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

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Abstract

We use the Islamic holy month of Ramadan as a natural experiment in fasting and fetal health. In Michigan births 1989-2006, we find prenatal exposure to Ramadan among Arab mothers results in lower birthweight. Exposure to Ramadan in the first month of gestation is also associated with a sizable reduction in the number of male births. In Census data for Uganda and Iraq we find strong associations between *in utero* exposure to Ramadan and the likelihood of being disabled as an adult. Effects are particularly large for mental (or learning) disabilities. To a lesser extent, we also find that wealth proxies are compromised. We find no evidence that negative selection in conceptions during Ramadan accounts for our findings, suggesting that avoiding Ramadan exposure during pregnancy is costly or the long-term effects of fasting unknown.

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1 Introduction

Restricted maternal nutrition during critical windows of fetal development can lead to adaptive physiologic responses that are irreversible and later lead to poor adult outcomes [Gluckman and Hanson, 2005]. Recent studies by economists have utilized exogenous shocks "caused by conditions outside the control of the mother" [Currie, 2009] to provide compelling observational evidence on the general importance of prenatal development, which can impact both subsequent health capital and skill formation [Cunha and Heckman, 2007]. These studies have typically leveraged uncommon and severe historical events, such as exposure to famine or infectious disease, for identification. There is less conclusive evidence as to whether more commonly encountered circumstances such as compromised nutrition during fetal development also exert significant long-term effects.[1] Such exposures are not only more directly relevant to the physiologic pathways described in the biomedical literature, but also may be more amenable to outside intervention.

In this study, we consider a common early-life exposure that is ongoing today: disruptions to the timing of nutrition during pregnancy.[2] Specifically we consider the effects of maternal fasting. Muslims generally fast each day during the lunar month of Ramadan. Fasting includes abstaining from eating and drinking during daylight hours. Certain persons are automatically exempted from fasting: "children, those who are ill or too elderly, those who are traveling, and women who are menstruating, have just given birth, or are breast feeding" [Esposito, 2003]. While pregnant women may be exempted, most report observing the fast. Because Ramadan overlaps with pregnancy in three of every four births, roughly 1 billion Muslims alive today were *in utero* during Ramadan.

As we discuss in Section 2, previous studies in both developed and developing countries have shown that fasts associated with Ramadan during pregnancy can lead to sharp declines in maternal glucose levels along with other biochemical changes in the fetal environment, a phenomenon known as "accelerated starvation"[Prentice et al., 1983, Malhotra et al., 1989]. The altered metabolic profiles that occur with fasting have been associated

[1] The chief exceptions are analyses of seasonal variation in health at birth [Doblhammer and Vaupel, 2001, Costa and Lahey, 2005] and economic contractions [Van Den Berg, Lindeboom, and Portrait, 2006, Banerjee, Duflo, Postel-Vinay, and Watts, 2010].

[2] Nearly 1 in 4 women report skipping meals during pregnancy in the US [Siega-Riz et al., 2001].

with diminished cognitive function during childhood and experimental animal studies suggest that these alterations may hamper neurological development. For these reasons, medical authorities generally discourage meal skipping during pregnancy.

More generally, the growing literature on the developmental origins of adult health and disease has emphasized that the supply of glucose and oxygen are the two key signals of the maternal environment during early embryonic development [Gluckman and Hanson, 2005]. Numerous animal studies have documented that nutritional disruptions during the prenatal period can lead to permanent physiological adaptations that may later lead to poor health conditions such as diabetes and heart disease. One proposed mechanism is that restricted nutrition leads to a reprogramming of the neuro-endocrine system. Consistent with this pathway, a recent study has documented heightened levels of the hormone cortisol among pregnant women fasting during Ramadan [Dikensoy et al., 2009].

Since sharp declines in glucose and elevated cortisol have been associated with maternal fasting during Ramadan, our study presents a relatively direct way to assess the long term effects of alterations in the fetal environment emphasized in the fetal origins literature (*cf* infectious disease during pregnancy). The hypothesized mechanisms linking prenatal nutrition to long term health are specifically related to the *timing* of prenatal nutrition rather than the total caloric intake of pregnant mothers, which may or may not decline during Ramadan as we discuss later.

We provide new evidence on fasting's effects on birth outcomes and the first evidence of effects later in life using large-sample microdata on Muslims in Iraq and Uganda. Our methodological approach addresses a key shortcoming of previous studies of Ramadan fasting and birth outcomes. Epidemiological studies have compared pregnant women who fasted to those who did not at a point in time, under the basic assumption that the decision to fast is exogenous.[3] Instead, we compare births over many years where Ramadan overlaps with pregnancy to those where Ramadan does not and estimate the reduced form effect of Ramadan's timing.[4] That is, we estimate an "intent to treat" (ITT) effect without relying on the decision whether to fast for identification.[5] This

[3]Pre-pregnancy BMI, along with other characteristics, has been found to predict fasting observance [Kavehmanesh and Abolghasemi, 2004].

[4]We do not observe whether mothers fasted in our data. See Section 6.

[5]We draw an analogy with research designs where there is random assignment to treatment and control

approach yields distinct ITT estimates for specific months of gestation; Muslim births where Ramadans falls in the early postnatal period serve as the control group.

Using Census data for Iraq and Uganda we find long-term effects on adult health and economic outcomes. We generally find the largest effects on adults when Ramadan falls early in pregnancy. Rates of adult disability are roughly 20% higher, with specific mental disabilities showing substantially larger effects. Our estimates are conservative to the extent that Ramadan is not universally observed.

Although nutritional deprivations during the prenatal period may have pronounced effects on long-term health, it is not clear that these changes in latent health will be perceptible when using rough proxies for fetal health, such as birth weight [Gluckman and Hanson, 2005]. Nevertheless, using natality data from Michigan, we do find evidence that prenatal exposure to Ramadan lowers birth weight. Some studies have also suggested that declines in maternal glucose levels serve as a signal of a poor future environment and lead to fewer completed pregnancies of male offspring. We find that the likelihood of a male birth is about 12% lower when Ramadan falls very early in pregnancy and occurs during the peak period of daylight fasting hours.

Although we use a relatively mild prenatal nutritional deprivation, our results are broadly consistent with studies of more extreme historical events such as the Dutch famine and 1918 Influenza Pandemic which also found large long-term health effects associated with early-pregnancy exposure. Our results are also consistent with studies that have documented that maternal nutrition during pregnancy varies positively with male births (in the cross-section).

Our identification strategy allows us to address seasonality in birth outcomes, a potential confounder in previous studies that have used the occurrence of Ramadan in a single year or just a few years. Because Ramadan follows a lunar calendar, its occurrence moves forward by roughly 11 days each year according to the Gregorian (Western) calendar. Therefore, over 32 years Ramadan will complete a full circuit of the Western calendar. Our sample for Uganda utilizes 60 birth cohorts which enables us to disentangle the effects of prenatal overlap with Ramadan from season of birth, which is also related

groups but where compliance may be endogenous. In our case we assume that the timing of Ramadan relative to pregnancy is exogenous, but that the decision to fast is endogenous and generally unobserved.

to health in adulthood [Doblhammer and Vaupel, 2001, Costa and Lahey, 2005, Costa et al., 2007, Buckles and Hungerman, 2008]. For our Michigan sample, however, our data only cover 18 birth cohorts leaving some concern about whether seasonality may persist as a confounding factor. Therefore, in addition to directly controlling for seasonality, we also present "difference in differences" estimates that remove any common seasonal effects experienced by the untreated group of non-Muslims (which yields remarkably similar impact estimates).

Our identifying assumption is that pregnancies are not timed relative to Ramadan along unobserved determinants of health. We present evidence that pre-determined maternal and paternal characteristics are not systematically related to the timing of conception relative to Ramadan. In our Michigan data, we observe mothers' education, whether the pregnancy was paid for by Medicaid (income proxy), mother's age, father's age, father's education, tobacco use during pregnancy, alcohol use during pregnancy, parity, whether a previous child was born dead, an indicator for missing father's education, whether the mother had previously delivered a small baby and whether diabetes was considered a risk factor for the mother: each is unrelated to the timing of pregnancy relative to Ramadan. Not surprisingly, controlling for these factors has a negligible effect on our ITT point estimates.

Although we find strong effects both at birth and in adulthood in multiple datasets, we urge further research to corroborate our findings and to better understand mechanisms. Our data cannot, for example, show whether the individuals experiencing disabilities actually experienced adverse fetal conditions. We only know that the timing of their birth is consistent with such an effect. In addition, while the available data for some samples suggests that the timing of pregnancy around Ramadan does not account for our results, there may be unobservable attributes influencing conception timing that we have not accounted for. It is also possible that patterns of selective timing of fertility may differ across countries.

Finally, although we argue that fasting is the likely explanation for our results, there are other behavioral changes associated with Ramadan observance that could conceivably affect fetal health and contribute to our findings. For example, dehydration from fluid restriction or changes in sleep patterns may also occur during Ramadan and affect fetal health. Our approach cannot disentangle these separate effects or their possible interactions. Instead our results may be more cautiously interpreted as capturing the "reduced form" effect of Ramadan.

The remainder of the paper is organized as follows. Section 2 describes previous epidemiological work on Ramadan and health, referencing additional material in the Appendix. Section 3 describes our natality and Census data, ITT measures, and econometric model. Section 4 presents our results for birth outcomes in Michigan and Section 5 describes our findings for adult outcomes in Uganda and Iraq. Section 6 synthesizes and interprets our results and discusses future research.

