant reports more than one paid job, average hours worked is calculated as a weighted average across jobs. Religion is captured via the caste variable, which contains a category for Muslim individuals, because it is not directly reported.
- Regressions in Columns (1)-(3) include individual fixed effects, a control for the number of days between surveys, and year-month of interview fixed effects. Robust standard errors clustered by individual are in brackets.
- Columns (4)-(6) utilize data from the Indian National Sample Survey (NSS), Schedule 10 (Employment), rounds 60, 61, 62, 64, and 66. These rounds are selected because they contain survey dates while earlier rounds do not. The sample includes individuals for whom agricultural work is their primary or secondary occupation.
- The NSS Schedule 10 provides data on labor supply (to the half day) and wages during the preceding week. Labor supply is calculated as the number of days of labor excluding domestic work in the past week.
- Columns (4)-(6) include district-year and calendar month fixed effect. Robust standard errors clustered by district-year are in brackets.
- Robust standard errors clustered by district-year are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table VI: Daily Calories per Capita in Rural Agricultural Households

	Primary	Robustness			
	(1) No topcoding	(2) P99 to mean	(3) P99 to P99	(4) P99 to mean, cond. on pos.	(5) P1 and P99, cond. on pos.
Muslim*Full overlap	-612.598	-601.279*	-620.198*	-880.169**	-725.513**
	(384.806)	(340.301)	(336.879)	(400.575)	(368.854)
Muslim	-107.497***	-96.837***	-89.493***	-106.743***	-92.462***
	(41.543)	(28.134)	(27.486)	(28.881)	(28.859)
Full overlap	455.086*	279.832	395.840	405.555	427.228
	(259.091)	(274.727)	(274.719)	(302.973)	(271.533)
Observations	36618	36618	36618	36618	36618
Mean of DV	2262.406	2019.813	2135.572	2143.297	2198.235

Notes: This table tests for changes in caloric consumption during Ramadan in Muslim households.

- The sample is drawn from the Indian National Sample Survey, Schedule 1 (consumption), rounds 60, 62, and 64 and is limited to households with survey periods with no overlap or full (29 day) overlap between the survey period and Ramadan. These rounds are included because they contain survey dates while earlier rounds do not.
- All regressions include district-year fixed effects and month of interview fixed effects. In addition, indicator variables for other major religions and their interaction terms with overlap between the survey period and Ramadan as well as overlap between the survey period and Eid (to address the fact that food purchases are lumpy and made in advance) and the interaction between this variable and the religion indicators are included in the regressions but omitted from the table for simplicity.
- The dependent variables are per capita daily caloric intake with six different methods of topcoding. Given concerns around units, all topcoding is done by food item before aggregating across the food items. The dependent variable is per capita daily caloric availability. Column (1) makes no adjustments to reported values. Columns (2) and (3) windsorize at the 99th percentile to the mean, and 99th percentile, respectively. Columns (4) and (5) are similar to (2) and (3), but use means and 99th percentiles conditional on households that have positive consumption of the good.
- NSS sampling weights are used and are reweighted to weight each round of the survey equally.
- Robust standard errors clustered by district-year are in brackets.
- * p<0.1, ** p<0.05, *** p<0.01.

Table VII: Test of Dehydration Driving Production Declines

	(1) ln(quantity)	(2) ln(value)
Overlap sowing	-0.065**	-0.062*
	(0.031)	(0.032)
High sowing PET	-0.001	0.010
	(0.029)	(0.029)
Overlap sowing*High sowing PET	0.047	0.050
	(0.066)	(0.067)
Overlap harvest	-0.072**	-0.075**
	(0.029)	(0.029)
High harvest PET	0.016	0.019
	(0.036)	(0.036)
Overlap harvest*High harvest PET	-0.052	-0.057
	(0.047)	(0.048)
Observations	11356	11356
Mean of DV	1.601	1.877

Notes: This table provides a test of whether declines in production during Ramadan are due to dehydration by examining changes in agricultural production in each district-crop-year as a function of overlap between Ramadan and sowing (or harvesting) seasons fully interacted with a measure of weather features which impact dehydration (evaporative potential or PET).

- PET is a measure of the propensity of water to evaporate. It is calculated based on temperature, vapor pressure, and cloud cover as recommended by the Food and Agricultural Organization (FAO). PET measures are not available for all districts in all years, resulting in a lower sample size.
- Regressions include district-crop, district-year, crop-year, district, year, and crop fixed effects as well as time varying controls for average rainfall and temperature during the sowing and harvesting seasons, two month leads to each season, and a two month lag following the sowing season.
- Robust standard errors clustered by district-year are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

