Health Capital and the Prenatal Environment: The Effect of Ramadan Observance During Pregnancy

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WEB APPENDIX

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C Appendix Tables & Figures

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A Biomedical Studies of Fasting

We begin by summarizing evidence on the "first stage" effect of fasting during Ramadan. That is, what is the existing evidence that Ramadan fasting can have a detectable effect on health? In Section A.1, we summarize survey data on the prevalence of Ramadan fasting among pregnant women and studies of caloric intake and weight change during intermittent fasting. Second, we discuss the potential impacts of maternal biochemical changes caused by fasting (accelerated starvation) on the fetus in Section A.2. Third, we examine potential pathways by which intermittent fasting could have lasting effects through "fetal programming" in Section A.3. Fourth, we review the empirical studies that have explicitly examined the effects of Ramadan on birth and early childhood outcomes in Section A.4. Fifth, we briefly summarize a separate literature on nutrition and the sex ratio at birth – which to date has not used Ramadan fasting for identification – in Section A.5 . Finally, we distill the preceding into research hypotheses which we will apply to our data in Section A.6.

A.1 First Stage Effects of Ramadan

A.1.1 Is Ramadan Observed by Pregnant Muslims?

Pregnant women who request an exemption from fasting are expected to "make up" the fasting days missed during pregnancy after delivery. Anecdotal evidence suggests that this may discourage pregnant women from seeking the exemption since they may be the only member of the household fasting [Hoskins, 1992, Mirghani et al., 2004].[1] Mirghani et al. [2004] noted: "Most opt to fast with their families rather than doing this later":636. In addition, some Muslims interpret Islamic Law as requiring pregnant women to fast. For example, the religious leader of Singapore's Muslims held that: "a pregnant woman who is in good health, capable of fasting and does not feel any worry about herself or to her foetus, is required and expected to fast like any ordinary woman" [Joosoph and Yu, 2004].[2] Furthermore, since fasting during Ramadan is one of the five pillars of Islam and is a central part of the culture of the Muslim community, many women fear a loss of connection with the community or would feel guilty about not observing Ramadan

[1] There are some differences in interpretation of the Koran among Imams regarding whether pregnant women must make up the fasting days later or simply pay alms for the poor, or both. See, for example, http://islam1.org/iar/imam/archives/2006/09/09/fasting_the_month_of_ramadaan.php

[2] Similarly, Arab and Nasrollahi [2001] noted that "According the Islamic teaching pregnant women are allowed to fast if it is not harmful to them"; faculty at the Kurdistan Medical Science University in Iran noted that pregnant and breastfeeding women "who fear for the their well being or that of the foetus/child" may be exempted from fasting [Shahgheibi et al., 2005].

[Robinson and Raisler, 2005].

As far as we are aware, comprehensive data on Ramadan fasting during pregnancy do not exist. Various surveys of Muslim women suggest that fasting is the norm. For example, of the 4,343 women delivering in hospitals in Hamadan, Iran in 1999, 71% reported fasting at least 1 day, "highlighting the great desire of Muslim women to keep fasting in Ramadan, the holy month"[Arab and Nasrollahi, 2001]. In a study in Singapore, 87% of the 181 muslim women surveyed fasted at least 1 day during pregnancy, and 74% reported completing at least 20 days of fasting [Joosoph and Yu, 2004]. In a study conducted in Sana'a City, Yemen, more than 90 percent fasted over 20 days [Makki, 2002]. At the Sorrento Maternity Hospital in Birmingham, England, three quarters of mothers fasted during Ramadan [Eaton and Wharton, 1982]. In a study conducted in Gambia, 90 percent of pregnant women fasted throughout Ramadan [Prentice et al., 1983]. In the US, a study of 32 Muslim women in Michigan found that 28 had fasted in at least one pregnancy and reported that 60-90 percent of women from their communities fast during pregnancy [Robinson and Raisler, 2005].

In summary, survey data indicate that most but not all women observe the Ramadan fast during pregnancy. To the extent that pregnant Muslim women do not fast, ITT estimates are conservative estimates of fasting's effect. As discussed in Section 6 of the main paper, fasting observance is likely highest in early pregnancy.

A.1.2 Caloric Intake and Weight Among Fasting Adults

Ramadan fasting in the adult population (i.e. not conditioning on pregnancy) has been associated with modest but statistically significant declines in the weight of fasters of around 1 to 3 kg (Husain et al. [1987]; Ramadan et al. [1999]; Adlouni et al. [1998]; Mansi [2007]; Takruri [1989]) Reductions in weight are sometimes (but not always) accompanied by declines in caloric intake and likely depend on dietary customs in specific countries.[3]

Two studies are of particular relevance. First, in a study of 185 pregnant women, Arab [2003] found that over a 24 hour period encompassing the Ramadan fast, over 90 percent of the women had a deficiency of over 500 calories relative to the required energy intake and 68 percent had a deficiency of over 1000 calories. Second, in the only large scale population-based study we are aware of, Cole [1993] found striking evidence of sharp weight changes during Ramadan for women in Gambia. The study was notable because it used fixed effects with 11 years of panel data and controlled for calendar month, calendar

[3]For example, Husain et al. [1987] found reductions in caloric intake of between 6 percent and 25 percent relative to nonfasting conditions among Malaysians. In contrast, Adlouni et al. [1998] found a 20 percent increase in calories per day among Moroccans.

year, and stage of pregnancy (or lactation). Appendix Figure A1, taken from the study, shows that relative to the rest of the year, there is an increase in weight during the four weeks prior to Ramadan and a sharp increase in weight at the very beginning of Ramadan. This is followed by an abrupt fall in weight of over 1kg (2.2 pounds) during the subsequent 3 weeks of fasting. The figure provides striking visual evidence that daytime fasting during Ramadan is affecting weight gain.

In any case, as we discuss in section 2.2 of the paper, fasting may induce maternal biochemical changes and reprogramming of the neuro-endocrine system due to alterations in the the *timing* of nutritional intake even if overall caloric intake or weight change is unaffected.

A.2 Ramadan and Fetal Health

A.2.1 Pathways from Maternal to Fetal Health

Does exposure to ketones during "accelerated starvation" (Section 2.1 of the main text) impair the neural development of the fetus? Controlled studies of mice and rats have shown that prenatal exposure to ketones result in impaired neurological development. [Hunter and Sadler, 1987, Moore et al., 1989, Sheehan et al., 1985]. Hunter and Sadler [1987] reference studies showing ketones "rapidly diffuse from the maternal circulation across extraembryonic membranes":263. They also point out that in addition to the period of neurulation (3rd to 4th week of gestation in humans), the earliest stages of embryogenesis when the "primitive streak" is observed (the 13th day post-conception), may be especially susceptible to ketones. Moore et al. [1989] noted that "even a relatively brief episode of ketosis might perturb the development of the early embryo":248. They also emphasize that the effects of ketones were to slow neurological development rather than to produce a malformation. This may explain why similar studies in human populations have not (for the most part) found evidence of congenital malformations [ter Braak et al., 2002]

A related literature has examined the effects of poor metabolic regulation during pregnancy in mothers with Type 1 diabetes. In this case although the primary concern is avoiding hyperglycemia (abnormally high blood glucose), this sometimes results in severe cases of hypocglycemia (abnormally low blood glucose). The latter case may be instructive for understanding the potential effects of accelerated starvation since blood glucose drops after a prolonged fast. Some studies of *in utero* exposure to hypocglycemia among diabetic mothers have shown that fetal growth is reduced and that the key period is between the fourth to sixth weeks of gestation [ter Braak et al., 2002]). It has also been shown that hypoglycemia among *non-diabetic* mothers is also associated with lower birth weight [Scholl et al., 2001]. Studies of diabetic mothers have shown long-term effects of accelerated starvation on cognitive functioning during childhood (Rizzo et al. [1991], Langan et al. [1991]).