2 Previous Literature

We briefly summarize the relevant literature in this section and refer the reader to additional background material in Appendix, Section A.[6] We begin with the "first stage" effect of fasting during Ramadan, i.e. existing evidence on the actual observance of the Ramadan fast by pregnant women and whether it has a measurable effect on nutritional intake and weight change. We then briefly discuss previous studies relating maternal fasting to health or human capital outcomes. In discussing previous work on fasting and health it is instructive to separate studies that have evaluated: 1) measures of maternal and fetal health during pregnancy, and; 2) health at birth. In contrast to prenatal health, measurement of newborn health is relatively standardized (e.g., by birth weight or infant mortality). However, studies of maternal and fetal health allow for comparisons over time for the same pregnancy – in and out of the fasting state – addressing the potential endogeneity of the fasting decision.

Our review of the previous literature suggests that fasting early in pregnancy is most likely to matter for adult outcomes whereas birth outcomes (e.g. birthweight) could potentially be affected throughout gestation. This literature is further distilled into several hypotheses laid out in Appendix Table A1, which we use to inform our analysis. The table

[6] Appendix Section A summarizes the rates of observance of Ramadan fasting by pregnant women; the effects of fasting on caloric intake and weight gain; the potential health effects of maternal biochemical changes on offspring; fasting and fetal programming; studies of Ramadan fasting's effect on birth outcomes; and our hypotheses relating specific periods of exposure to particular outcomes.

summarizes which outcomes may be affected and which specific months of pregnancy are most vulnerable to exposure to fasting for each outcome.

2.1 First Stage Effects of Ramadan

2.1.1 Do Pregnant Women Observe the Ramadan Fast?

Although pregnant women may request an exemption from fasting, they are expected to "make up" the fasting days missed during pregnancy after delivery and this requirement 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]. Anecdotal evidence also suggests that guilt and cultural expectations may also prevent women from seeking exemptions [Robinson and Raisler, 2005]. Our review of the literature on fasting observance among pregnant women, detailed in Appendix section A.1.1, suggests that fasting is the norm. For example, estimates of fasting rates range from 70 to 90 percent and include studies from England, Gambia, Iran, Singapore, United States, and Yemen. We note that to the extent that pregnant Muslim women do not fast, our ITT estimates are conservative estimates of fasting's effect.

2.1.2 Caloric Intake and Weight Change During Ramadan

There is mixed evidence of the effects of fasting during Ramadan on caloric intake (among adults generally) that varies depending on the dietary customs in specific countries. However, among pregnant women in Iran, 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.

With respect to weight, Cole [1993] using panel data found striking evidence of a decline in weight of about 1 Kg during Ramadan for women in Gambia (see Appendix Figure A1). As we discuss below, fasting may impact fetal health due to alterations in the the timing of nutritional intake even if overall caloric intake or weight change is unaffected.

2.2 Ramadan and Health During Pregnancy

Writing in *The Lancet*, Metzger et al. [1982] documented a set of divergent biochemical measures among pregnant women who skipped breakfast in the second half of pregnancy. Relative to twenty-seven non-pregnant women with similar characteristics, "circulating fuels and glucoregulatory hormones" changed profoundly in twenty-one pregnant women when the "overnight fast" was extended to noon on the following day (relative to post-prandial baseline). Further, plasma glucose and alanine was lower in the pregnant women than in the non-pregnant women after 12 hours of fasting while levels of free fatty acids and beta-hydroxybutyrate, a ketone[7], were significantly higher. This set of biochemical changes, also known as "accelerated starvation", occurred after only "minor dietary deprivation" for both lean and obese women. Metzger et al. [1982] concluded that meal-skipping "should be avoided during normal pregnancy." Meis and Swain [1984] found that *daytime* fasts during pregnancy caused significantly lower glucose concentrations than nighttime fasts. Accelerated starvation has been associated with diminished cognitive function [Rizzo et al., 1991] and animal studies have linked ketone exposure very early in pregnancy to neurological impairments [Hunter and Sadler, 1987, Moore et al., 1989, Sheehan et al., 1985]. Gluckman and Hanson [2005] emphasize the importance of glucose supply during early embryonic development noting that "the developing embryo will change the relative assignment of cells to the inner cell and outer cell mass according to whether it perceives a problem in glucose supply" and show that among rats "poor maternal nutrition at this stage produces offspring with higher blood pressure".

Following the study of breakfast skipping by Metzger et al. [1982], Ramadan fasting was likewise found to cause accelerated starvation among pregnant women in Gambia [Prentice et al., 1983] and in England [Malhotra et al., 1989]. Mirghani et al. [2004] found that maternal glucose levels were lower in the fasting state compared to the postprandial baseline, a difference accentuated by the number days fasted: "the effect on maternal glucose levels during Ramadan fasting is cumulative." Several studies of maternal fasting during Ramadan have found adverse effects carried over to measures of fetal health: fetal

[7]Ketones bodies are produced as a byproduct when fatty acids are broken down by the liver. They serve as an alternate source of energy during fasting when glucose levels fall. They are an especially critical source of energy for the brain during fasting.

breathing movements and fetal heart rate accelerations [Mirghani et al., 2004, 2005].

Recently, Dikensoy et al. [2009] reported that Ramadan fasting is associated with increases in cortisol levels during pregnancy, but not for non-fasting pregnant women (both relative to pre-pregnancy levels). This finding is of interest because cortisol is a stress hormone frequently invoked as a potential mechanism through which prenatal experiences may "program" adult health [Kapoor et al., 2006] (See Appendix Section A.3 for more details).

To summarize, there is fairly consistent evidence that fasting during pregnancy has an effect on maternal and fetal health measures. We summarize the literature on potential fasting sequelae in Appendix Section A. Despite uncertainty whether these first stage effects carry over to birth outcomes and longer-term effects (See Section 2.3 below), the Institute of Medicine nevertheless recommends pregnant women should "eat small to moderate sized meals at regular intervals, and eat nutritious snacks" [Institute of Medicine, 1992:45]. Similarly, the American College of Obstetricians and Gynecologists recommends that pregnant women avoid skipping meals.[8]

2.3 Ramadan and Perinatal Health

Whether there is an effect of fasting on birth outcomes has not been established. However, it is important to note that measures of birth size are highly imperfect proxies for capturing nutritional disruptions during embryonic or fetal development [Gluckman and Hanson, 2005]. Therefore, the absence of a finding of effects of fasting on birth weight, for example, does not preclude the possibility of adverse effects on long-term outcomes. Nevertheless it is useful to review the previous literature on fasting and birth outcomes. Most previous studies have drawn comparisons over only a single Ramadan season. Since the panel-data dimension is generally absent for analyses of birth outcomes, studies have resorted to strong assumptions on the comparability of fasters and non-fasters. These two groups are likely different in ways that would generate differences in birth outcomes absent any causal effect of fasting. Pre-pregnancy BMI, along with other characteristics, has been found to predict fasting observance [Kavehmanesh and Abolghasemi, 2004]. This basic

[8] http://www.acog.org/publications/patient_education/bp087.cfm?printerFriendly=yes

weakness in design has been exacerbated by: 1) small sample sizes that in general would only be able to distinguish quite large effects from zero; 2) consideration of Ramadan fasts observed exclusively in mid or late gestation. We refer the reader to the more detailed discussion of these studies in Appendix A.4.1.

No previous study has exploited idiosyncratic variation across birth cohorts in the timing of Ramadan relative to birth. As Ramadan's forward movement through the western calendar is slow, the separation of Ramadan from seasonal effects on birth outcomes (e.g., Doblhammer and Vaupel [2001], Costa and Lahey [2005]) requires data across many birth years. Cohort coverage, therefore, may have precluded implementation of an ITT analysis like ours. Similarly, no previous study has exploited the number of daylight hours during the Ramadan fast for identification (not feasible for populations living near the equator, e.g., in Uganda or Indonesia).

Finally, ours is the first study to analyze the relationship between outcomes in adulthood and *in utero* Ramadan exposure. The study closest to ours in this respect is by Azizi et al. [2004] who found no significant difference in the IQ's of school-age children by maternal fasting behavior during the third trimester (please see Appendix Section A.4.2 for details). Subsequent to our study, Van Ewijk [2011] analyzed IFLS data from Indonesia, finding evidence of long-term effects of fasting.[9]

3 Data and Methodology

Our identification strategy requires microdata with information on:

1. a substantial number of Muslims;
2. precise information on birth date (i.e., more detailed than age in years);
3. coverage of many birth cohorts (i.e., birth years);
4. health outcomes.

In this section, we briefly describe the datasets we use (see Appendix B for more detail) followed by our econometric approach.

[9] Van Ewijk [2011] graciously notes that we are "the first to systematically examine [Ramadan's] long-term effects."

3.1 Michigan Natality Files

From Michigan's Division for Vital Records and Health Statistics, we obtained birth certificate microdata for 1989 to 2006 in Michigan – approximately 2.5 million birth records.[10] Although, there is no information on religion, ancestry of the mother is reported (ancestry information is not recorded in the national vital statistics data produced by NCHS). This feature of Michigan's natality data allows us to construct a proxy for whether the mother is Muslim based on reported "Arab" ancestry (Michigan's Muslim population is disproportionately from Arab countries).[11] Compared to other US states, Michigan has a relatively large Arab population.[12] There are a total of about 50,000 births to mothers of Arab ancestry (about 2.2 percent of MI births) over this period. While there is a large population of Arabs around Detroit, they are reasonably dispersed throughout the State (see Appendix Figure A2, Panel A).

Since a large fraction of Arabs in Michigan are actually Chaldeans – a denomination of Christianity – simply using Arab ancestry as a proxy may misclassify many mothers and thereby attenuate estimated effects.[13] We use the 2000 US Census SF3 (1 in 6 sample) data to identify Michigan zipcodes with heavy concentrations of Chaldeans – who presumably do not observe the fast – relative to Arabs (see Appendix Figure A2, Panel B). We drop observations from these zipcodes to compare ITT estimates.[14]

For our main anlysis we restrict our sample to full term births, those defined as having a gestation length of between 39 and 42 weeks. We use the reported exact date of birth and estimated gestation length to infer the gestation period.[15] The restriction to full term births allows us to focus on the effects of maternal nutritional restriction on birth weight that arises from effects on the intrauterine growth retardation (IUGR) which is the main

[10] We thank Michael Beebe and Glenn Copeland in Michigan's Vital Statistics Office for their assistance with these data.