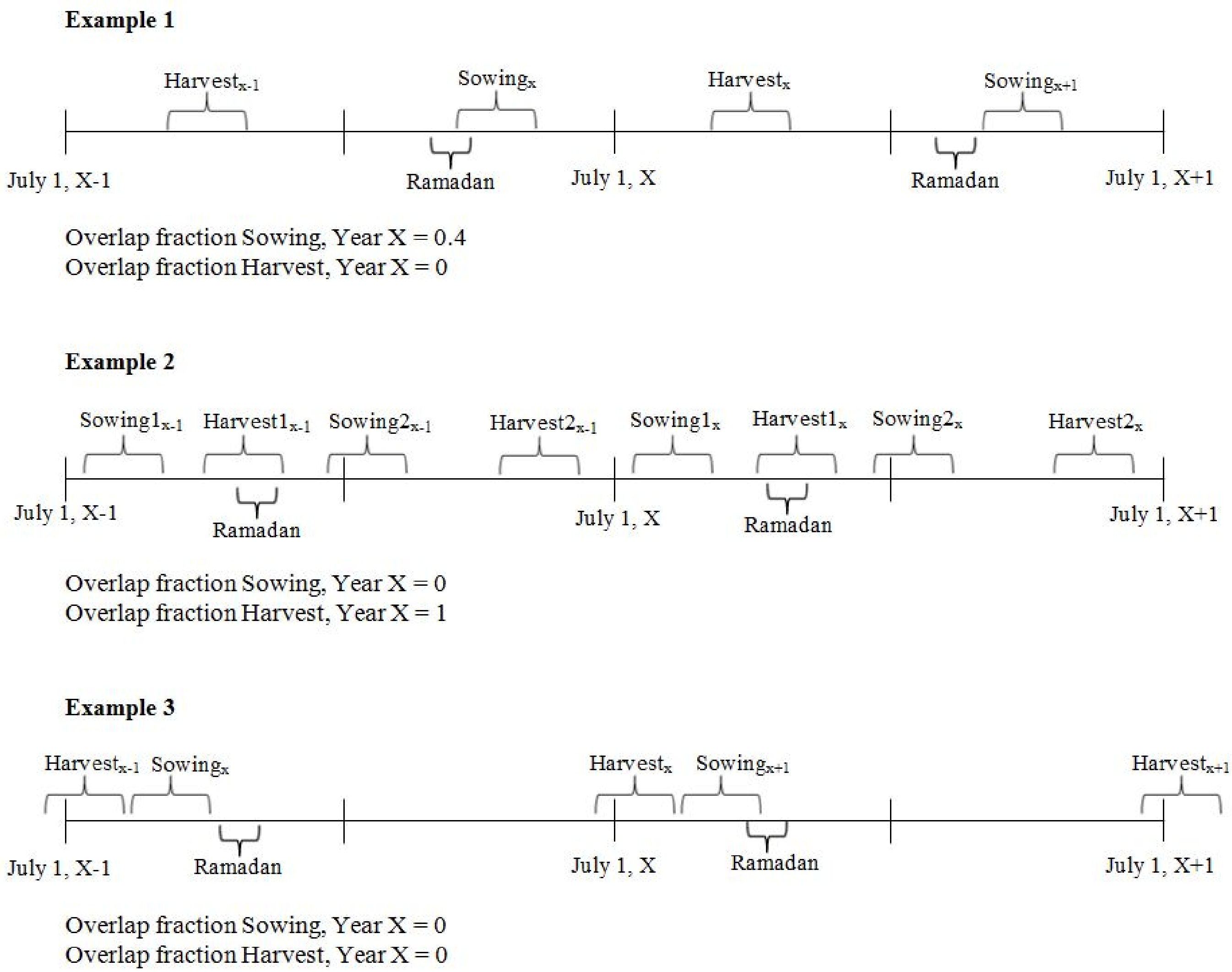
Table VIII: Persistence of Declines in Output Following Ramadan (and Eid)

	Short (2 day) Eid		**Long (4 day) Eid**	
	(1)	(2)	(3)	(4)
	ln(quantity)	ln(value)	ln(quantity)	ln(value)
Overlap sowing and 1st week post Eid	-0.016	-0.014	-0.022	-0.023
	(0.017)	(0.017)	(0.017)	(0.017)
Overlap sowing and 2nd week post Eid	-0.016	-0.018	-0.026	-0.025
	(0.017)	(0.017)	(0.018)	(0.017)
Overlap harvest and 1st week post Eid	-0.023	-0.004	-0.043***	-0.027**
	(0.014)	(0.013)	(0.014)	(0.014)
Overlap harvest and 2nd week post Eid	0.011	-0.006	0.024*	0.011
	(0.014)	(0.013)	(0.014)	(0.013)
Observations	103104	103104	103088	103088
Mean of DV	1.517	1.517	1.837	1.837

Notes: This table provides a test of whether declines in production during Ramadan are due to low caloric intake, which causes longer lasting decreases in productivity, or other potential factors including dehydration or sleep deprivation, from which recovery is rapid, or time spent on religious activities during the holiday. To accomplish this, this table examines changes in agricultural production (in log thousands of tons) in each district-crop-year as a function of the overlap between the first and second week following Eid (the holiday following Ramadan) and the sowing (harvesting) season for that crop-district-year.