A.2.2 Empirical Studies of Fetal Health

Fetal health measures have the advantage of permitting panel data techniques to address selection in to maternal fasting but the disadvantage of not being standardized health metrics. Several studies of maternal fasting during Ramadan have found adverse effects on at least two of these fetal health indicators. Mirghani et al. [2004] found evidence of reduced fetal breathing movements where measures of fetal breathing were taken both before and after fasting on the same day. The same study, however, found no change in overall body movements, fetal tone or maternal appreciation.[4] Mirghani et al. [2005] found a significantly fewer heart rate accelerations among pregnant women who were fasting during Ramadan late in pregnancy compared to controls. This was observed despite relatively short diurnal fasts (less than 10 hours duration) and the absence of significant changes in glucose levels. DiPietro et al. [2007] found a strong association between variation in fetal heart rate *in utero* and mental and psychomotor development and language ability during early childhood. Finally, Mirghani et al. [2007] found no effect of Ramadan fasting on uterine arterial blood flow.

In contrast, studies of hypoglycemia in animals and humans have examined the fetal heart rate, fetal breathing movements, and limb and body movements in order to identify impairments to fetal development. A review of these studies in ter Braak et al. [2002] do not show much affect of moderate hypoglycemia on fetal conditions.

A.3 Mechanisms of Fetal Programming

We now discuss how disruptions to fetal health can have permanent effects. In a review of epidemiological studies on the fetal origins of adult diseases, Jaddoe and Witteman [2006] describe two hypotheses related to our study. The first is described as "fetal undernutrition." According to this view, inadequate prenatal nutrition leads to developmental adaptations that are beneficial for short-term survival but lead to lower birth weight. However, by permanently reprogramming the physiology and metabolism of the fetus,

[4] A significant reduction in upper limb movements was noted but there was a concern that this might be due to observer bias.

this ultimately makes the body susceptible to heart disease and diabetes during adulthood.[5] Although most studies of fetal origins have relied on blunt measures such as birth weight to proxy for nutritional restriction during pregnancy, a recurring theme in many studies is that fetal programming may occur even in the absence of birth weight effects. For example, studies of the Dutch famine have showed that those exposed to the famine early in gestation had dramatically higher rates of heart disease but did not have lower birth weight [Painter et al., 2005]. Similarly animal studies have often found evidence of fetal programming without detecting significant changes in fetal weight. e.g. Nishina et al. [2004]

A second prominent hypothesis is that nutritional restrictions inhibit the development of a placental enzyme that is required to convert cortisol into inactive cortisone, thereby exposing the fetus to excessive amounts of cortisol. It is suggested that exposure to glucocorticoids such as cortisol *in utero* leads to a reprogramming of the hypothalamic–pituitary adrenal axis (HPA) which in turn, could lead to impaired fetal development and worse health during adulthood.

In controlled animal studies, researchers have linked nutritional restrictions very early in gestation to an altered neuro-endocrine system, e.g., Nishina et al. [2004]. With respect to humans, Herrmann et al. [2001] have shown an association between fasts of 13 hours or longer and higher levels of plasma corticotrophin-releasing hormone (CRH) which could reflect a reprogramming of the HPA axis. As noted in the main text, Dikensoy et al. [2009] show that Ramadan fasting is associated with elevated cortisol levels during pregnancy (relative to pre-pregnancy levels), but not for non-fasting mothers. Kapoor et al. [2006] describe how the effects of fetal programming of HPA in humans may result in cognitive impairment; due to the complex feedback mechanisms involved, these effects may not be evident "until adulthood or early old age". The authors also emphasize that many of the long-term effects may be sex-specific.

The existing literature on fetal origins however, has made little use of quasi-experimental research designs to address potential confounding factors or to identify the underlying mechanisms. Jaddoe and Witteman [2006] recently concluded: "Thus far, it is still not known which mechanisms underlie the associations between low birth weight and diseases in adult life. The causal pathways linking low birth weight to diseases in later life seem to be complex and may include combined environmental and genetic mechanisms in various periods of life. Well-designed epidemiological studies are necessary to estimate the

[5] Jaddoe and Witteman [2006] note that this view has evolved into a more "general developmental plasticity model in which various fetal and post-natal environmental factors lead to programming responses":93.

population effect size and to identify the underlying mechanisms" Jaddoe and Witteman [2006, 91].

A.4 Ramadan and Perinatal Health

A.4.1 Birth Outcomes

Existing studies of birth outcomes have relied on comparisons between mothers who reported fasting to those who did not. Kavehmanesh and Abolghasemi [2004] compared 284 births to mothers in Tehran with a "history of fasting during pregnancy" to 255 mothers who did not fast. Although there were no statistically significant differences with respect to maternal education or height, pre-pregnancy BMI's were substantially higher in the fasting group. For such comparisons, the conditional independence assumption required for causal inference [Angrist and Pischke, 2009] is tenuous. Shahgheibi et al. [2005] studied 179 newborns for whom Ramadan fell in the third trimester of pregnancy. Among fasters, birth weight was lower by 33 grams, birth length was lower by about 0.2 centimeters while head circumference was larger by 0.08 centimeters. Since these differences were not statistically significant with the small sample used, the authors concluded that fasting during the third trimester had "no effect" on growth indices. Arab and Nasrollahi [2001] studied 4,343 pregnancies in the Hamdan province of Iran and concluded that fasting did not impact birth weight. They did note however, that the incidence of low birth weight (< 2500 grams) was higher among fasters in the second trimester but that this was significant only at the 9 percent level.

The largest and perhaps most commonly cited study on the effects of Ramadan on birth weight conducted a retrospective analysis of 13,351 babies born at *full term* from 1964-84 in Birmingham, England Cross et al. [1990]. Babies were categorized as Muslim on the basis of the first three letters of the mother's surname and were matched to control groups by age. However, this study did not compare the birthweights of Muslims *in utero* during Ramadan to Muslims who were not *in utero* during Ramadan but instead compared across groups of Muslims and Non-Muslims. Although Cross et al. [1990] found no significant effects on mean birth weight, like Arab and Nasrollahi [2001], they also found a higher incidence of low birth weight among fasters during the second trimester. Opaneye et al. [1990] found that in Al-Kharj, Saudi Arabia, the incidence of low birth weight increased during Islamic festivals, Ramadan in particular. 9.9% of the 415 births were below 2,500 grams during Ramadan, versus 6.3% for the 4,865 births in non-Ramadan months. Finally, Malhotra et al. [1989] and Mirghani and Hamud [2006] found no effects on birthweight and APGAR scores, even though they detected substantial biochemical changes.