[11] See Section B.1 of the Appendix for more detail.

[12] We thank Carlos Dobkin (UCSC) for suggesting we focus on Michigan's Muslim population.

[13] According to the 2000 Census, about a quarter of those of an Arabic speaking ancestry in Michigan are Chaldean Christians. Our estimates based on the Detroit Arab American Study (DAAS) suggest that about 47% of those who self-identify as "Arab American" in the Detroit area are Chaldean.

[14] Specifically we drop zipcodes where the ratio of Chaldeans to non-Chaldean Arabs is greater than 1. We have found similar, though less pronounced effects if we include these zipcodes (see Almond and Mazumder [2008]).

[15] Gestation based on last menstrual period (LMP) is used except if it is missing or if it differs with the physician estimated gestation by more than 14 days, in which case the physician estimated measure is substituted. The conception date is estimated as occurring 14 days after LMP.

focus of the developmental origins literature.[16] Appendix Table A2 provides summary statistics for Michigan's natality data.

3.2 Data from National Censuses

To consider whether health in adulthood is affected by prenatal Ramadan exposure, we analyze Census microdata for the two countries where our identification strategy can be implemented in publicly-available data. Data from the Uganda 2002 Census are best suited for our analysis because religion is reported, there are large numbers of both Muslims and non-Muslims in Uganda, month of birth is reported, and a host of disability measures are queried.[17]

3.2.1 Uganda Census 2002

Our sample of Muslim adults includes approximately 80,000 men and women between the ages of 20 and 80 in 2002. Muslims constitute about 11% of Uganda's population and have more schooling and lower rates of disability than non-Muslims (Appendix Table A3). Both Muslims and non-Muslims share a strong seasonality in the number of births. Muslims tend to live in the southeastern portion of the country.

Unlike other national censuses, the Uganda Census asks a battery of questions about specific disabilities, including: blindness or vision impairments, deafness or hearing impairments, being mute, disabilities affecting lower extremities, disabilities affecting upper extremities, mental/learning disabilities, and psychological disabilities (lasting six months or longer). As only about 5% of adults report a disability compared to over 10% in the US Census, disabilities recorded in the Uganda Census may be more severe. Further, Uganda reports information on the origin of disabilities: congenital, disease, accident, aging, war injury, other or multiple causes. In the absence of direct measures of economic status we use home ownership. We also consider several other socioeconomic outcomes such as literacy, schooling, and employment.

[16] We have found very similar results when we have included pre-term births (see Table A4 in Almond and Mazumder [2008]).

[17] In a previous version of this paper we also analyzed US Census Data and found consistent results, however, our analysis was limited to quarter of birth rather than month of birth.

3.2.2 Iraq Census 1997

Although religion is not reported in the Iraq Census, roughly 97% of the population is Muslim, minimizing concerns about misclassification of religion. Our main sample includes over 250,000 individuals born from 1958 to 1977 who were between the ages of 20 and 39 in 1997 and for whom we have reliable information on birth month.[18] Because we only cover 20 birth cohorts compared to 60 in Uganda, we may be more concerned about confounding from seasonality. In addition, although our sample size is large this is offset to some degree by surprisingly low rates of reported disabilities. At 1.5%, Iraqis are substantially less likely than Americans (around 12%) or Ugandans (around 5%) to report a disability. Part of this is of course, due to the fact that we have a younger sample. Along with a general disability question, there are specific questions about disabilities involving sight, hearing, lower extremities, upper extremities, and psychological disabilities. In contrast to Uganda, there is no variable to assess mental/learning disabilities.

In addition to home ownership, we consider a second proxy for wealth/status: polygyny. Under Iraqi law, courts may only allow polygyny if husbands are able to financially support multiple wives and if they are able to maintain separate households for each wife [Iraq Legal Development Project, 2005].[19] More generally, polygyny reflects high male status [Edlund, 1999]. Since polygyny is relatively infrequent for a young sample, we expand our sample to include up to 45 year olds. Sample means for our outcomes are shown with the regression results in Table 7.

[18] Only 20 percent of those born prior to 1958 provide reliable data on birth month. We discuss these data limitations in greater detail in Appendix section B.3

[19] Under Iraqi Personal Status Code Number 188, Article 3(4) it is written that: *Marriage of more than one wife is prohibited in the absence of judicial permission on two conditions: (a) The husband has financial sufficiency to marry more than one wife. (b) He should have a legal interest.*

Iraqi Personal Status Code Number 188, Article 26 states that: *The husband should not house his second wife in the same house with the first one without her approval, and should not house any other relative with her without her approval, except his minor child.*

Roughly 2% of Iraqi men report polygynous unions.

3.3 Ramadan Measures

We record start and end dates for the 104 Ramadans in the 20th century [20] and use these dates to construct a variety of measures of prenatal Ramadan exposure tailored to the datasets we analyze.

3.3.1 Michigan sample

Our simplest measure is an indicator for whether Ramadan overlapped with pregnancy. We also construct indicators for whether Ramadan occured during the first, second, or third trimester.[21] Although these basic measures are easy to interpret, they may not be suited to capture effects that occur during narrowly-defined "critical windows" of fetal development (see Appendix Table A1 and accompanying text in Appendix Section A). They also do not capture the duration of the daily fast, which will vary with the amount of daylight hours. Therefore we construct an exposure measure called "*exp hours*".[22] For each day of the year we construct a fraction where the numerator is the number of daylight hours over the next 30 days that overlap with Ramadan and the denominator is the maximum number of daylight hours over any 30 day period over the entire sample period (which depends only on latitude). Daylight hours in Michigan vary from a low of around 9 to a high of over 15 at the summer solstice when the effects of accelerated starvation may be most evident. Please see Appendix Figure A3 for a an illustrative example from 1989 (and the associated text in Appendix Section B.1).

For each observation, *exp hours* is assigned to up to nine different points in time corresponding to the day beginning each gestation month (ten in some specifications where we include the month prior to conception).[23] We have also estimated effects where

[20]Many websites translate dates from the Islamic (Hijri) calendar. We used the following website hosted at the Institute of Oriental studies at the University of Zurich http://www.oriold.unizh.ch/static/hegira.html, but verified the dates from a second source.

[21]In cases where Ramadan began in the first trimester and extended into the second trimester we assign the treatment to the first trimester. Similarly we assign treatment to the second trimester if Ramadan overlapped between the second and third trimesters.

[22]The beginning of the Ramadan fast actually precedes sunrise and begins at the time of the morning prayer (*fajr*). The precise timing of the morning prayer may vary across mosques and typically depends on a rule regarding the angle of the sun relative to the horizon. For this reason we actually understate the number of fasting hours in our data. Daylight hours are measured for the city of Dearborn, Michigan which contains a large share of the state's Arab population.

[23]We first match each individual to an estimated date of conception. We then assign *exp hours* for

we have ignored the gestation information and have assigned exposure measures based only on the date of birth and have found similar results (see Almond and Mazumder [2008]).

3.3.2 Uganda and Iraq samples

For our Census samples where we only know the month of birth, we simply use the fraction of days in each month that overlap with Ramadan as our preferred exposure measure.[24] We refer to this measure as "*days*". Since we cannot distinguish between full-term and pre-term births with the Census data, we do not refer to "gestation" months with this data and instead refer to the effects of treatment "X months before birth". It is also worth noting that since Uganda straddles the equator, the number of daylight hours is fairly constant over the year at 12.

3.4 Econometric Model

For our Michigan analysis, we regress each outcome, y_i, on either:

i. an indicator dummy for whether Ramadan overlapped with pregnancy.

ii. a set of three indicator variables for whether Ramadan occurred during the first, second or third trimesters.

iii. a set of nine Ramadan *exp hours* measures.

For our third specification, separate coefficients for each gestation month k are included simultaneously in each regression. An individual will be exposed to Ramadan in at most two (adjacent) months of gestation. The effects of Ramadan exposure in a given month of gestation, therefore, are measured relative to no prenatal exposure to Ramadan – i.e.,

the first month based on the exposure measure for the date that is 4 days prior to the estimated date of conception. We then proceed to assign Ramadan exposure measures forward in 30-day increments. Using this approach, gestation for a full-term birth is measured exactly 270 days prior to birth allowing us to divide the prenatal period into 9 periods of exactly 30 days each. This strategy also allowed us to mimic an earlier approach that ignored the gestation data entirely, and only counted backwards from the date of birth in 30 day intervals (see Almond and Mazumder [2008]).

[24]We opted to use this measure, rather than a simple dummy variable since it provides a continuous measure of treatment (more power).

when Ramadan falls in the two to three months after birth. We estimate:

$$y_{itmg} = \sum_{k=1}^{9} \theta^k \cdot \texttt{exp hours}_{tm}^k + \beta X_{itmg} + \delta_t + \gamma_m + \omega_g + \varepsilon_{itmg}. \quad (1)$$

The Ramadan exposure measure `exp hours` varies at the level of birth year t and conception month m. The combination of year of birth and conception calendar month together imply both the gestation month k of Ramadan exposure, as well the hours of daylight for that Ramadan (since we are using seasonal variation in daylight for a given latitude). Controls include separate dummies for each year of birth t and dummies for 11 calendar months of conception m, so as to remove the effects of seasonality in parental characteristics and bith outcomes. We also include a set of dummies that measure geographic location g at the time of birth.[25] In our most detailed specifications we also include a number of largely predetermined variables as additional controls X_{itmg}: mother's age, mother's age squared, mother's years of education, father's age, father's age squared, father's education, a dummy for missing father's education, parity, tobacco use during pregnancy, alcohol use during pregnancy, the number of previous pregnancies where the child was born dead, and whether the birth was paid for by Medicaid (an income proxy).[26] In specifications where we include the nine exposure measures simultaneously, we also run an F-test on the joint significance of all nine coefficients. This tests the overall effect of Ramadan exposure during any point in gestation. In addition, since our hypotheses for some outcomes (Table A1) suggest an effect only in specific gestation months, we also run tests of equality of all coefficients.