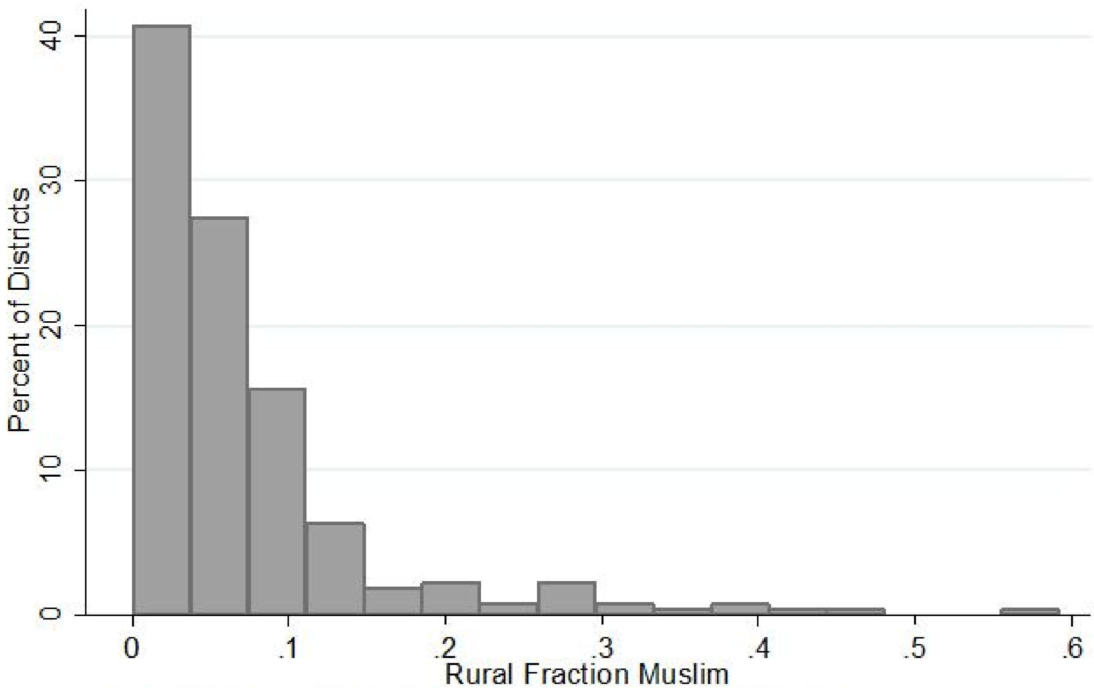
- Eid is defined as a two day period in Columns (1) and (3) a four day period in Columns (2) and (4). These formulations are used because the holiday is lunar so the exact day of Eid will depend on the sighting of the crescent moon, which varies across locations. I build in a one day buffer to account for the uncertainty in sighting the moon. In addition, while the official holiday is only one day, some individuals continue to celebrate for up to three days. Hence, to span the possible durations of the holiday, I examine periods following both a two day and a four day lag for the Eid holiday.
- All regressions include district-crop, district-year, crop-year, district, crop, and year fixed effects. In addition, time varying controls for average rainfall and temperature during the sowing and harvesting seasons, two month leads to each season, and a two month lag following the sowing season are included.
- Robust standard errors clustered by district-year are in brackets.
- * p<0.1, ** p<0.05, *** p<0.01.

FIGURE I: Overlap Between Ramadan and Cropping Cycles, Calculation Examples



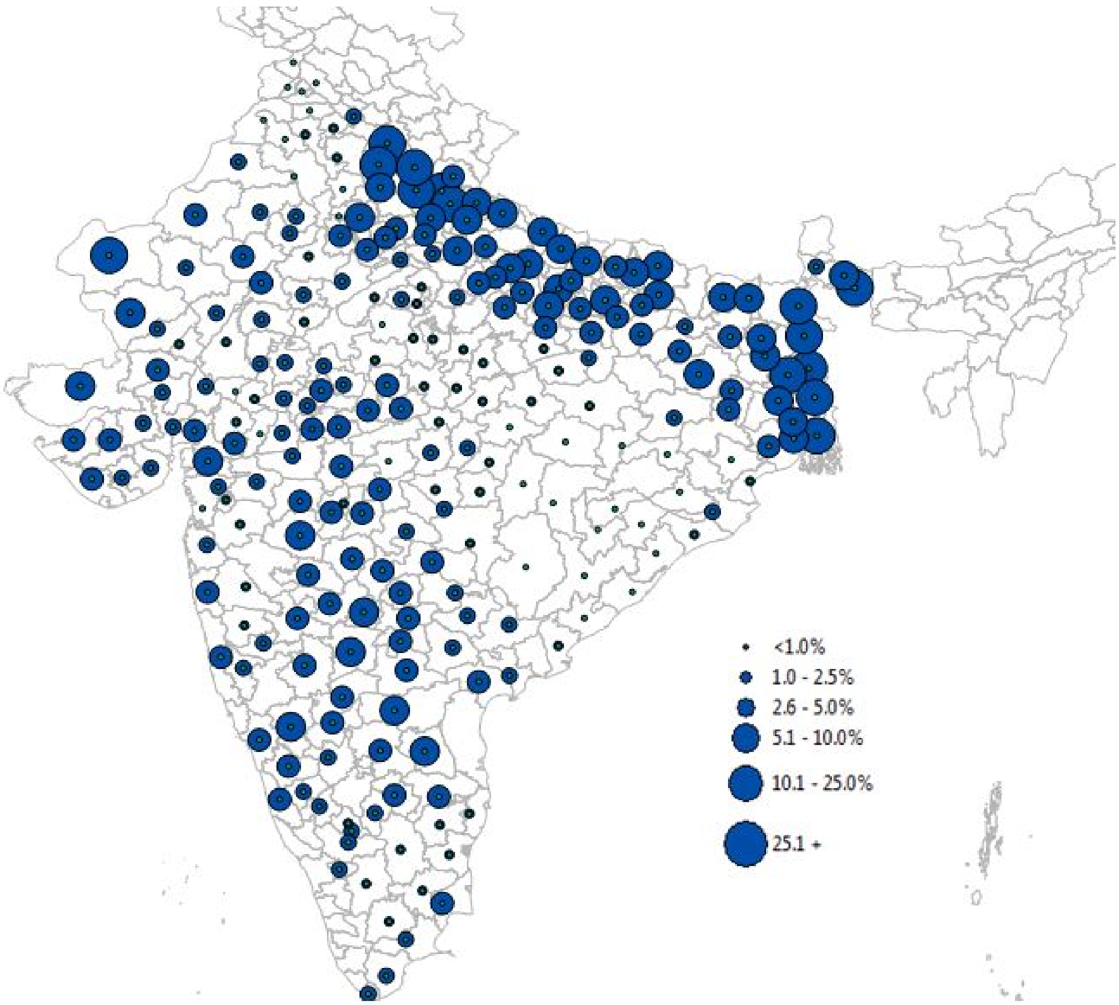
Notes: Agricultural years run from July 1 to June 30. A description of the overlap calculation procedure is provided in Section B.2.