A separate literature has found that skipping meals (not associated with Ramadan) has been associated with preterm delivery. Siega-Riz et al. [2001] studied diets during the second trimester of pregnancy for over 2000 women in North Carolina and found that women who did not follow the optimal guidelines of three meals and two snacks a day were 30 percent more likely to deliver preterm. They suggest that this is consistent with experimental evidence from animal studies. Herrmann et al. [2001] also reported that women who fasted for 13 hours or more were three times more likely to deliver preterm.

While most studies have focussed on birth weight, Mirghani and Hamud [2006] considered a broader range of birth outcomes. Specifically, they compared 168 pregnant fasters to a control group of 156 non-fasting mothers and found significantly higher rates of gestational diabetes, induced labor, cesarian sections, and admission to the special baby care unit.

A.4.2 Longer-term Effects

We are aware of just one previous study of on long-term effects of Ramadan. Azizi et al. [2004] surveyed outcomes among 191 children enrolled in 15 Islamic primary schools in Iran and their mothers about Ramadan fasting during pregnancy. Approximately half of the mothers selected for the analysis sample reported fasting. More than 1,600 mothers returned questionnaires regarding their fasting behaviour during pregnancy. However, the fraction of this initial sample who fasted during pregnancy is not reported by Azizi et al. [2004]. Among fasting mothers, those fasting during the third trimester were over-sampled. No significant difference in the IQ's of the children were found by maternal fasting behaviour. As mentioned in the main text, Ewijk [2009] analyzes long-term Ramadan effects using the Indonesian Family Life Study data. This work was inspired by ours and generally finds corroborative results.

A.5 Nutrition and the Sex Ratio at Birth

Widely studied in evolutionary biology, the Trivers-Willard hypothesis posits that the reproductive success of sons is more sensitive to maternal condition than that of daughters [Trivers and Willard, 1973]. Therefore, parents experiencing better conditions may favor male offspring. More generally, the sex ratio at birth and early childhood may proxy for unobserved health conditions given disproportionate male susceptibility to fetal and infant mortality [Kraemer, 2000, Mathews and Hamilton, 2005]. One proposed mechanism by which adjustment to the sex ratio may take place is through the nutritional status of the mother while pregnant [Cameron, 2004]. Roseboom et al. [2001] found that prenatal exposure to the Dutch famine of 1944-45 reduced the sex ratio of live births. Similarly, Almond et al. [2007] found the sex ratio in China was skewed toward females for cohorts born during the Great Leap Forward Famine. Askling et al. [1999] showed that women who experience severe morning sickness were much more likely to have girls.

A widely-publicized study by Mathews et al. [2008] has for the first time drawn a link between maternal nutrition prior to conception and the sex ratio at birth. The authors collected detailed information on food intake prior to pregnancy, early in pregnancy (14 weeks gestation) and late in pregnancy (28 weeks gestation) in Britain. They found no differences in the rates of male births arising from differences in nutritional intake either early or late in pregnancy but found a highly statistically significant positive relationship between high nutritional scores prior to conception and the birth of male offspring. They further examined the detailed data on sources of nutrition and found that among 133 food items consumed prior to pregnancy, only breakfast cereals was strongly associated with infant sex. The authors speculated that the mechanism underlying this connection is that the skipping of breakfast

> "*extends the normal period of nocturnal fasting, depresses circulating glucose levels and may be interpreted by the body as indicative of poor environmental conditions.*"

Mathews et al. [2008] also referenced work by Larson et al. [2001] on *in vitro* fertilization of bovine embryos showing that glucose "enhances the growth and development of male conceptuses while inhibiting that of females."

The study by Mathews et al. [2008] was observational and did not explore the source of dietary differences across mothers, nor did it control for some other factors known to influence the sex ratio (e.g., partnership status at the time of conception [Norberg, 2004]). Short of a controlled experiment, the research design utilized here has the advantage of leveraging plausibly exogenous differences in maternal fasting.

A.6 Hypotheses: Outcomes and Timing

In this section, we distill findings from the biomedical literature most relevant to our Ramadan analysis. Appendix Table A1 summarizes the set of health outcomes we might expect to be affected by fasting (column 1), notes the mechanism (column 2), and lists the months of prenatal exposure that have been found or suggested to be particularly important (column 3). These hypotheses are based on either a clearly defined pathway linking fasting to a particular outcome, or an empirical result that has been established, irrespective of whether there is an explicit mechanism described in the study. In many of the studies, the period of *in utero* exposure was selected by design and therefore does not exclude effects in other periods.

In the case of birthweight, we describe four mechanisms through which fasting might operate and one empirical finding based on the Dutch famine. Two of the birthweight mechanisms are tightly linked to exposures occurring in early pregnancy. For several outcomes there are no clear hypotheses concerning timing that we could discern; a reasonable hypothesis would be to jointly test the effects of Ramadan exposure during all gestation months.

With respect to longer-term effects, in virtually all cases exposure to fasting during early pregnancy is the predominant hypothesis. For cognitive function, there are several arguably distinct channels through which prenatal fasting might be detrimental.

B Data

B.1 Michigan Natality Microdata

Our ancestry-based proxy for Muslim status is coded as follows. For births from 1989 to 1992, we include mothers who report their ancestry as "Arab/Middle Eastern" in the ITT (whose pregnancies also overlap with a Ramadan). Starting in 1993, several specific country codes for ancestry are reported. From 1993 to 2006 our ITT group includes mothers who report ancestry as: Arab/Middle Eastern, Arab/North African, Iran, Afghanistan, Mauritania, Somalia, Turkey or Western Sahara. Overall, 96% of our treatment group report their ancestry as Arab/Middle Eastern, hence we refer to the group as Arabs.

We also implement several other sample selection rules to minimize measurement error and misclassification of Muslims into the control group. We dropped births with no reported ancestry or where the ancestry might possibly include non-Arab parents who are practicing Muslims (e.g. Southeastern Asians). We also dropped non-Arab Blacks to avoid the possibility that there might be "Black Muslims" in our sample. We also dropped twin births and restricted the sample to births among mothers between the ages of 14 and 45.

The summary statistics are shown in Appendix Table A2. Arab mothers reported a year less education than non-Arab mothers on average, and are substantially more likely to receive Medicaid (46% versus 27%). Arab families are also larger (average parity is 18% higher for Arabs). Despite these differences in socioeconomic measures, birth outcomes are more similar. Rates of low birth weight and prematurity are actually slightly lower for Arabs than for non-Arabs. The geographic distribution of the Arab population (not share) by zipcode in Michigan is shown in Appendix Figure A2. As the map shows the Arab population is not just limited to the Dearborn and Detroit area (Panel A).

The key variables for assigning *in utero* Ramadan exposure are birth date and gestation length. Michigan natality data include exact date of birth and a self-reported date of last menstrual period (LMP) for about 70 percent of the sample. The problem of selective reporting of LMP based on socioeconomic status is well known [Hediger et al., 1999]. There is also a field containing the physician's estimate of gestation length, but we do not know how it is calculated or when during gestation.[6] We follow related epidemiological studies that utilize a simple algorithm for coding gestation (e.g., Siega-Riz et al. [2001], Herrmann et al. [2001]): gestation based on LMP is used except if it is missing or if it differs with physician estimated gestation by more than 14 days, in which case the physician estimated measure is substituted.