In our Michigan analysis, in addition to running these specifications separately for our treatment and control groups, we also run a "difference in differences" specification where all of the right hand side variables are fully interacted with an indicator for being Arab. Therefore, we allow, for example, for Arabs and non-Arabs to have different birth timing and birth location effects. For estimates on population counts by month we use aggregate measures at the cell level where cells are defined by each of the distinct conception or

[25]In Michigan we use 84 county dummies, in Uganda 56 district of birth dummies, and Iraq 18 governates of birth.

[26]Parity is defined as the number of previous live births. Alcohol and tobacco use are arguably endogenous since their use may be reduced during the month of gestation that overlaps with Ramadan.

birth months over the sample period. For Michigan, this yields 216 cells (18 years × 12 calendar months).

For our analysis of Census data we use the *days* variable as a substitute for *exp hours* in (1). We also replace controls for month of conception with month of birth. In our pooled samples of adult men and women in Uganda and Iraq we also include a female dummy.

4 Michigan Results

4.1 Birth Weight

We begin the analysis of birth weight by presenting our simplest Ramadan exposure measure in Table 1. In column 1 of Panel A we show the effect of Ramadan's occurrence at anytime during pregnancy. We find that birth weight is about 18 grams lower for Arab pregnancies that overlap with Ramadan, statistically significant at the 3 percent level. In Panel B we find slightly larger effects of 20 to 25 grams if Ramadan occurs during the first or second trimesters, and a smaller and statistically insignificant effect during the third trimester. As a check on the validity of these comparisons, we also apply the same approach to our non-Arab sample. Results are shown in column 2. We find very precisely estimated effects of close to 0 grams in all cases. This suggests that our estimates are not driven by seasonal patterns or time trends. Not surprisingly the difference in differences estimates in the third columns of both panels are nearly identical to what we find for our Arab-only sample.

To preview our later findings concerning possible selective timing of pregnancies around Ramadan, we show that there are no significant effects on the education levels of mothers whose pregnancies overlap with Ramadan. These are presented in columns 4 through 6. For example, mother's years of education is, if anything, slightly *higher* (.03) among Arab women whose pregnancies overlap with Ramadan during the second trimester.

We now turn to our richer specifications that utilize more precise measures of Ramadan exposure by gestation month in Table 2. Specifically, we utilize the *exp hours* measure that captures the length of the Ramadan fast. For Arab women (column 1), we find negative effects on birth weight of around 40 grams in the first two months of pregnancy if Ramadan were to coincide with the peak period of daylight hours (15 hours). We also find large and statistically significant negative effects in months 5 and 7. We also find that the F-test on the joint importance of all the prenatal Ramadan exposure measures is significant at the 7 percent level. The test of the equality of coefficients is not rejected at conventional significance levels. Once again we find no effects for Non-Arabs (column 2) and most effects remain statistically significant in our difference in differences specifications (column 3).

We have also found that Ramadan exposure in the month *prior to conception* has a small but statistically insignificant *positive* effect (11 grams) on birth weight. This serves as an additional validity check to the extent that pre-conception nutritional restriction is not expected to affect birth weight. In previous work, we have also found that our results are robust to a wide variety of sample selection choices (see Almond and Mazumder [2008].

4.2 Discussion of Birth Weight Results

Because birth weight may be a poor proxy for the underlying effects of nutritional shocks on fetal development (e.g. Franko et al. [2009]), we interpret our findings on birth outcomes conservatively, using them primarily as confirmation that prenatal fasting is indeed having a "first stage" effect on health measured at birth. Although we find that *in utero* exposure to Ramadan is associated with lower birth weight, the size of our estimated effects are relatively small: for example, 40 grams is only about 1.2 percent of the mean birth weight for Arabs. However, these effects are population averages and do not account for the fact that some fraction of these women are not actually fasting and we may still be including a sizable fraction of Non-Muslim women among the Arabs.

With respect to the birth weight distribution, it appears that most of the estimated effect for early pregnancy exposure is in the middle of the distribution (see Almond and Mazumder [2008]), rather than a disproportionate increase in the likelihood of low birth weights. Gluckman and Hanson [2005] emphasize that adaptive responses to nutritional restrictions may occur throughout the birth weight distribution (p.99). On the other hand, increases in low birth weight may be more closely tied to other measures of newborn health than reductions at higher birth weights [Almond, Chay, and Lee, 2005]. Since our sample is restricted to full-term births, the estimated effects on birth weight can be directly attributed to intrauterine growth retardation (IUGR) as opposed to an increase in pre-term births.[27]

Finally, if Ramadan observance during pregnancy varied by socioeconomic or health status, treatments effects would presumably also show a corresponding gradient, other things equal. Interestingly, we observe no systematic gradient in the size of the birth weight effects by maternal education, Medicaid use, or month prenatal care was initiated (results available from authors). If treatment effects are relatively homogeneous, this suggests that fasting observance is high or fairly uniform across socioeconomic groups by month of gestation.

4.3 Fetal Death and the Sex Ratio at Birth

Mathews et al. [2008] found that poor maternal nutrition (possibly due to breakfast skipping), around the time of conception skews the sex ratio in favor of girls, most likely through the selective attrition of male conceptuses. Similarly, Almond et al. [2009] found that severe morning sickness in early pregnancy is associated with female births, but also a 50% fetal death rate due to severe nausea and vomiting.[28] More generally, maternal nutrition among mammals close to conception is positively associated with the likelihood of male offspring [Cameron, 2004].

We consider Ramadan's effect on the fraction of male births in in columns 4 through 6 of Table 2. For Arab mothers (column 1) we find a strikingly large effect of -6.1 percentage points (p-value = 0.02) on the likelihood of a male birth from exposure to Ramadan during the longest diurnal fast in month 1 of pregnancy. Column 5 shows no analogous effects for non-Arabs. In column 6 we show the difference in differences estimates are extremely

[27] In previous work we found some evidence that Ramadan exposure was linked to lower gestation length when we expanded our sample to include pre-term births (see Almond and Mazumder [2008] Table A4). In some specifications we also found tiny but statistically significant negative effects of Ramadan exposure on the gestation length of Non-Arab women. This likely reflects some residual seasonal effects that we cannot fully control for with our limited cohorts. This highlights the potential importance of using a difference in differences specification for certain outcomes.

[28] By fetal death, we mean any attrition between conception and live birth. This could include attrition during embryonic development before the fetal period.

close to our column 4 estimates.

In appendix Table A4 we conduct a cell level analysis of total births, male births and female births to better understand this change in the sex composition of births. We find that peak exposure to the Ramadan fast in the month after conception is associated with a 13 percent decline in total births. If male vulnerability [Kraemer, 2000] is the culprit, this drop should be concentrated among male births. When we examine this by sex, we indeed find this is driven by a 26 percent drop in male births (p-value = 0.005), while female births fall by a statistically insignificant 2.5 percent.[29] This decline in births associated with fasting around the time of conception is probably not due to other behavioral changes associated with Ramadan since it is difficult to imagine an alternative mechanism which impacts sex-specific fertility.

4.4 Selective Timing of Conceptions Around Ramadan

Our identifying assumption is that the composition of Muslim parents does not change systematically by their children's *in utero* exposure to Ramadan. One concern could be that parents of higher socioeconomic status (SES) seek to avoid having pregnancies overlap with Ramadan by concentrating conceptions during the two to three months just after Ramadan. If this were the case it would affect our interpretation of the simple estimates that compare pregnancies with any Ramadan overlap with those with no overlap, though it would not alter our conclusions concerning differences due to exposure *within* the gestation period.

Another concern could be if less healthy or less educated women are more likely to conceive in a particular month relative to Ramadan. For example if there is negative selection of conceptions in the month prior to Ramadan then this could provide an alternative explanation for findings related to first month exposure. There may also be general behavioral changes in society in the period around Ramadan. For example the end of Ramadan is a highly festive period in Muslim society.[30]

We assess whether Ramadan exposure during pregnancy and the month prior to con-

[29]Several other gestation months show much larger drops for female births associated with Ramadan exposure, though they are never statistically significant.

[30]We note however, that we do not detect a statistically significant increase in conceptions following Ramadan (see Table A4).

ception is associated with a set of pre-determined characteristics of the pregnancy that may be correlated with birth outcomes.[31] Table 3 estimates equation (1) with twelve "outcome" variables: mothers' education, whether the pregnancy was paid for by Medicaid (income proxy), mother's age, father's age, father's education, tobacco use during pregnancy, alcohol use during pregnancy, parity, whether a previous child was born dead, an indicator for missing father's education, whether the mother had previously delivered a small baby and whether diabetes was considered a risk factor for the mother.

Out of the 120 estimates, we would expect that by chance, 6 coefficients would be significant at the 5 percent level. We find 4 coefficients that are significant at the 5 percent level and all suggest that if anything, there is positive rather than negative selection.[32] Similarly we find a total of 11 coefficients that are significant at at least the 10 percent level –12 would be expected by chance. All of these point estimates also suggest positive selection. For example mothers who had high exposure in the first month of gestation were older than mothers whose pregnancies did not overlap with Ramadan and were less likely to have pregnancies covered by Medicaid.[33]

Overall, we find no evidence indicating positive selection in mothers who conceive in the month after Ramadan (gestation month 0) and no evidence suggesting that mothers who conceive in the month before Ramadan are negatively selected. In an additional check, we have run our birth weight results dropping mothers who conceived in the month after Ramadan so that our effects are estimated only relative to mother's who conceived two to three months after Ramadan but whose pregnancies did not overlap with Ramadan, and found very similar results.