FIGURE II: Rural Fraction Muslim Distribution



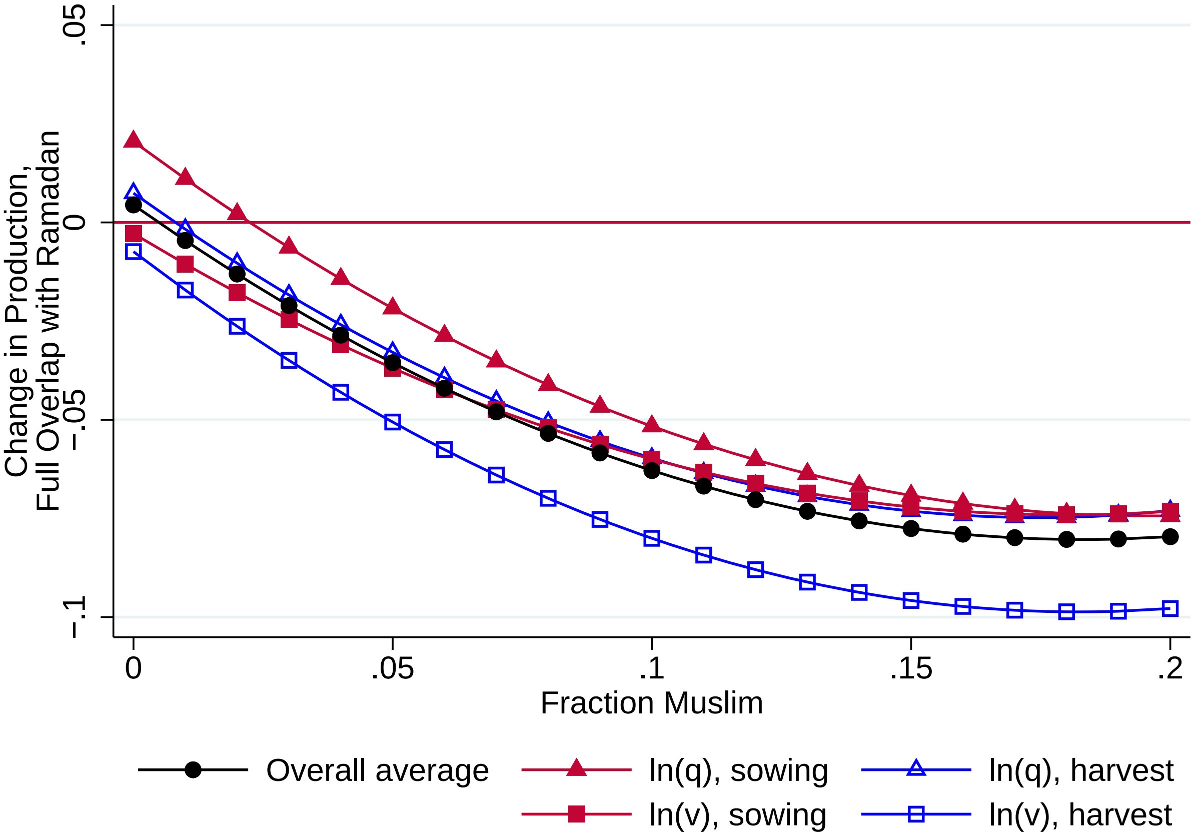
Note: Figure includes only the 270 districts in the Agricultural and Climate dataset

FIGURE III: Geographic Distribution of Muslims in India



Notes: Includes only the 270 districts included in the Indian Agriculture and Climate Dataset.

FIGURE IV: Production Declines by Fraction Muslim, Fitted Model



Appendix A Supplementary Tables and Figures

Table A.I: Overview of Data Sources

	Data set	Content	Analysis	Notes
(1)	Indian Agriculture and Climate Dataset (World Bank)	Annual agricultural production, prices, and inputs for 270 districts (85% of landarea) over 32 years for 20 crops	Output declines	Crop calendar information is available for 18 of the 20 crops
(2)	1967 Indian Crop Calendar	District specific sowing and harvesting seasons for 18 crops	Output declines	Compiled by Donaldson (2013)
(3)	University of Delaware Climate Resource Data	0.5 x 0.5 gridded monthly total rainfall and average temperature	Output declines	
(4)	Ramadan Dates	Start and end of Ramadan each year	All	Available online: http://www.timeanddate.com/holidays
(5)	Indian Census (1961)	The fraction of individuals of a given religion by district	Heterogeneity in output declines	
(6)	British Atmospheric Data Center (BADC) and Climatic Research Unit (CRU) Databases	0.5 x 0.5 gridding daily potential evapotranspiration (PET, a measure of evaporative potential) and maximum temperatures	Dehydration analysis	
(7)	National Sample Survey (NSS)	Consumer expenditures on food, labor supply	Labor supply and caloric intake analyses	Consumer Expenditure (Schedule 1, Rounds 60, 62, 64); Employment (Schedule 10, Rounds 43, 60, 61, 62, 64, and 66)
(8)	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Village Dynamics in South Asia Micro-level Data, Second generation	Labor supply	Labor supply analysis	