Appendix Figure A3 provides a hypothetical example to illustrate how our daily measures of Ramadan exposure are calculated. In 1989, Ramadan began on April 7th and ended on May 6th. For someone who was conceived on April 6th, his or her entire first month of gestation would overlap with Ramadan. Since during this Ramadan, daylight hours averaged about 13.7 hours per day, compared to 15.2 during the summer solstice, the hours exposure measure (exp hours) peaks at about 0.9.

B.2 Uganda Census 2002

The Uganda Census contains roughly 2.5 million records (10% sample). Our main analysis sample includes men and women ages 20 to 80. Individuals whose birth month or birth year were imputed are dropped.[7] For each outcome measure, we recoded those with imputed data to missing. The disability question in the Uganda survey instrument asks:

[6] A key concern is that this could be endogenous to Ramadan exposure. For example, if Ramadan affects fetal size and if physician estimates of LMP are based on measures of fetal size, this could lead to mis-measurement of the timing of Ramadan exposure. In addition, this measure might not be calculated uniformly and may depend on the timing of the first doctor visit and could therefore, be correlated with mother's socioeconomic status. In previous work we have found that our results are not very different if we ignore LMP data and just assume a full gestation length for all births.

[7] The IPUMS-I "unharmonized" variables contain imputation flags. We allowed records with "logical imputations" but dropped records imputed by "hot-deck".

"Does (name) have any difficulty in moving, seeing, hearing, speaking difficulty, mental or learning difficulty, which has lasted or is expected to last 6 months or more?" The following specific disabilities are recorded in the dataset: blind or vision impaired, deaf or hearing impaired, mute, disability affecting lower extremities, disability affecting upper extremities, mental/learning disabilities and psychological disabilities. The original unharmonized variables label the last two variables "mental retardation" and "mental illness" while IPUMS-I relabelled them as "mental" and "psychological". Our own reading of the instructions to the Uganda Census enumerators suggests that this relabelling was indeed appropriate. The former measure appears to identify those with "mental or learning disabilities" while the latter identifies those exhibiting "strange behaviors". A subsequent question asks about the origin of the reported disability. The responses are coded into the following categories: congenital, disease, accident, aging, war injury, other or multiple causes.

The summary statistics are reported in Appendix Table A3. In contrast to Michigan, Uganda Muslims tend to have higher average SES. Muslims are less likley to be illiterate than non-Muslims (30% versus 36%) and completed more schooling. Disability rates for Muslims are also lower – 3.8% versus 5.2% for non-Muslims. Both Muslims and non-Muslims share a strong seasonality in the frequency of births by month. For both groups, birth in June was more than 50% more likely than birth in December. The frequency distribution across Ramadan ITT gestation months is much more uniform, and similar between Muslims and non-Muslims.

ITT assignment is determined by the reported birth month. We found age heaping: spikes in the number of respondents reporting of ages ending in zeroes (e.g. 20, 30, 40), suggesting measurement error. We therefore excluded records reporting these round-number ages.

B.3 Iraq Census 1997

The Iraq Census is also a 10 percent sample. We dropped individuals who reported ages ending in seven because of heaping at those ages. We also drop those reporting birth months of January and July because of heaping at those months. We also drop those born before 1958 due to extremely high levels of missing values for month of birth. This leaves us with a sample of over 250,000 individuals between the ages of 20 and 39 in 1997.

The reduced number of birth cohorts can potentially affect our ability to separate the effects of Ramadan exposure from season of birth trends for outcomes that are highly seasonal. We found school related outcomes to be highly seasonal in Iraq. We suspect that this is due to institutional factors that determine school starting or leaving ages at particular dates of the calendar year. We find, for example, that mean schooling levels were about 12 percent higher for those born between September and December than for those born between February and April. Because of the timing of Ramadan among the 1958 to 1977 cohorts, those born between February through April had no exposure to Ramadan in the first month of pregnancy, while those born between September and December had mean exposure of about 0.11 thereby inducing a highly positve correlation between early Ramadan exposure and schooling. In contrast, we find no evidence of strong season of birth patterns in our main outcomes of interest. For example, mean disability rates are only about 1.2 percent lower for those born in September through December compared to those born between February and April with no discernible monthly pattern.

B.4 Other Suitable Datasets?

The Uganda and Iraq Census microdata were obtained from the Integrated Public Use Microdata Series - International (IPUMS-I). Other potentially relevant IPUMS-I samples are those for Egypt, Jordan, and Malaysia. Each has a large population of Muslims with Census data that purportedly include birth month.[8] Religion is not reported for Egypt and Jordan, but like Iraq, are overwhelmingly Muslim. However, in Egypt 85% of the sample is missing birth month. 40% are missing birth month in Malaysia, and only .5% of adults report a work disability. In Jordan's data, birth year and place of birth are missing.

In the US, month of birth is not reported in the decennial Census. While the National Health Interview Survey (NHIS) reports birth month, it does not disclose religion, detailed ethnicity, or country of birth.

References

A Adlouni, N Ghalim, R Sale, N Had, and A Bensliman H Parra and. Beneficial effect on serum apo ai, apo b and lp ai levels of ramadan fasting. *Clinica Chimica Acta*, 271 (2):179–189, March 1998.

Douglas Almond, Lena Edlund, Hongbin Li, and Junsen Zhang. Long-term effects of the 1959-61 china famine: Mainland china and hong kong. *NBER Working Paper No. 13384*, September 2007.

[8]Birth month and religion are available in the census of South Africa (unharmonized variables in IPUMS-I), but South Africa's Muslim population is relatively small (roughly 1.5% of the population).

Joshua D. Angrist and Jörn-Steffen Pischke. *Mostly Harmless Econometrics: An Empiricist's Companion*. Princeton University Press, Princeton, New Jersey, 2009.

M Arab. Ketonuria and serum glucose of fasting pregnant women at the end of a day in ramadan. *The Journal of Physiology*, 553(2):637–647, 2003.

Malihe Arab and Shahla Nasrollahi. Interrelation of ramadan fasting and birth weight. *Medical Journal of the Islamic Academy of Sciences*, 14(3):91–95, 2001.

J. Askling, G. Erlandsson, M. Kaijser M, O. Akre, and A. Ekbom. Sickness in pregnancy and the sex of the child. *Lancet*, 354(9195):2053, December 1999.

Fereidoun Azizi, Hossein Sadeghipour, Behnam Siahkolah, and Nasrollah Rezaei-Ghaleh. Intellectual development of children born to mothers who fasted during pregnancy. *International Journal of Vitamin and Nutrition Research*, 74(5):374–380, September 2004.

Elissa Z. Cameron. Facultative adjustment of mammalian sex ratios in support fo the trivers-willard hypothesis: evidence for a mechanism. *Proceedings of the Royal Society B: Biological Sciences*, 271(1549):1723–1728, 2004.

TJ Cole. *Seasonality and Human Ecology*, chapter Seasonal Effects on Physical Growth and Human Development, pages 89–106. Cambridge University Press, Cambridge, 1993.