[31] Because we only observe those conceptions which result in a live birth, effects of post-conception Ramadan exposure may be manifested in pre-determined characteristics if Ramadan-induced fetal mortality has a gradient in these same characteristics (or Ramadan observance).

[32] We find that exposure during the fifth and ninth months of pregnancy are associated with *lower* alcohol use. We also find that mothers listed as having a risk of diabetes are less likely to have overlap with Ramadan in the first and third months of gestation.

[33] We find that first month exposure is associated with a 1.6 percent *lower* likelihood of being a teenage mother which is both statistically significant and quantitatively meaningful as the rate of teenage motherhood among Arab mothers is 7.5 percent.

5 Census Results

5.1 Results from Uganda Census

Our presentation of potential long-term effects begins with Uganda, where self-reported religion, birth month, and various health outcomes are available for a sizable number of adult Muslims and non-Muslims. As in data from other countries (e.g., the US Census), disability is the primary measure of health.

5.1.1 Disability Outcomes

Table 4 shows disability outcomes for Muslims and non-Muslims. Because these outcomes have a low incidence rate we have multiplied the coefficients and standard errors by 100 to make them easier to read. The effects are therefore measured in percentage points. In the first column we show the effects of Ramadan exposure over each of the nine months preceding birth. In column (1) we find a statistically significant increase in the likelihood of a disability (of any kind) for Muslims born nine months after Ramadan (point estimate of 0.819 and p-value of 0.02). Relative to the mean disability rate of 3.8 percent, the effect is substantial at 22 percent. We find that no other month prior to birth is statistically significant and the p-value on the joint test of all nine coefficients does not approach statistical significance. We cannot reject that all of the coefficients are equal.

Turning to specific disabilities (columns (2) to (5)), the most striking finding is the increased incidence of a mental or learning disability (column (4)) when Ramadan occurs during the first month pregnancy. The point estimate is 0.250 with a p-value of 0.001. Given the mean rate of 0.14 percent this implies that the occurrence of Ramadan early in pregnancy nearly doubles the likelihood of a disability related to diminished cognitive function. Thus, the increase in mental/learning disabilities from month-one Ramadan exposure would account for about 15% of all mental/learning disabilities among Muslims. Furthermore, those with exposure in month 8 have a 100% increase (significant at the 5% level) and those with Ramadan exposure in months 5 or 6 show smaller increases (significant at the 10% level). The joint test on all gestation months of no effect is rejected at the 4 percent significance level.

We also find that the incidence of sight/blindness and hearing/deafness are higher for those born 9 months after Ramadan. Specifically, the magnitude of the effects relative to those not *in utero* are 33 percent for blindness (p-value = 0.07) and 64 percent for deafness (p-value = 0.04). For hearing/deafness we also find a marginally significant effect for those exposed to Ramadan in the fifth month of gestation.

We run the same specifications on our sample of non-Muslims in columns (6)-(10). We find no cases of a corresponding significant result for Muslims also occurring for Non-Muslims for these outcomes. We tested the sensitivity of the results for Muslims to also including exposure during the 10th month prior to birth and found that the results were unaffected and that in no case was the coefficient on the 10th month statistically significant or quantitatively meaningful.[34] We also ran our specifications separately for men and women (not shown) and found that the results were qualitatively similar though the estimates were much less precise.

5.1.2 Causes of Disability

Previous falsification tests have considered Ramadan exposure outside of pregnancy and Ramadan exposure during pregnancy for non-Muslims. Information on the causes of disabilities provides a third test. We group these reported causes – accident, occupational injury, war injury, aging, disease, or congenital – by whether they can reasonably be linked to fasting via the mechanisms discussed earlier. Disabilities that arise from accidents, occupational injuries, or war injuries are postnatal and are likely to be unrelated to maternal fasting during Ramadan. On the other hand, the developmental origins hypothesis suggests that extended periods of nutritional restriction may be associated with a reprogramming of the body's systems that result in poor health outcomes later in life (see Appendix for additional discussion). This would be consistent with those who report "aging" as the source of a disability. Respondents who report disabilities due to "disease" (e.g., diabetes) could plausibly be related to the timing of Ramadan. Finally, whether maternal nutrition affects congenital disabilities (those present at birth) is not clear-cut.[35]

In Table 5 we show that we find no significant effects from accidents, occupational

[34] See Table A6 of Almond and Mazumder [2008].

[35] If the disability is epigenetic then it may be associated with maternal fasting.

injury or war injuries for Muslims or non-Muslims in any gestation month. In contrast, Muslims born nine months after Ramadan have an increased incidence of disabilities due to aging of 0.37 percentage points (p-value = 0.006). We find no evidence linking Ramadan exposure to disease-related or congenital disabilities (consistent with Michigan results for congenital anomalies). We found no comparable effect of first month exposure to Ramadan on disabilities caused by aging for non-Muslims.[36]

In order to address possible concerns about selective timing of pregnancy in Uganda, we used a sample of children aged 17 or under and living with their parents and regressed parent characteristics (education, illiteracy, and disability) on the child's Ramadan exposure using equation (1). As with Michigan, we found no statistically significant effects of negative selection on parent characteristics. This is only informative about selection for more recent cohorts and cannot speak to any selection related to the cohorts we observe as adults in the Census. Finally, we also found that the results were insensitive to excluding outlier cohorts that had extremely large or small disability rates. If anything, excluding outliers slightly increased the point estimates and their precision.

5.1.3 Sex Composition of Adult Population

With the Uganda data we explore the possibility that maternal fasting may influence the sex composition of the adult population. This could arise either from alterations to the sex composition at birth or because of selective mortality by sex after birth as implied by some of the fetal origins literature (see Appendix Section 1). To assess this, we conduct an analysis parallel to our Michigan analysis. First we simply regress male as an outcome in equation (1). Second, we aggregate the population by cells constructed by birth month both for the pooled sample as well as separately by sex and take the log of the population counts as an outcome.

Results are shown in the left most panel of Table 6. In column (1) we find that every month prior to birth has a negative coefficient and that the 1st, 4th and 7th months of gestation are statistically significant at the 5 percent level The joint test of all the

[36]Among non-Muslims the only significant effect is that those exposed to Ramadan one month before birth are 0.12 percentage points (p-value = 0.017) more likely to have a congenital disability. This is a 20 percent effect relative to the mean.

exposure months is significant at the 10 percent level. In column (2) we find only weak evidence that cohort size is related to Ramadan exposure when we pool men and women. When we look at the log of population counts of males in column (3), seven of the nine months have negative coefficients and the 7th month of gestation has a particularly large and statistically significant effect (15%). The effects on the sex in column (1) appear to be driven by reductions in the number of males. In column (4) we show the analogous results for women where the effects are all positive but only significant in one month. In other results (not shown) we find no comparable effects on the sex composition for non-Muslims.

Thus, for Ramadans that fall nine months prior to birth (where the disability effects are concentrated), we find relatively modest evidence of Ramadan-induced selective attrition – less than a third the corresponding magnitude for Michigan. Thus, the disability effects may be only modestly downward biased by selective attrition.

5.1.4 Other Outcomes in Uganda

The remaining columns of Table 6 show results for non-health outcomes. Unfortunately preferred economic outcomes, such as wages, income, and wealth, are not available. In column (5) we examine whether home ownership, a proxy for wealth, is affected. We restrict the sample to men since they are the vast majority of property owners in Uganda.[37] We find that men exposed to Ramadan in the first month of gestation are 2.6 percentage points less likely to own their home (p-value=0.027) and that men exposed in the 2nd month of gestation are 2.1 percentage points less likely to own their home (p-value=0.051). Given the high rate of male home ownership (73.4 percent), these effects are not especially large. We can reject that there is no effect of Ramadan exposure over all gestation months on home ownership at the 5 percent level. In contrast, we find no statistically significant effects of Ramadan exposure on home ownership for non-Muslims.

In columns (6) through (9) we examine illiteracy, completed years of schooling, a dummy for no schooling, and employment status at the time of the Census. We find

[37]Uganda is a patriarchal society where land is passed down through sons. Although women are not prevented from owning land, by one estimate, 93 percent of Ugandan land is owned by men. (http://www.womensenews.org/article.cfm/dyn/aid/1456/context/archive).

no statistically significant effects that associate greater Ramadan exposure with higher illiteracy or lower schooling. In fact those born 8 months after Ramadan appear to have *higher* human capital levels by both of these measures. The magnitude of these effects, however, is small. For example, the increase in years of schooling for these individuals is only about a tenth of a year, or 1.6 percent of the sample mean.

In sum, the non-health effects we estimate are smaller and less consistent than those for disability. In this respect, our Uganda findings are similar to the Dutch Famine, where effects have been most consistently found for health outcomes. We also speculate that these small but perverse results might reflect a selective effect on surviving males, who seem to bear the brunt of Ramadan-related attrition (either prenatally or postnatally). When we split the sample by gender, we only found these positive education effects for men and found negative (though insignificant) effects on women. When we split the sample by those above age 50 versus those aged 50 or younger, the effects are much larger for the older groups. These facts are consistent with the possibility of modest sex-specific selective mortality.[38]

5.2 Results from Iraq Census

We replicate the basic Uganda results using 1997 Iraq Census data. Columns (1) to (4) of Table 7 show the effects on disability. Full exposure to Ramadan nine months before birth is associated with a 0.33 percentage point increase in the probability of having a disability (p-value = 0.016). While in Uganda the overall disability rate was 3.8 percent, in Iraq it is just 1.5 percent. However, the effect size relative to the mean in Iraq is 23 percent, close to the 22 percent effect size that we estimated in Uganda. In Iraq the rates of disabilities involving sight and hearing, however, are a much smaller fraction of the reported rates for Uganda and this may explain why we detect no effect on these measures for first month exposure in columns (2) and (3).[39] We do find that exposure in month 5 of pregnancy has an effect on vision related disabilities.