Notes: This table provides a brief overview of the data used in the paper.

Table A.II: Summary Statistics for Crops in the Agricultural Analysis

	(1) Mean quantity	(2) Mean value	(3) Percent of districts with positive production	(4) Sowing start, SD	(5) Sowing end, SD	(6) Harvest start, SD	(7) Harvest end, SD
Bajra (pearl millet)	19.21	17.00	84.30	24.26	35.34	28.47	30.76
Barley	12.36	10.93	90.63	15.27	19.26	18.83	17.57
Cotton	3.97	9.93	77.65	41.95	45.38	57.05	59.64
Groundnut (peanut)	21.33	39.70	98.82	32.54	38.20	31.64	35.49
Gram (lentils, chickpeas)	22.56	29.60	100.00	13.73	18.93	22.44	21.54
Jowar (sorghum)	39.58	35.67	92.15	50.28	57.05	52.80	54.62
Jute	5.84	9.86	64.71	60.58	49.09	50.49	43.00
Maize	17.86	15.03	99.26	31.46	33.32	34.96	33.70
Other pulses	8.15	12.03	78.89	41.56	48.28	45.57	53.12
Potato	21.06	11.70	86.67	62.43	62.22	58.49	58.56
Ragi (finger millet)	1.05	0.93	13.10	41.87	50.75	40.67	56.26
Rice	150.09	180.09	99.59	99.86	88.17	81.54	82.70
Rapeseed and Mustard (oils)	3.59	8.11	94.55	17.80	19.73	24.71	23.47
Sesamum (sesame)	1.35	3.79	99.16	50.95	54.10	46.92	52.71
Sugar	47.67	63.68	98.52	88.36	102.80	65.04	67.13
Tobacco	1.31	6.19	91.11	60.04	76.01	60.00	69.12
Tur (pigeon pea)	8.98	13.49	88.98	27.29	25.45	48.01	39.47
Wheat	107.72	108.72	99.05	10.57	16.05	19.95	21.34
Average	27.43	32.03	86.51	42.82	46.67	43.75	45.57

Notes: This table provides summary statistics for the crops used in this analysis.

- Production, Column (1), is in metric tons. Value, Column (2), is in 1,000,000 Rs deflated to 1973.
- Columns (4) through (7) provide the standard deviation of sowing and harvesting start and end dates to demonstrate the variation in the timing of cropping seasons.

Table A.III: Within District Variation in Cropping Cycles

	(1) Sowing start	(2) Sowing end	(3) Harvest start	(4) Harvest end
Average SD	74	72	74	76
Average Range	260	258	234	244

Notes: This table displays measures of the variation in the timing of cropping cycles for different crops within a district.

- The "Average Standard Deviation" is calculated as the standard deviation of the element of the cropping cycle listed at the top of the column within each district averaged across all districts. Similarly, the "Average Range" is the range in the timing of that element of the cropping cycle within a district, averaged across districts.
- Roughly 7 percent of crop-district combinations have more than one cropping cycle per year. All cycles are included in these figures (as well as all analyses).

Table A.IV: Distribution of Fraction of Ramadan Covered by Sowing and Harvesting Seasons

Percentile	Fraction of Ramadan covered by sowing	Fraction of Ramadan covered by harvest
50	0.00	0.00
75	0.00	0.03
90	0.86	0.93
95	1.00	1.00
99	1.00	1.00
Mean	0.16	0.17
N	103104	103104

Notes: This table provides distributional information for the primary independent variable of interest; the fraction of Ramadan covered by the labor-intensive portions of the cropping season, sowing and harvesting.

- The sample utilized for this table matches that of the primary specification listed in Table 9, Column (1).

Table A.V: Distribution of Muslims in Rural Areas

Percentile	Percent of the population that is Muslim
1	0.1
5	0.3
10	0.7
25	2.1
50	4.6
75	8.8
90	15.3
95	27.1
99	42.1
Mean (district weighted)	7.2
Mean (population weighted)	9.9

Notes: This table provides data on the fraction of the population that is Muslim in each district.

- Data in the table are drawn from the 1961 Indian Census and based on the 270 districts in the Indian Agricultural and Climate Dataset.
- The census disaggregates the district into rural and urban areas. Given that the analysis examines agricultural production, the data here are drawn from rural areas only.