JH Cross, J Eminson, and BA Wharton. Ramadan and birth weight at full term in asian moslem pregnant women in birmingham. *Archives of Disease in Childhood*, 653: 1053–56, 1990.

E. Dikensoy, O. Balat, B. Cebesoy, A. Ozkur, H. Cicek, and G. Can. The effect of Ramadan fasting on maternal serum lipids, cortisol levels and fetal development. *Archives of gynecology and obstetrics*, 279(2):119, 2009.

Janet A. DiPietro, Kathleen Costigan, Marc H. Bornstein, Chun-Shin Hahn, and Aristide Achy-Brou. Fetal heart rate and variability: Stability and prediction to developmental outcomes in early childhood. *Child Development*, 78(6):1788–1798, November/December 2007.

PM Eaton and PA Wharton. *Applied Nutrition*, chapter Sorrento Study of Nutrition in Pregnancy, pages 89–91. John Libbey, London, 1982.

Reyn Van Ewijk. Long-term health effects on the next generation of ramadan fasting during pregnancy. April 2009. CEP Discussion Paper No 926.

Mary L. Hediger, Mary D. Overpeck, Andrea McGlynn, Robert J. Kuczmarski, Kurt R. Maurer, and William W. Davis. Growth and fatness at three to six years of age of children born small- or large-for-gestational age. *Pediatrics*, 104(3):e33, 1999.

Tracy S Herrmann, Anna Maria Siega-Riz, Calvin J Hobel, Chandra Aurora, and Christine Dunkel-Schetter. Prolonged periods without food intake during pregnancy increase risk for elevated maternal corticotropin-releasing hormone concentrations. *American Journal of Obstetrics and Gynecology*, 185(2):403–412, 2001.

Ann Hoskins. Pregnancy and fasting during ramadan. *British Medical Journal*, 304(6836): 1247, May 1992.

ES Hunter and TW Sadler. D-(-)-beta hydroxybutyrate-induced effects on mouse embryos in vitro. *Teratology*, 36:259–64, 1987.

R Husain, MT Duncan, SH Cheah, and SL Chng. Effects of fasting in ramadan on tropical asiatic moslems. *British Journal of Nutrition*, 5833(1):41–48, 1987.

Vincent W.V. Jaddoe and Jacqueline C.M. Witteman. Hypotheses on the fetal origins of adult diseases: Contributions of epidemiological studies. *European Journal of Epidemiology*, 21:91–102, 2006.

J Joosoph and S.L. Yu. A survey of fasting during pregnancy. *Singapore Medical Journal*, 45(12):583–586, 2004.

Amita Kapoor, Elizabeth Dunn, Alice Kostaki, Marcus H. Andrews, and Stephen G. Matthews. Fetal programming of hypothalamo-pituitary-adrenal function: Prenatal stress and glucocorticoids. *Journal of Physiology*, 572(1):31–44, 2006.

Zohreh Kavehmanesh and Hassan Abolghasemi. Maternal ramadan fasting and neonatal health. *Journal of Perinatology*, 24:748–750, 2004.

Sebastian Kraemer. The fragile male. *BMJ*, 321(7276):1609–1612, 2000.

SJ Langan, IJ Deary IJ, DA Hepburn, and BM Frier. Cumulative cognitive impairment following recurrent severe hypoglycaemia in adult patients with insulin-treated diabetes mellitus. *Diabetologia*, 34:337–344, 1991.

Melissa A. Larson, Koji Kimura, Michael Kubisch, and R. Michael Roberts. Sexual dimorphism among bovine embryos in their ability to make the transition to expanded blastocyst and in the expression of the signaling molecule ifn-t. *PNAS*, 98(17):9677–9682, 2001.

Abdulwahab M. Makki. Impact of ramadan fasting on birth weight in 4 hospitals in sanaa city,yemen. *Saudi Medical Journal*, 23(11):1419–1420, 2002.

Ashok Malhotra, P.H. Scott, J.S. Scott, H. Gee, and B.A. Wharton. Metabolic changes in asian muslim pregnant mothers observing the ramadan fast in britian. *British Journal of Nutrition*, 61(3):663–672, May 1989.

Kamal Mohmoud Saleh Mansi. Study the effects of ramadan fasting on the serum glucose and lipid profile among healthy jordanian students. *American Journal of Applied Sciences*, 3(8):565–569, 2007.

Fiona Mathews, Paul J. Johnson, and Andrew Neil. You are what your mother eats: evidence for maternal preconception diet influencing foetal sex in humans. *Proceedings of the Royal Society B*, pages 1–8, April 2008.

T.J. Mathews and Brady E. Hamilton. Trend analysis of the sex ratio at birth in the united states. *National Vital Statistics Reports*, 53(20), June 14 2005.

Hisham M. Mirghani, Sarath Weerasinghe, Shamsaa Al-Awar, Lolowa Abdulla, and Mutairu Ezimokhai. The effect of intermittent maternal fasting on computerized fetal heart tracing. *Journal of Perinatology*, 25:90–92, 2005.

Hisham M. Mirghani, Muntha Salem, and Sarath D. Weerasinghe. Effect of maternal fasting on uterine arterial blood flow. *Journal of Obstetrics and Gynaecology Research*, 33(2):151–154, April 2007.

H.M. Mirghani and Omer A. Hamud. The effect of maternal diet restriction on pregnancy outcome. *American Journal of Perinatology*, 23(1):21–24, 2006.

H.M. Mirghani, S.D. Weerasinghe, J.R. Smith, and M. Ezimokhai. The effect of intermittent maternal fasting on human fetal breathing movements. *Journal of Obstetrics and Gynaecology*, 24(6):635–637, September 2004.

DCP Moore, M Stanisstreet, and CA Clarke. Morphological and physiological effects of beta-hydroxybutyrate on rat embryos grown in vitro at different stages. *Teratology*, 40: 237–51, 1989.

Hidenori Nishina, Lucy R. Green, Hugh H. G. McGarrigle, David E. Noakes, Lucilla Poston, and Mark A. Hanson. Effect of nutritional restriction in early pregnancy on isolated femoral artery function in mid-gestation fetal sheep. *Acta Medica Iranica*, 42 (3):209–212, 2004.

Karen Norberg. Partnership status and the human sex ratio at birth. *Proceedings of the Royal Society B: Biological Sciences*, 271(1555):2403–2410, 2004.

A.A. Opaneye, D.D. Villegas, and Ali Abdel Azeim. Islamic festivals and low birthweight infants. *The Journal of the Royal Society for the Promotion of Health*, 110(3):106–107, June 1990.

Rebecca C. Painter, Tessa J. Roseboom, and Otto P. Bleker. You are what your mother eats: evidence for maternal preconception diet influencing foetal sex in humans. *Reproductive Toxicology*, 20:345–352, 2005.

AM Prentice, A Prentice, WH Lamb, PG Lunn, and S. Austin. Metabolic consequences of fasting during ramadan in pregnant and lactating women. *Human nutrition. Clinical nutrition*, 37(4):283–94, July 1983.

J Ramadan, G Telahoun, NS Al-Zaid, and M Barac-Nieto. Responses to exercise, fluid, and energy balances during ramadan in sedentary and active males. *Nutrition*, 15(10): 735–739, 1999.