[38]Furthermore, in developing countries a reduction in health capital could be manifested in less productive childhood labor and possibly lead to increased schooling.

[39]For vision/blindness only 0.14 percent report this disability which is only about one-tenth of the share reporting a comparable disability in Uganda. For deaf/hearing only 0.02 percent report this disability which is only one-sixteenth of the rate found in Uganda.

"Insane" is the sole mental disability queried, which IPUMS relabeled as "psychological" disability. Interestingly, at 0.36 percent, Iraq's psychological disability rate is actually higher than the combined rate of 0.28 percent for mental/learning *plus* psychological disabilities in Uganda (despite Iraq's lower overall disability rate). This suggests that mental/learning disabilities that are related to cognitive impairments may be subsumed in the psychological disability measure for Iraq. In column (4) we find strong effects on psychological disabilities just as we did for mental/learning disabilities in Uganda. First month exposure to Ramadan is associated with 0.23 percentage point increase in the likelihood of a psychological disability or a 63 percent effect relative to the mean (p-value = 0.001). We also estimate positive but insignificant effects in 6 of the other 8 gestation months. As was the case in Uganda with mental/learning disabilities, the joint test of zero effect across all gestation months is easily rejected at the 5 percent level, as is the test of equality of coefficients. The fact that both overall disability as well as disabilities that likely capture cognitive impairments appear to be impacted in precisely the same period of fetal development in two different societies is remarkable and reinforces that our findings are probably not due to chance.

In columns (5) through (8) of Table 7 we turn to socioeconomic outcomes.[40] The 1997 Iraqi Census asks about instances of men having multiple wives which we use to proxy for wealth (as described earlier). For this measure, shown in column (5) we find that men with first month exposure are more than half a percentage point less likely to have multiple wives and negative point estimates are found throughout pregnancy. A large and significant effect is also found during month 6 of gestation. Similarly, for home ownership (column 6), we see highly significant effects of exposure throughout the *in utero* period and the joint test of all gestation month coefficients is significant at the 8 percent level. In column (7) we see no effects on the sex composition of the adult population. Finally, in column (8) we find both small positive and small negative effects of Ramadan exposure on employment that are statistically significant. We note that among males, home owners are

[40]We experimented with measures of human capital such as years of schooling and illiteracy but found that there were extremely strong month of birth trends in these variables that could not be adequately controlled for without either having a full set of birth cohorts for whom Ramadan occurred throughout the entire calendar year, or a large sample of non-Muslims to serve as a control group. The seasonality in birth month are likely related to institutional issues concerning education (e.g. cutoff ages for starting or ending school tied to specific dates).

less likely to be employed (73%) than non-home owners (82%) suggesting that employment may be a poor proxy for economic status in Iraq and may actually signal lower status.[41] As with our Uganda results, we have also run all of these estimates including exposure 10 months prior to birth and in no case did it meaningfully alter the results.

6 Discussion and Future Research

6.1 How does fasting observance affect our estimates?

As rates of fasting by pregnant women during Ramadan approach unity, our ITT estimate approaches the treatment effect of fasting (which cannot be said of previous comparisons between fasters and non-fasters). Fasting observance may be highest in early pregnancy, both because mothers may be unaware they are pregnant and the burden of pregnancy is lower.[42] Thus, the estimated health damage attributable to Ramadan falling in the first month of pregnancy may approximate the treatment effect of fasting during this period. Correspondence between our ITT estimate and fasting's effect is likely higher in Iraq and Uganda where we have little classification error in Muslim status. In our Michigan data, our proxy for Muslims will still include a higher fraction of non-Muslims due to the likely presence of some Chaldeans who report Arab ancestry even though we have dropped zipcodes with high shares of Chaldeans among the Arab population. As compliance (fasting during Ramadan) is presumably zero for non-Muslims, our Michigan estimates are likely attenuated.

Ideally, we would observe fasting behavior by month of pregnancy and subsequent health or human capital outcomes for a large sample of Muslims. With this information and a sufficiently long span of birth years, we could construct Wald estimates of the effect of fasting on health during each pregnancy month. Ramadan's coincidence with pregnancy month would be the binary instrumental variable for fasting observance. As

[41] If we control for home ownership and multiple wives (despite their being endogenous) the instances of positive effects of Ramadan exposure on male employment are eliminated.

[42] The only study that we are aware of that documented differences in fasting behavior across pregnancy was by Arab and Nasrollahi [2001] who found that of the 4,343 women delivering in hospitals in Hamadan, Iran in 1999, fasting was only slightly more common when Ramadan fell in the first trimester (77%) than in the second trimester (72%) or third trimester (65%).

long as Muslims are not fasting for other reasons during the month of Ramadan (as seems reasonable), this Wald estimate could be interpreted as the effect of fasting on fasters (i.e., the treatment on the treated rather than simply a *LATE* estimate, see Angrist and Pischke [2009]). Failing this, data on fasting behavior and pregnancy month could be used to estimate the first stage effects of Ramadan timing (preferably for the US, Uganda, or Iraq), and combined with our ITT estimates in a two-sample IV procedure. This approach would also integrate potential heterogeneity in fasting rates by pregnancy month.

The most compelling previous studies of the developmental origins of health and disease have relied on exogenous shocks external to the family. These shocks have also typically involved relatively uncommon and severe historical events and so the relevance to policy may be somewhat tenuous. Our study departs from these in considering a treatment that to a greater degree is within the control of the mother (but still identified by exogenous timing) and may potentially be amenable to interventions. We also study a phenomenon that conforms more closely to the established theories relating a decline in circulating levels of maternal glucose during critical windows of embryonic and fetal development. That obtaining a dispensation to postpone fasting until after pregnancy is apparently the exception rather than the norm (see Appendix A.1.1) suggests two possibilities. First, the cost of requesting the dispensation may be high – in part because mothers usually become aware of their pregnancies after the first month [Floyd et al., 1999]. Alternatively, it may be that the full health consequences of Ramadan fasting during pregnancy are unknown. This explanation also seems plausible as ours is the first study to find long-term effects (and our impact magnitudes did not vary by socioeconomic status in Michigan).

An alternative approach families could adopt is to time pregnancies to commence shortly after Ramadan, and thereby avoid the overlap. That we do not observe this behavior could suggest that timing pregnancies is costly or unreliable,[43] or again that fasting during pregnancy is not considered teratogenic.

[43]Dickert-Conlin and Chandra [1999] found a responsiveness to tax incentives in the timing of deliveries, not conceptions.

6.2 Synthesizing the Results

In accordance with our hypotheses (see Table A1), we find evidence that fasting affects birth weight and the sex composition at birth using natality data from Michigan. For birth weight we find negative effects that are primarily concentrated in the first two trimesters of pregnancy which is broadly consistent with our reading of the literature which shows birth weight effects throughout pregnancy. Our results on the sex composition of births are also consistent with the hypothesis that nutrition shortly after conception matters.

We take these findings as confirmation that there is a detectable effect of fasting that is evident at birth. The absence of such evidence would make the case for long-term effects superficially more suspect but still plausible from the point of view of biological theory. Although some may interpret evidence of negative effects on birth weight as an important finding in and of itself, we take the more conservative view that it merely demonstrates the potential importance of nutritional disruptions during fetal development on long-term outcomes.

Our literature review further suggests that irrespective of when in pregnancy fasting may affect birth outcomes, adult outcomes are generally likely to be affected by prenatal nutritional disruptions early in pregnancy.[44] Accordingly, we find large effects on disability from early exposure in Uganda and Iraq. Interestingly we find almost the same magnitude of the size of the effect of just over 20 percent.[45] In general, the socioeconomic outcomes show a less consistent impact than disability, particularly in Uganda. In this respect, we view our results are similar to those of the Dutch Famine studies. That said, we detect more consistent negative effects on wealth measures in Iraq.

6.3 Generalizability and Future Research

An important caveat of our analysis is that we only measure the reduced form effect of exposure to all aspects of Ramadan's occurrence, not just fasting. The fact that Ramadan may alter other behaviors (e.g. sleeping patterns) may lead one to question whether the

[44]Evidence from the 1918 and 1957 influenza pandemics suggests that the first half of pregnancy is particularly important to subsequent health and human capital [Almond, 2006, Kelly, 2011].

[45]In earlier work we have also found a similar sized effect on adult disability in the US (see Almond and Mazumder [2008])

effects of fasting during Ramadan generalize to other contexts such as dieting during pregnancy. We would first emphasize that there is a strong physiologic and empirical basis in the medical literature for expecting that maternal fasting can lead to metabolic changes in the intra-uterine environment (i.e. reductions in glucose and increases in ketones) that could potentially result in adverse birth outcomes. Further, there is much less evidence linking other behavioral aspects of Ramadan observance among pregnant women to adverse pregnancy or birth outcomes. Therefore, the fact that accelerated starvation has been documented in both developed and developing countries during Ramadan provides *a priori* evidence that Ramadan is of direct relevance for understanding the implications of nutritional deprivation during pregnancy more generally. The presence of elevated levels of cortisol provides further evidence of a likely effect. At a minimum, the results of this paper are a clarion call for further research. Future studies could analyze the extent to which other behavioral aspects of Ramadan may interact with fasting behavior and whether these other factors may serve to amplify or dampen the effects of restricted prenatal nutrition. Finally, setting aside the issue of generalizability, the fact that millions of pregnant Muslim women will fast each year implies that understanding the long-term impacts of Ramadan is an important question *per se*.