Table A.VI: Effect of Overlap Between Ramadan and Cropping Cycles, Robustness

	No Weather Controls		Levels	
	(1) ln(quantity)	(2) ln(value)	(3) quantity	(4) value
Overlap sowing	-0.023**	-0.036***	-2.512***	-1.715***
	(0.010)	(0.011)	(0.425)	(0.525)
Overlap harvest	-0.028***	-0.047***	-1.962***	-2.438***
	(0.009)	(0.009)	(0.414)	(0.504)
Observations	103104	103088	136960	136960
Mean of DV	1.517	1.837	27.459	32.156

Notes: This table tests for changes in agricultural output in each district-crop-year as a function of overlap between Ramadan and the sowing and harvesting seasons for that district-crop-year.

- The dependent variables are: log production in thousands of tons and log value of production (in 1,000,000 Rs deflated to 1973) in Columns (1) and (2), respectively. Levels of these variables are considered in Columns (3) and (4).
- Regressions include district-crop, district-year, crop-year, district, year, and crop fixed effects. In addition, time varying controls for average rainfall and temperature during the sowing and harvesting seasons, two month leads to each season, and a two month lag following the sowing season are included in Columns (3) and (4).
- Robust standard errors clustered by district-year are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.VII: Robustness: Labor Supply and Earnings as a Test of Religious Obligations Driving Production Declines (NSS)

	Agricultural Laborers Full Year			**Agricultural Laborers High Labor Demand Seasons**			**Rural Casual Laborers Full Year**			**Rural Casual Laborers High Labor Demand Seasons**		
	(1) Labor days	(2) Total earnings	(3) ln(total earnings)	(4) Labor days	(5) Total earnings	(6) ln(total earnings)	(7) Labor days	(8) Total earnings	(9) ln(total earnings)	(10) Labor days	(11) Total earnings	(12) ln(total earnings)
Overlap*Muslim	-0.013	2.986	0.011*	-0.015	2.933	0.018**	0.017	1.797	0.005	0.005	3.178	0.013**
	(0.010)	(2.083)	(0.006)	(0.017)	(2.029)	(0.008)	(0.015)	(1.861)	(0.005)	(0.022)	(2.389)	(0.006)
Muslim	0.058**	51.685***	0.184***	0.099***	14.337***	0.072***	0.065	33.535***	0.140***	0.230***	20.324***	0.098***
	(0.024)	(6.859)	(0.024)	(0.034)	(4.655)	(0.017)	(0.047)	(6.139)	(0.016)	(0.054)	(7.139)	(0.019)
Overlap	0.003	-0.171	-0.001	0.001	0.282	0.001	-0.002	-1.468**	-0.001	-0.000	-0.677	0.001
	(0.004)	(0.535)	(0.003)	(0.008)	(0.767)	(0.004)	(0.009)	(0.731)	(0.002)	(0.013)	(1.166)	(0.004)
Observations	395505	395510	123007	130154	130156	50742	174386	174386	138478	67377	67377	55951
Mean of DV	6.007	135.623	5.727	5.931	142.412	5.610	4.863	306.767	5.727	4.962	289.329	5.633

Notes: This table provides a test of whether time spent on religious or social activities reduces production during Ramadan by decreasing the labor supply of Muslims during this time. Given the somewhat coarse nature of the labor supply variable, the table also examines wages.

- Samples are drawn from the Indian National Sample Survey, Schedule 10 (Employment), rounds 60, 61, 62, 64, and 66. These rounds are selected because they contain survey dates while earlier rounds do not. "Agricultural laborer" samples include only individuals who indicate that agricultural work is their primary or secondary occupation. The "Rural casual laborers" sample includes individuals living in rural areas who indicate that they participate in the casual labor market. "Full year" samples include the full survey periods. "High Labor Demand" additionally restricts the samples to surveys conducted during the sowing or harvesting seasons for the crop with the greatest acreage by state for the states included in the agricultural calendar.
- The NSS Schedule 10 provides data on labor supply (to the half day) and wages of the respondent during the week preceding the survey date. Labor supply is calculated as the number of days of labor excluding domestic work in the past week. The wages variable is calculated as the sum of cash and in-kind wages during the week.
- All regressions include district-year fixed effects and month fixed effects.
- Robust standard errors clustered by district-year are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.VIII: Labor Supply and Earnings as a Test of Religious Obligations Driving Production Declines (Icrisat)

	Agricultural Laborers All Seasons			**Agricultural Laborers High Season**			**Full Sample All Seasons**		
	(1) Labor days	(2) Average work hours	(3) ln(total earnings)	(4) Labor days	(5) Average work hours	(6) ln(total earnings)	(7) Labor days	(8) Average work hours	(9) ln(total earnings)
Muslim*Overlap	0.155*	-0.003	0.002	0.142	-0.008	-0.007	0.180***	-0.001	0.002
	(0.089)	(0.011)	(0.006)	(0.142)	(0.019)	(0.008)	(0.068)	(0.006)	(0.003)
Overlap	-0.039	-0.002	-0.004***	-0.024	-0.002	-0.006***	-0.016	0.001	-0.002***
	(0.035)	(0.001)	(0.001)	(0.038)	(0.002)	(0.001)	(0.022)	(0.001)	(0.001)
Observations	31432	19417	19287	19481	12641	12520	72048	34267	33977
Mean of DV									
mean	21.752	7.131	6.816	21.874	7.212	6.778	17.921	7.182	7.014

Notes: This table provides a test of whether time spent on religious activities reduces production during Ramadan by decreasing the labor supply of Muslims during that period.