T Rizzo, BE Metzger, WJ Burns, and K Burns. Correlations between antepartum maternal metabolism and child intelligence. *New England Journal of Medicine*, 325:911–916, 1991.

Trinka Robinson and Jeanne Raisler. Each one is a doctor for herself: Ramadam fasting among pregnant muslim women in the united states. *Ethnicity and Disease*, 15:S1–99 to S1–103, Winter 2005.

Tessa J. Roseboom, Jan H.P. Meulen, Anita C.J. Ravelli, Clive Osmond, David J.P. Barker, and Otto P. Bleker. Effects of prenatal exposure to the dutch famine on adult disease in later life: An overview. *Twins Research*, 4(5):293–298, October 2001.

Theresa O Scholl, MaryFran Sowers, Xinhua Chen, and Carine Lenders. Maternal glucose concentration influences fetal growth, gestation and pregnancy complications. *American Journal of Epidemiology*, 154(6):514–520, 2001.

Shole Shahgheibi, Ebrahim Ghadery, Arash Pauladi, Sabah Hasani, and Syroos Shahsawari. Effects of fasting during the third trimester of pregnancy on neonatal growth indices. *Annals of Alquds Medicine*, 1426(2):58–62, 2005.

EA Sheehan, F Beck, CA Clarke, and M Stanisstreet. Effects of beta-hydroxybutyrate on rat embryos grown in culture. *Experentia*, 41:273–75, 1985.

Anna Maria Siega-Riz, Tracy Hermann, David A Savitz, and John M Thorp. Frequency of eating during pregnancy and its effect on preterm delivery. *American Journal of Epidemiology*, 153(7):647–652, 2001.

Hamed R Takruri. Effect of fasting in ramadan on body weight. *Saudi Medical Journal*, 10(6):491–494, 1989.

Edith W. M. T. ter Braak, Inge M. Evers, D. Willem Erkelens, and Gerard H. A. Visser. Maternal hypoglycemia during pregnancy in type 1 diabetes: maternal and fetal consequences. *Diabetes/Metabolism Research And Reviews*, 19:96–105, 2002.

Robert L. Trivers and Dan E. Willard. Natural selection and the ability to vary the sex ratio of offspring. *Science*, 179(4068):90–92, January 1973.

Table A1: Summary of Hypotheses Concerning Outcomes Affected by Fasting and Timing In Utero

Outcome	Description of Mechanism (studies)	Gestation month
Birth Outcomes		
Birthweight	Direct effect of low blood glucose (Scholl et al, 2001)	6 to 7
Birthweight	Exposure to ketones, animal studies (Hunter, 1987; Moore, 1989)	1
Birthweight	HPA axis (various studies)	1 to 2
Birthweight	Low birthweight due to shorter gestation (Siega-Riz et al, 2001)	5 to 7
Birthweight	Empirical result --Dutch Famine (Painter et al 2005)	7 to 9
Low Birth Weight	Empirical result (Cross et al 1990; Arab and Nasrollahi, 2001)	4 to 6
Gestation	Fasting associated with high Plasma CRH (Siega-Riz et al, 2001)	5 to 7
NICU	empirical result (Mirghani and Hamud, 2006)	8
C-section	empirical result (Mirghani and Hamud, 2006)	8
Induced Labor	empirical result (Mirghani and Hamud, 2006)	8
Sex Ratio	Effect of low glucose, empirical result (Matthews et al, 2008)	0
Long-Term Outcomes		
Diabetes	Fetal nutrition (various studies)	1 to 3
Heart Disease	Fetal nutrition (various studies)	1 to 6
Cognitive Function	Exposure to ketones, animal studies (Hunter, 1987; Moore, 1989)	1
Cognitive Function	Low blood glucose (Rizzo et al, 1991)	1 to 3
Cognitive Function	HPA axis (Kapoor et al, 2006)	1 to 2
Cognitive Function	Fetal Heart Rate (Mirghani, 2005)	7 to 9
Adult Sex Ratio	HPA axis (Kapoor et al, 2006)	1 to 2

Notes: This table is based on a review of selected studies and does not include all relevant studies in the medical literature. Studies include both human and animal studies. In many of the studies, the period of in utero exposure was selected by design and therefore the fact that an effect was found in the chosen gestation period does not rule out possible effects in other periods.

Table A2: Summary Statistics for Michigan Natality Data, 1989-2006

	Arab			Non-Arab		
	mean	s.d.	N	mean	s.d.	N
Mother's Age	27.54	5.72	46979	27.41	5.73	1638059
Mother's Education	12.03	3.55	45584	13.18	2.37	1625226
Father's Age	33.81	6.48	45588	30.21	6.13	1462349
Father's Education	12.92	3.33	43931	13.40	2.39	1428050
Male Child	0.52	0.50	46983	0.51	0.50	1638213
Tobacco	0.04	0.19	46203	0.19	0.39	1611440
Alcohol	0.00	0.04	46170	0.02	0.12	1608527
Maternal Weight Gain	29.73	12.70	42216	31.04	13.03	1520595
No Prenatal Care	0.01	0.10	45068	0.01	0.08	1607940
Prenat. Care Begins 1st Trim.	0.86	0.34	45068	0.87	0.34	1607940
Prenat. Care Begins 2nd Trim.	0.10	0.29	45068	0.11	0.31	1607940
Prenat. Care Begins 3rd Trim.	0.03	0.17	45068	0.02	0.13	1607940
Medicaid	0.46	0.50	46315	0.27	0.45	1616231
Fraction Arab, Zipcode	0.21	0.25	46369	0.01	0.03	1612481
Birthweight	3325.08	513.65	46896	3427.71	565.23	1635183
Low Birthweight	0.04	0.21	46988	0.05	0.21	1638244
Infant Death	0.01	0.07	46988	0.01	0.08	1638244
Parity	1.64	1.74	46592	1.39	1.49	1628783
Preterm	0.06	0.23	46868	0.07	0.25	1633654
Gestation (author's calc.)	39.27	1.72	46868	39.29	1.85	1633654
Apgar 5 minute	8.94	0.56	46902	8.94	0.67	1632994
NICU	0.03	0.17	46915	0.04	0.19	1634113
Complication	0.25	0.43	46188	0.28	0.45	1618589
Abnormal Condition	0.06	0.24	46012	0.07	0.25	1611065
Medical Risk	0.20	0.40	46169	0.23	0.42	1618107
Medical Risk Diabetes	0.03	0.16	46169	0.03	0.17	1618107
Born January	0.077	0.27	46988	0.078	0.27	1638244
Born February	0.074	0.26	46988	0.077	0.27	1638244
Born March	0.083	0.28	46988	0.087	0.28	1638244
Born April	0.079	0.27	46988	0.084	0.28	1638244
Born May	0.084	0.28	46988	0.088	0.28	1638244
Born June	0.087	0.28	46988	0.086	0.28	1638244
Born July	0.089	0.29	46988	0.089	0.28	1638244
Born August	0.091	0.29	46988	0.088	0.28	1638244
Born September	0.087	0.28	46988	0.085	0.28	1638244
Born October	0.084	0.28	46988	0.083	0.28	1638244
Born November	0.081	0.27	46988	0.076	0.27	1638244
Born December	0.083	0.28	46988	0.078	0.27	1638244
Exp Hours 1	0.056	0.15	46868	0.056	0.15	1633654
Exp Hours 2	0.059	0.15	46868	0.058	0.16	1633654
Exp Hours 3	0.058	0.15	46868	0.059	0.16	1633654
Exp Hours 4	0.059	0.15	46868	0.060	0.16	1633654
Exp Hours 5	0.057	0.15	46868	0.060	0.16	1633654
Exp Hours 6	0.056	0.15	46868	0.060	0.16	1633654
Exp Hours 7	0.056	0.15	46868	0.061	0.16	1633648
Exp Hours 8	0.057	0.15	46865	0.061	0.16	1633617
Exp Hours 9	0.059	0.16	46861	0.060	0.16	1633475