Future research should also confirm whether other commonly-experienced disruptions to prenatal nutrition exert similar effects as Ramadan fasting. As mentioned above, most US pregnancies are not recognized until after the first month of gestation [Floyd et al., 1999]. Given the results of this study, maternal behavior particularly during the first month of pregnancy, can have permanent impacts on offspring health. Roughly 40% of US women of childbearing age are attempting to lose weight [Cohen and Kim, 2009] and 24% of women reported meal-skipping during pregnancy [Siega-Riz et al., 2001]. Among those women who are attempting to become pregnant, the negative consequences of dieting prior to pregnancy recognition should be considered.[46] Thus, even in relatively well-nourished populations, prenatal nutrition (and at a minimum its timing) may be sub-optimal for fetal development. Future research should employ new identification strategies to evaluate both short and long-term health effects of nutrition in early pregnancy on health and other end points, e.g., test scores.

[46]Furthermore, approximately 5% of pregnant women manifest eating disorders [Turton et al., 1999].

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Table 1: Effects of Ramadan's Occurrence During Pregnancy on Birth Weight

Panel A: Effect of Ramadan Occuring at Any Time During Pregnancy

	Birthweight			Mother's Education		
	(1)	(2)	(3)	(4)	(5)	(6)
	Arabs	Non-Arabs	Difference	Arabs	Non-Arabs	Difference
	-17.87**	-0.21	-17.66**	-0.03	0.00	-0.02
	(8.01)	(1.38)	(8.63)	(0.07)	(0.01)	(0.04)
N	23573	929666	953239	23609	931091	954700
Mean	3445.2	3566.5	3563.5	12.0	13.2	13.2

Panel B: Effects of Ramadan's Occurrence by Trimester

	Birthweight			Mother's Education		
	(1)	(2)	(3)	(4)	(5)	(6)
Ramadan's Occurrence During	Arabs	Non-Arabs	Difference	Arabs	Non-Arabs	Difference
First Trimester	-20.09**	-0.58	-19.50**	0.00	0.02*	-0.01
	(9.02)	(1.55)	(9.73)	(0.07)	(0.01)	(0.05)
Second Trimester	-25.53**	-0.50	-25.03**	0.04	0.00	0.03
	(10.14)	(1.71)	(10.93)	(0.08)	(0.01)	(0.06)
Third Trimester	-12.56	0.34	-12.89	-0.08	-0.02***	-0.06
	(9.34)	(1.60)	(10.07)	(0.08)	(0.01)	(0.05)
N	23573	929666	953239	23609	931091	954700
Mean	3445.2	3566.5	3563.5	12.0	13.2	13.2

Notes: Entries show the coefficent on the relevant Ramadan exposure measure. Samples use full-term births and exclude zipcodes where the the ratio of Chaldeans to non-Chaldean Arabs is greater than 1. Controls include mother's age, mother's age squared, month of conception dummies, year of birth dummies and county dummies. Columns 1 through 3 also control for mother's education. Standard errors in parentheses, *significant at 10%; ** significant at 5%; *** significant at 1%

Table 2: Effects of Ramadan *Hours* Exposure on Birth Outcomes

Coefficient on Ramadan daylight hours exposure as a fraction of peak daylight hours

Gestation Month	*Birthweight* (1) Arabs	(2) Non-Arabs	(3) Difference	*Fraction Male Births* (4) Arabs	(5) Non-Arabs	(6) Difference
1	-38.0*	-5.7	-32.3	-0.061**	0.001	-0.061**
	(21.8)	(3.6)	(23.2)	(0.026)	(0.004)	(0.026)
2	-44.0**	2.2	-46.2**	0.018	0.000	0.018
	(20.8)	(3.4)	(22.1)	(0.025)	(0.004)	(0.025)
3	-19.3	-3.4	-15.9	-0.001	0.005	-0.006
	(21.4)	(3.5)	(22.8)	(0.025)	(0.004)	(0.026)
4	-20.3	0.4	-20.7	-0.008	0.002	-0.011
	(21.6)	(3.5)	(23.0)	(0.026)	(0.004)	(0.026)
5	-38.4*	0.8	-39.2*	-0.019	-0.001	-0.018
	(22.2)	(3.5)	(23.6)	(0.026)	(0.004)	(0.027)
6	-27.7	-1.3	-26.4	-0.007	0.003	-0.011
	(22.0)	(3.5)	(23.4)	(0.026)	(0.004)	(0.026)
7	-53.5**	-0.7	-52.8**	-0.014	-0.003	-0.011
	(21.2)	(3.5)	(22.6)	(0.025)	(0.004)	(0.025)
8	26.7	-0.6	27.3	-0.003	0.001	-0.005
	(20.7)	(3.3)	(22.1)	(0.025)	(0.004)	(0.025)
9	-24.8	-3.9	-20.9	-0.031	0.000	-0.030
	(21.1)	(3.5)	(22.5)	(0.025)	(0.004)	(0.025)
N	22901	895196	918097	22927	896234	919161
Mean	3445.0	3566.9	3563.9	0.512	0.505	0.505
joint test, coefficients on months 1 to 9 equal to 0						
p -value	0.07	0.85	0.12	0.54	0.95	0.59
joint test, coefficients on months 1 to 9 are equal						
p -value	0.18	0.81	0.24	0.51	0.93	0.56

Notes: Samples use full-term births and exclude zipcodes 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%

Table 3: Effects of Ramadan Hours Exposure on Characteristics of Pregnancies Resulting in Live Births, Michigan Arabs

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Gestation Month	Mother's Education	Medicaid	Mother's Age	Father's Age	Father's Education	Tobacco	Alcohol	Parity	Previous Child Born Dead	Father's Educ. Miss.	Previous Small Baby	Diabetes Risk Factor
0	-0.095	-0.010	-0.085	-0.187	0.060	0.011	-0.003	0.098	-0.005	-0.019	0.005	-0.013*
	(0.192)	(0.026)	(0.307)	(0.362)	(0.183)	(0.011)	(0.002)	(0.086)	(0.033)	(0.013)	(0.003)	(0.008)
1	-0.067	-0.047*	0.551*	0.126	0.016	-0.006	-0.002	-0.019	-0.039	-0.009	-0.005*	-0.016**
	(0.180)	(0.024)	(0.288)	(0.339)	(0.171)	(0.010)	(0.002)	(0.081)	(0.031)	(0.012)	(0.003)	(0.007)
2	-0.034	-0.007	0.463	0.252	-0.039	0.015	-0.004*	-0.015	-0.025	0.011	-0.001	-0.007
	(0.184)	(0.025)	(0.294)	(0.347)	(0.175)	(0.010)	(0.002)	(0.082)	(0.032)	(0.013)	(0.003)	(0.008)
3	0.022	-0.018	0.283	-0.091	0.071	0.000	-0.003*	0.045	-0.008	-0.007	-0.006*	-0.019**
	(0.185)	(0.025)	(0.296)	(0.349)	(0.176)	(0.010)	(0.002)	(0.083)	(0.032)	(0.013)	(0.003)	(0.008)
4	0.246	-0.029	0.335	-0.021	0.164	-0.010	0.000	-0.110	-0.017	-0.015	0.000	-0.008
	(0.187)	(0.025)	(0.299)	(0.353)	(0.178)	(0.010)	(0.002)	(0.084)	(0.032)	(0.013)	(0.003)	(0.008)
5	-0.006	-0.005	0.201	-0.151	0.028	0.016	-0.005**	-0.052	-0.005	-0.006	-0.002	-0.009
	(0.189)	(0.026)	(0.303)	(0.358)	(0.181)	(0.010)	(0.002)	(0.085)	(0.033)	(0.013)	(0.003)	(0.008)
6	-0.011	0.003	0.328	0.433	-0.151	-0.002	-0.001	0.049	0.009	-0.010	-0.003	0.000
	(0.186)	(0.025)	(0.299)	(0.353)	(0.178)	(0.010)	(0.002)	(0.084)	(0.032)	(0.013)	(0.003)	(0.008)
7	-0.094	-0.013	0.171	-0.227	-0.013	-0.003	0.000	-0.096	-0.020	-0.019	0.004	-0.004
	(0.181)	(0.024)	(0.290)	(0.343)	(0.173)	(0.010)	(0.002)	(0.081)	(0.031)	(0.013)	(0.003)	(0.007)
8	-0.245	-0.029	0.259	0.034	-0.036	-0.010	-0.003*	0.099	0.001	0.002	-0.001	-0.008
	(0.176)	(0.024)	(0.282)	(0.334)	(0.168)	(0.010)	(0.002)	(0.079)	(0.030)	(0.012)	(0.003)	(0.007)
9	-0.038	-0.044*	0.051	-0.177	0.072	-0.004	-0.006***	-0.012	0.001	-0.005	-0.001	-0.001
	(0.184)	(0.025)	(0.295)	(0.350)	(0.176)	(0.010)	(0.002)	(0.083)	(0.032)	(0.013)	(0.003)	(0.008)
N	23604	23908	24256	23455	22678	23902	23888	24114	24123	24261	24087	24087
Mean	12.0	0.497	27.2	33.5	13.1	0.039	0.002	1.4	0.230	0.07	0.004	0.021

Notes: All entries are coefficients on Ramadan exposure to daylight hours over subsequent 30 days as fraction of peak daylight hours during sample period. Samples use full-term births and exclude zipcodes where the the ratio of Chaldeans to non-Chaldean Arabs is greater than 1. Regressions include dummies for conception month, county and birth year. Standard errors in parentheses, *significant at 10%; ** significant at 5%; *** significant at 1%

Table 4: Effects of Ramadan Exposure in Months Prior to Birth on Disability Outcomes in Uganda