- Samples are drawn from the second generation ICRISAT village level studies survey. "Agricultural Laborers" samples include only individuals who indicate that agricultural work is their primary occupation. "Agricultural Laborers, High Season" samples include observations from individuals in the "Agricultural Laborers" sample for which the interview period had at least 15 days of overlap with a "high labor demand" period, defined as the sowing or harvesting seasons for the crop with the greatest acreage by state. The "Full" sample includes all individuals in the sample.
- ICRISAT surveys participants approximately once per month and elicits information on labor supply, hours, and wages of the respondent during the month preceding the survey date. The number of days of overlap between Ramadan and the survey period is calculated as the number of days of Ramadan falling within the 30 days preceding the survey date. Labor supply is defined as the number of days of labor including both paid and unpaid labor but excluding domestic work in the past month. The wages variable is calculated as the sum of cash and in-kind wages during the month. Average hours worked is only reported for paid labor. If the participant reports more than one paid job, average hours worked is calculated as a weighted average across jobs. Religion is captured via the caste variable, which contains a category for Muslim individuals, because it is not directly reported.
- All regressions include individual fixed effects, a control for the number of days between surveys, and year-month of interview fixed effects.
- Robust standard errors clustered by individual are in brackets.
- * p<0.1, ** p<0.05, *** p<0.01.

Appendix B Additional Information for Reference

B.1 Literature – The Impact of Caloric Intake on Economic Productivity

There has been significant interest in the effect of caloric intake on productivity and labor market outcomes for many years. The earliest of these studies, relying on quasi-exogenous changes in caloric intake among men working at various tasks (e.g. coal mining, embankment construction) during war time, found that caloric availability was positively correlated with output (Kraut and Muller, 1946). Strauss (1986) improved on these correlational studies by utilizing a vector of food prices, farm assets, and household demographic characteristics to instrument for average caloric intake per adult equivalent to estimate a farm production function in Sierra Leone. The estimated production function showed a strong positive relationship between caloric consumption and farm production, with higher returns at lower levels of consumption. Yet, given the relatively high price of calories and the levels of caloric intake in Sierra Leone, the increased productivity did not account fully for the cost of the additional calories for the median individual. Using panel data from southern India to estimate both wage equations and farm production functions with individual fixed effects, Deolalikar (1988) found no significant impact of caloric intake on wages or farm output once stature (weight for height) was accounted for.

Three additional studies have also examined the impact of adult caloric supplementation on productivity through experimental methods in an effort to address the endogeneity of caloric consumption. Immink and Viteri (1981a,b) find no significant change in production when treated participants were provided with an additional 350 calories per day. However, due to logistical constraints, this experiment relied on two villages randomized at the level of the village. In addition, laborers in this study worked in groups of four and were paid one quarter of the group's total production, potentially weakening individual incentives. Wolgemuth et al. (1982) were able to randomize at the level of the individual and provided the treated individuals with an additional 800 calories per day relative to the control group. Because participants in this study were construction workers, productivity was estimated by visual inspection of the quantity of earth moved and required adjustments of productivity measures to account for differences in output across types of tasks.[11] Although production per day showed a small marginally significant increase in the intention to treat estimate, the number of days worked on the roads project declined significantly among treated individuals, making an overall assessment of economic productivity changes difficult. Finally, in more recent work Schofield (2018) supplements the caloric intake of cycle-rickshaw drivers in India by 700 calories per day for approximately one month. Relative to control workers who received the equivalent value in cash, the treated drivers increased labor supply and income by approximately 10 percent by the final week of the study.

B.2 Calculating the Overlap between Ramadan and Agricultural Seasons

Data in the India Agricultural and Climate dataset is organized by the agricultural year running from July 1 of year X to June 30 of year X+1. To calculate the overlap between the sowing and harvesting seasons and Ramadan, I first organize the crop calendar relative to the agricultural year such that an

[11] The specific compensation method for workers is not explicitly stated in the paper. Wages are mentioned, however, the structure of the wages is not. Given that the labor provided was for a public works project, it is likely that there was simply a flat days wage for work on the project such that workers most likely faced relatively weak incentives.

agricultural cycle for agricultural year X is defined by the seasons leading up to a harvest which occurs in agricultural year X.[12] This calendar is then overlaid with the Ramadan dates during the agricultural year of interest as well as the preceding year to account for extended agricultural cycles and harvests which occur early in the agricultural year. For example, the cropping cycle for sugar cane is typically between one and two years such that for a harvest occurring in agricultural year X, the sowing season typically occurs in year X-1. Similarly, if a harvest were to occur in July of agricultural year X, the sowing season would typically occur in year X-1. However, the overlap between these sowing seasons and the previous year's Ramadan would be assigned to the year in which the harvest occurred to coincide with the production data in the India Agricultural and Climate data.

In addition, because certain crops (e.g. rice, potatoes) frequently have more than one agricultural cycle per year, I calculate the days of overlap between each season (i.e. sowing, harvesting) and Ramadan for each cycle and then sum across the cycles ending in the same agricultural year. Finally, this total number of days of overlap is divided by 29, the number of days in Ramadan.[13] Figure I provides example overlap calculations and Table A3 provides the distribution of overlap between Ramadan and each of the agricultural seasons.