Table A3: Summary Statistics for Uganda Census Sample

	Muslim			Non-Muslim		
	mean	s.d.	N	mean	s.d.	N
female	0.494	0.500	81197	0.498	0.500	643300
age	34.546	12.675	81197	36.697	13.907	643300
illiterate	0.304	0.460	78990	0.356	0.479	626473
years of schooling	6.944	3.269	60117	6.797	3.599	449968
no schooling	0.247	0.431	80142	0.290	0.454	635282
employed	0.660	0.474	74348	0.631	0.483	581842
elementary occupation	0.042	0.200	46284	0.042	0.200	347248
home ownership (males)						
# of wives (males)						
disability	0.0380	0.191	80924	0.0521	0.222	640825
blind/vision impaired	0.0106	0.102	80922	0.0149	0.121	640789
deaf/hearing impaired	0.0038	0.062	80923	0.0061	0.078	640781
mute/speech impaired	0.0009	0.030	80921	0.0015	0.038	640780
lower extremities	0.0125	0.111	80921	0.0161	0.126	640794
upper extremities	0.0039	0.062	80921	0.0056	0.075	640779
mental/learning	0.0014	0.037	80921	0.0017	0.041	640777
psychological	0.0014	0.038	80921	0.0020	0.045	640776
epilepsy	0.0005	0.023	80921	0.0009	0.031	640777
rheumatism	0.0009	0.030	80921	0.0016	0.039	640776
congen	0.0050	0.070	80921	0.0058	0.076	640778
disease	0.0203	0.141	80924	0.0283	0.166	640803
accident	0.0056	0.074	80921	0.0079	0.088	640782
occupational injury	0.0053	0.072	80921	0.0074	0.086	640786
war_injury	0.0007	0.027	80921	0.0013	0.036	640777
aging	0.0053	0.072	80921	0.0074	0.086	640786
Born January	0.105	0.306	81197	0.096	0.294	643300
Born February	0.076	0.265	81197	0.075	0.263	643300
Born March	0.072	0.258	81197	0.072	0.259	643300
Born April	0.110	0.313	81197	0.106	0.308	643300
Born May	0.070	0.256	81197	0.070	0.256	643300
Born June	0.102	0.302	81197	0.105	0.307	643300
Born July	0.094	0.292	81197	0.098	0.298	643300
Born August	0.079	0.269	81197	0.083	0.275	643300
Born September	0.079	0.269	81197	0.081	0.272	643300
Born October	0.078	0.268	81197	0.077	0.267	643300
Born November	0.069	0.253	81197	0.069	0.253	643300
Born December	0.067	0.250	81197	0.068	0.251	643300
Days 1	0.081	0.215	81197	0.081	0.216	643300
Days 2	0.079	0.214	81197	0.079	0.215	643300
Days 3	0.077	0.211	81197	0.078	0.212	643300
Days 4	0.084	0.219	81197	0.083	0.218	643300
Days 5	0.086	0.223	81197	0.085	0.221	643300
Days 6	0.084	0.217	81197	0.083	0.217	643300
Days 7	0.087	0.222	81197	0.085	0.221	643300
Days 8	0.090	0.226	81197	0.089	0.226	643300
Days 9	0.087	0.221	81197	0.087	0.221	643300

Table A4: Effects of Ramadan Exposure on Sex at Birth and Live Births, Michigan Arabs and Non Arabs

	Dependent Variable is Log Live Births (Total, Male Female)					
Gestation	(1)	(2)	(3)	(4)	(5)	(6)
Month	Arab Sample			Non-Arab Sample		
exposure	Total	Male	Female	Total	Male	Female
0	0.070	-0.018	0.070	0.046**	0.040	0.049*
	(0.077)	(0.106)	(0.106)	(0.022)	(0.025)	(0.026)
1	-0.131*	-0.264***	-0.025	-0.021	-0.014	-0.034
	(0.070)	(0.100)	(0.095)	(0.020)	(0.022)	(0.023)
2	0.006	0.005	-0.002	0.038*	0.045*	0.038
	(0.074)	(0.102)	(0.101)	(0.022)	(0.025)	(0.025)
3	-0.084	-0.156	-0.079	-0.022	-0.020	-0.023
	(0.073)	(0.100)	(0.102)	(0.021)	(0.025)	(0.025)
4	0.071	0.006	0.096	-0.013	-0.002	-0.009
	(0.078)	(0.104)	(0.107)	(0.022)	(0.025)	(0.025)
5	-0.131*	-0.192*	-0.105	0.010	0.007	0.014
	(0.077)	(0.105)	(0.105)	(0.022)	(0.024)	(0.025)
6	0.097	0.027	0.142	0.016	0.021	0.013
	(0.073)	(0.101)	(0.099)	(0.021)	(0.024)	(0.024)
7	-0.090	-0.125	-0.123	-0.013	-0.004	-0.007
	(0.077)	(0.103)	(0.103)	(0.022)	(0.024)	(0.026)
8	0.027	-0.037	0.084	0.035*	0.041*	0.025
	(0.069)	(0.093)	(0.094)	(0.019)	(0.022)	(0.022)
9	-0.006	-0.136	0.055	0.029	0.041*	0.029
	(0.074)	(0.097)	(0.105)	(0.021)	(0.024)	(0.024)
joint test, coefficients on months 1 to 9 equal to 0						
p -value	0.48	0.52	0.77	0.07	0.17	0.32
N	216	216	216	216	216	216
Mean	4.68	4.00	3.95	8.37	7.68	7.66

Notes: Entries are coefficients on Ramadan exposure to daylight hours over subsequent 30 days as fraction of peak daylight hours during sample period. Samples include full-term births and exclude zipcodes where where the the ratio of Chaldeans to non-Chaldean Arabs is greater than 1. Regressions include controls for mother's age, mother's age squared, mother's education, tobacco use, alcohol use, parity, father's education, dummy for missing father's education, father's age, father's age squared, number of previous pregnancies that resulted in death at birth, conception month dummies, county dummies and birth year dummies. Standard errors in parentheses.
*significant at 10%; ** significant at 5%; *** significant at 1%