B.3 Calculating Rainfall and Average Temperature Controls

Although the Indian Agricultural and Climate dataset contains information on rainfall and temperature, the values are averages across all years. Hence, I use the University of Delaware data to provide time varying controls for rainfall and temperature. Because each crop is likely to be impacted differently by rainfall and temperature in a given month, instead of using weather controls by calendar month I create rainfall and temperature relative to the sowing and harvesting seasons for each crop. Specifically, the regressions control for the total rainfall and average temperature over the two months preceding each season, during the season itself, and for the two months following the sowing season at the centroid of each district. Because the rainfall and temperature data are provided as a monthly series, these variable are calculated as weighted averages created by summing the number of days in each month for the relevant period (e.g. sowing season) multiplied by the monthly value and dividing the total by the total number of days. Missing values are replaced with imputed values generated from a regression of existing values on district-crop and year fixed effects.

B.4 Calibrating Declines in Agricultural Productivity: "Free Energy" Available for Work

Adjustments to basal metabolic rates and energy use outside of work limit the precision of "free energy" calibrations. However, it is possible to calculate a measure of expected "possible" production based on caloric availability in order to determine whether the observed declines in productivity are roughly

[12]For harvest seasons which overlap two agricultural years I assign the crop cycle to the year in which the majority of the harvest falls. Because some crops such as sugar cane have very long growing cycles, production accrued in year X can begin with a sowing season up to roughly 1.5 years earlier.

[13]The exact dates of Ramadan depend on the sighting of the crescent moon. However, data are not available on when the moon is sighted in each district. Hence, I use a consistent start date for the holiday across all of India for each year and limit the duration of the holiday to 29 days (rather than the possible 30) to generate conservative estimates and ensure that I do not measure overlap with Eid, the holiday following Ramadan.

congruent with expectations based on energy availability. Rural residents in India were consuming roughly 2240 calories per day in 1983 (Deaton and Drèze, 2009). Researchers have measured the basal metabolic rates (BMR) of rural populations in southern India and have determined that typical basal metabolic rates for low BMI individuals require approximately 1,100 and 1,400 calories per day depending on size and gender (Ferro-Luzzi et al., 1997). Taking the lowest BMR estimates, the strong assumption that all calories not used in basal metabolism are used productively, and the estimated decline in caloric intake for Muslims during Ramadan, individuals have 1140 calories available for work when not fasting and 440 available calories for work when fasting. Passmore and Durnin (1955) review a variety of sources across five countries detailing energy expenditures in different agricultural activities and find that sowing season activities such as clearing brush, digging ridges, and ploughing typically require 4 to 9 calories per minute while harvesting activities such as bundling and threshing typically require 3 to 7 calories per minute. Hence, farm work is likely to burn roughly 180 to 540 calories per hour. Taking an estimate from the middle of this range of roughly 350 calories per hour, a typical farmer would be able to complete roughly 4 hours of active labor when not fasting and 2 hours of active labor when fasting. Accounting for the fact that some energy can be mobilized from fat reserves, these estimates suggest the observed declines in productivity per Muslim individual are consistent with the free energy available.

B.5 Calibrating Expected Water Losses During Ramadan

Perspiration rates depend on a number of factors, key among which are the intensity of the physical activity and factors which influence evaporation rates (i.e., temperature, vapor pressure). The intensity of physical activity can be approximated via the rate at which calories are burned in the activity and the weather variables can be measured directly. A 50 kg individual would be expected to burn approximately 1200 calories in a day of hard farm work during the active labor seasons (Fluck, 1992; Nag et al., 1980). In order to benchmark the expected perspiration rates, I compare this energy usage to the energy consumed by running, one of the most commonly studied activities in which perspiration rates are measured, in similar weather conditions. Rehrer and Burke (1996) reviews the literature and finds that accounting for water intake, running a marathon typically results in a loss of approximately three percent of body weight. Although predicted rather than measured, Sawka et al. (2007) estimate that in temperatures similar to those likely to be experienced by farmers in India running a marathon would result in a loss of four to five percent of body weight.[14] However, running a marathon requires roughly 2500 calories for a 50 kg individual, twice the energy required for a day of intensive farm labor. Hence, one would expect roughly half the water losses for farming as well, suggesting an overall loss of roughly 1.5 to 2.5 percent in body weight. However, two additional factors are likely to reduce sweat rates relative to this benchmark. First, the lower rate of caloric burn for farming will reduce sweat production due to greater passive cooling and less "wasted" sweat lost to dripping (Candas et al., 1979; Shapiro et al., 1982). Second, a higher surface area to mass ratio (negatively correlated with BMI), lower overall weight, low body fat percentage, and

[14] This prediction is based on an ambient temperature of 28C, or approximately 82F. The overall mean temperature in the districts included in this study during sowing and harvesting periods was 27 and 24 degrees Celsius respectively (University of Delaware (2013), author's calculations). Although based on a more limited sample, the mean daily maximum temperature over the sowing and harvesting periods was 31 and 29 degrees C, respectively (Climatic Unit Research Database at the British Atmospheric Data Center (BADC), author's calculations.

acclimatization to heat all improve core body temperature management and substantially reduce sweat rates in hot humid climates (Havenith et al., 1995; Havenith, 2001; Casa, 1999b). This suggests that Indian farmers are likely to have relatively low sweat rates relative to many individuals in the studies cited previously due to their small size, very low body fat percentage, and acclimatization to hot temperatures. Hence, it is unlikely that the two percent of body weight threshold at which decrements in performance begin to be observed is surpassed for a significant number of farmers during Ramadan.