Figure A1: Women's Weight Change Around Ramadan in Gambia

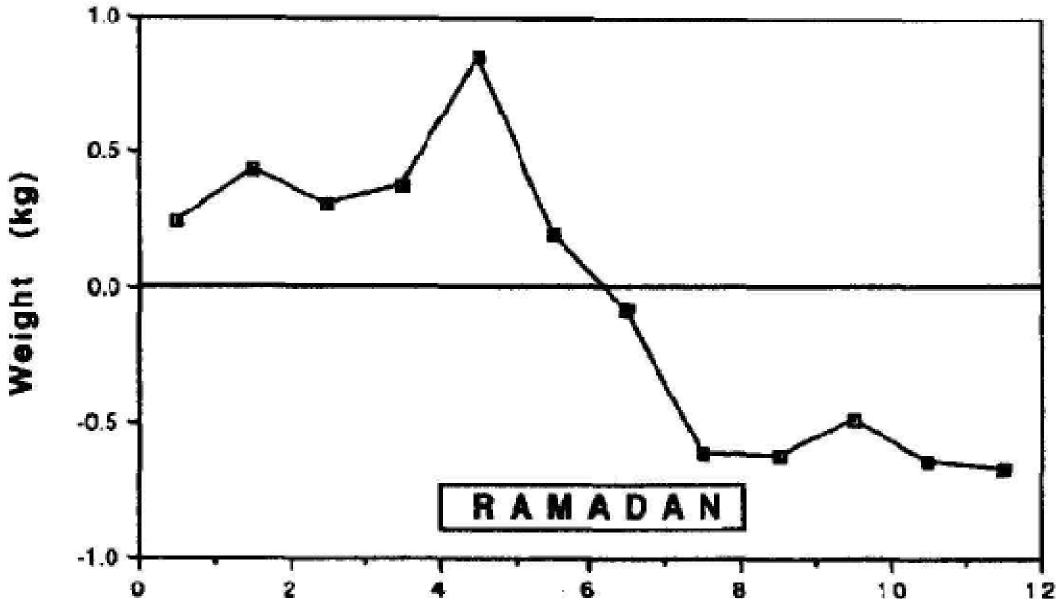
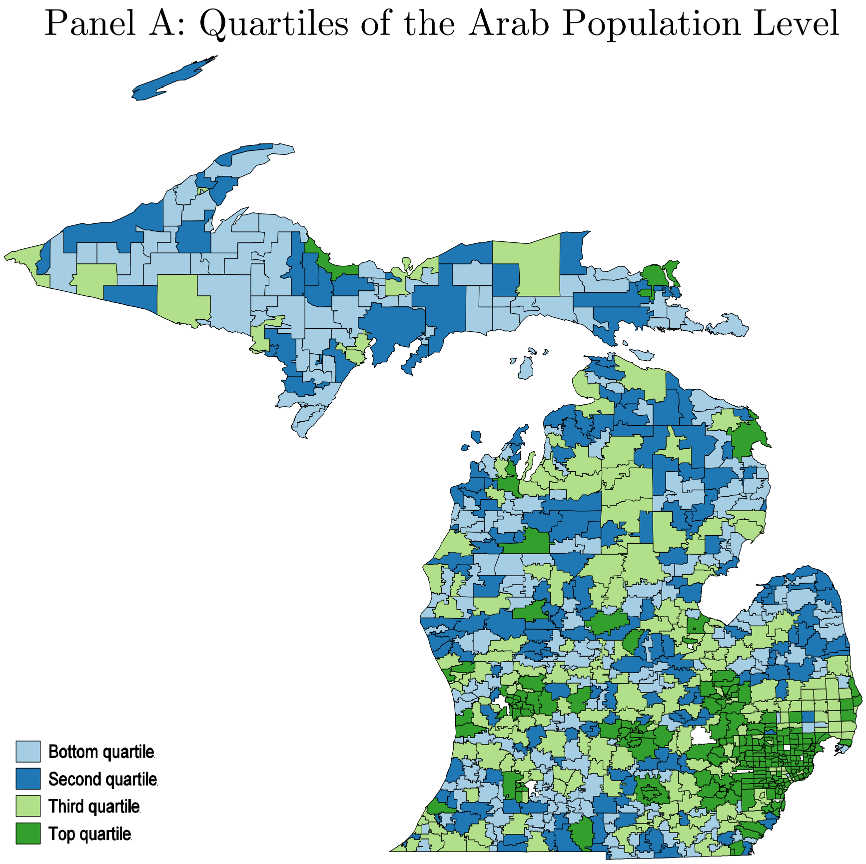
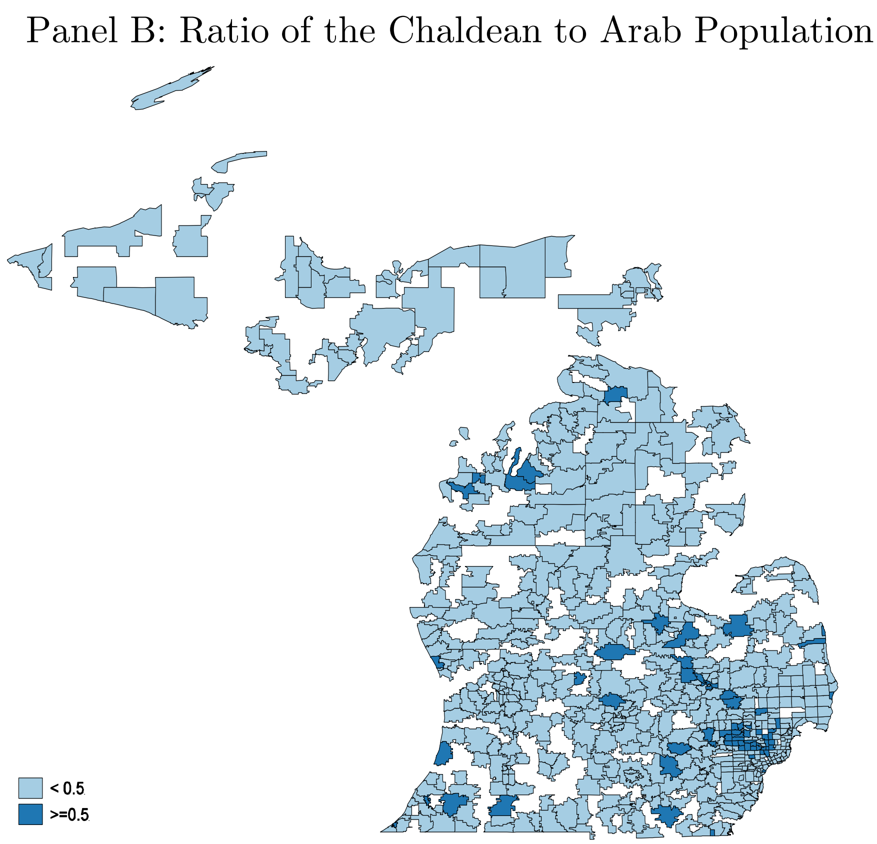


Fig. 8.5. Weight change in Gambian women during 3 months around the fast of Ramadan, expressed relative to mean weight for the other 9 months of the year. Each point has a standard error of about 0.15 kg. The data are adjusted for calendar month and year of measurement, and stage of pregnancy/lactation, using within-subject regression.

Source: Cole (1993)

Figure A2: Michigan Arab Population by Zipcode





Source: Author's calculations using the 2000 Census SF3 file

Figure A3:
First Gestation Month Exposure to Ramadan