Months Prior to Birth	*Muslims*					*Non-Muslims*				
	(1) Disability	(2) Sight/Blind	(3) Hear/Deaf	(4) Mental/Learn.	(5) Psych.	(6) Disability	(7) Sight/Blind	(8) Hear/Deaf	(9) Mental/Learn.	(10) Psych.
9	0.819**	0.349*	0.243**	0.250***	-0.098	-0.023	-0.052	0.028	-0.037	0.045
	(0.359)	(0.193)	(0.117)	(0.071)	(0.072)	(0.146)	(0.080)	(0.052)	(0.028)	(0.030)
8	0.087	-0.078	0.162	0.103	-0.068	-0.015	-0.043	0.043	-0.005	-0.028
	(0.337)	(0.180)	(0.110)	(0.066)	(0.067)	(0.137)	(0.075)	(0.049)	(0.026)	(0.028)
7	-0.132	-0.022	0.13	0.028	0.058	-0.074	-0.142*	-0.006	-0.006	0.010
	(0.349)	(0.187)	(0.114)	(0.069)	(0.069)	(0.142)	(0.078)	(0.051)	(0.027)	(0.029)
6	0.197	0.074	0.161	0.100	-0.098	-0.091	0.082	-0.007	-0.017	0.017
	(0.353)	(0.189)	(0.115)	(0.070)	(0.070)	(0.144)	(0.079)	(0.051)	(0.027)	(0.029)
5	0.085	-0.004	0.197*	0.129*	-0.058	0.209	-0.111	0.051	0.034	0.006
	(0.348)	(0.187)	(0.114)	(0.069)	(0.069)	(0.143)	(0.079)	(0.051)	(0.027)	(0.029)
4	0.273	0.039	0.072	0.117*	-0.049	-0.090	-0.030	0.048	-0.004	-0.017
	(0.352)	(0.189)	(0.115)	(0.070)	(0.070)	(0.144)	(0.079)	(0.051)	(0.027)	(0.029)
3	0.104	0.124	0.099	0.039	-0.009	0.003	0.115	-0.018	-0.004	0.010
	(0.364)	(0.195)	(0.119)	(0.072)	(0.073)	(0.147)	(0.081)	(0.053)	(0.028)	(0.030)
2	-0.266	-0.272	0.026	0.144**	-0.019	0.039	-0.015	0.065	-0.043	0.036
	(0.350)	(0.187)	(0.114)	(0.069)	(0.070)	(0.142)	(0.078)	(0.051)	(0.027)	(0.029)
1	-0.103	0.018	0.086	0.089	-0.034	0.208	-0.061	0.035	0.010	0.023
	(0.366)	(0.196)	(0.120)	(0.072)	(0.073)	(0.148)	(0.082)	(0.053)	(0.028)	(0.030)
joint test, coefficients on months 1 to 9 equal to 0										
p -value	0.390	0.560	0.480	0.040	0.740	0.670	0.290	0.890	0.560	0.650
joint test, coefficients on months 1 to 9 are equal										
p -value	0.310	0.460	0.830	0.290	0.750	0.570	0.240	0.910	0.490	0.580
Mean	3.80%	1.06%	0.38%	0.14%	0.14%	5.21%	1.49%	0.61%	0.17%	0.20%
N	80924	80922	80923	80921	80921	640825	640789	640781	640777	640776

Notes: Entries are coefficients on the percent of days overlapping with Ramadan in the nine months preceding birth. Outcomes are multiplied by 100, so that coefficients are in units of percentage points. All regressions include an indicator for female, birth month dummies, district of birth dummies and birth year dummies. Standard errors in parentheses, *significant at 10%; ** significant at 5%; *** significant at 1%

Table 5: Effects of Ramadan Exposure on Causes of Disabilities, Ugandan Muslims, by Months Prior to Birth

Months Prior to Birth	*Unrelated to prenatal nutrition*			*Possibly Related to prenatal nutrition*		
	Accident	Occ. Injury	War Injury	Aging	Disease	Congenital
9	-0.060	0.059	0.054	0.373***	0.199	0.137
	(0.142)	(0.074)	(0.052)	(0.136)	(0.267)	(0.134)
8	0.042	-0.023	0.001	0.137	-0.025	-0.017
	(0.133)	(0.070)	(0.049)	(0.127)	(0.250)	(0.126)
7	-0.102	-0.063	0.000	-0.034	-0.248	0.131
	(0.137)	(0.072)	(0.050)	(0.132)	(0.259)	(0.130)
6	-0.025	0.050	0.043	0.222*	-0.369	0.210
	(0.139)	(0.073)	(0.051)	(0.134)	(0.262)	(0.132)
5	0.127	-0.009	-0.085*	-0.022	0.100	0.084
	(0.137)	(0.072)	(0.050)	(0.132)	(0.258)	(0.130)
4	0.179	0.018	0.064	0.055	-0.252	0.153
	(0.139)	(0.073)	(0.051)	(0.133)	(0.261)	(0.131)
3	-0.09	0.031	0.047	0.110	0.006	0.012
	(0.144)	(0.075)	(0.053)	(0.138)	(0.270)	(0.136)
2	0.161	-0.063	0.021	-0.011	-0.158	-0.225*
	(0.138)	(0.072)	(0.050)	(0.132)	(0.259)	(0.130)
1	0.002	-0.086	0.057	0.051	-0.044	-0.116
	(0.144)	(0.076)	(0.053)	(0.138)	(0.271)	(0.136)
joint test, coefficients on months 1 to 9 equal to 0						
p -value	0.710	0.730	0.460	0.210	0.750	0.080
joint test, coefficients on months 1 to 9 are equal						
p -value	0.640	0.640	0.400	0.210	0.730	0.060
Mean	0.56%	0.53%	0.07%	0.53%	2.03%	0.50%
N	80921	80921	80921	80921	80924	80921

Notes: All entries are coefficients on Ramadan exposure measured as the percent of days overlapping with Ramadan in the nine m preceding birth (rampct). Each outcome is multiplied by 100, so that coefficients are in units of percentage points. All regressions an indicator for female, birth month dummies, district of birth dummies and birth year dummies.

Table 6: Effects of Ramadan Exposure in Months Prior to Birth on Other Outcomes, Ugandan Muslims

Months Prior to Birth	Sex Composition of Adult Population				Socioeconomic Outcomes				
	(1) Male	(2) Log Pop.	(3) Log Males	(4) Log Fem.	(5) Home Owner	(6) Illiterate	(7) Yrs. Schl	(8) No Schl.	(9) Employed
9	-0.020**	0.001	-0.030	0.053	-0.026**	0.008	-0.088	-0.004	0.000
	(0.009)	(0.047)	(0.059)	(0.065)	(0.012)	(0.008)	(0.068)	(0.007)	(0.009)
8	-0.015*	0.015	-0.034	0.081	-0.021*	-0.015**	0.119*	-0.007	-0.001
	(0.009)	(0.044)	(0.056)	(0.062)	(0.011)	(0.007)	(0.064)	(0.007)	(0.008)
7	-0.003	0.007	-0.055	0.083	-0.017	0.007	-0.009	0.001	-0.009
	(0.009)	(0.045)	(0.057)	(0.063)	(0.011)	(0.008)	(0.066)	(0.007)	(0.009)
6	-0.021**	-0.047	-0.081	0.01	0.008	-0.014*	0.01	-0.013*	0.013
	(0.009)	(0.045)	(0.057)	(0.063)	(0.011)	(0.008)	(0.067)	(0.007)	(0.009)
5	-0.015	0.069	0.014	0.150**	-0.018	0.012	-0.015	0.005	-0.019**
	(0.009)	(0.045)	(0.057)	(0.064)	(0.011)	(0.008)	(0.067)	(0.007)	(0.009)
4	-0.016*	0.002	-0.03	0.036	-0.010	0.008	-0.045	0.006	-0.001
	(0.009)	(0.045)	(0.057)	(0.064)	(0.011)	(0.008)	(0.067)	(0.007)	(0.009)
3	-0.026***	-0.085*	-0.148**	0.008	0.008	0.002	0.061	-0.002	0.005
	(0.010)	(0.046)	(0.057)	(0.064)	(0.012)	(0.008)	(0.069)	(0.008)	(0.009)
2	-0.009	0.025	0.001	0.066	-0.005	0.009	0.069	0.009	-0.002
	(0.009)	(0.045)	(0.056)	(0.063)	(0.011)	(0.008)	(0.067)	(0.007)	(0.009)
1	-0.009	-0.025	-0.031	0.012	0.000	0.005	-0.011	-0.005	0.001
	(0.010)	(0.047)	(0.059)	(0.065)	(0.012)	(0.008)	(0.069)	(0.008)	(0.009)
joint test, coefficients on months 1 to 9 equal to 0									
p-value	0.100	0.460	0.420	0.520	0.050	0.100	0.440	0.390	0.460
joint test, coefficients on months 1 to 9 are equal									
p-value	0.640	0.360	0.570	0.770	0.070	0.070	0.380	0.300	0.380
Mean	0.506	4.205	3.554	3.399	0.734	0.30	6.94	0.25	0.66
N	81197	648	653	649	40463	78990	60117	80142	74348

Notes: Entries are coefficients on the percent of days overlapping with Ramadan during the nine months preceding birth.. Regressions include birth month and birth year dummies. Columns 2-4 use data on population counts aggregated to the level of birth year and birth month. Column 1 and columns 5-9 also include district of birth dummies. Column 5 is restricted to men. Columns 6-9 include a dummy for females. Standard errors in parentheses, *significant at 10%; ** significant at 5%; *** significant at 1%

Table 7: Effects of Ramadan Exposure in Months Prior to Birth on Various Outcomes, Iraq

Months Prior to Birth	Disability Outcomes				Socioeconomic Outcomes			
	(1) Disability	(2) Blind/Vision	(3) Deaf/Hear	(4) Psych.	(5) Mult. Wives	(6) Home Owner	(7) Male	(8) Employed
9	0.333**	0.022	-0.002	0.228***	-0.542**	-1.422**	0.355	1.097**
	(0.141)	(0.041)	(0.016)	(0.070)	(0.276)	(0.724)	(0.586)	(0.444)
8	-0.160	-0.017	-0.001	0.013	-0.238	-0.734	0.591	0.079
	(0.129)	(0.037)	(0.015)	(0.064)	(0.252)	(0.662)	(0.536)	(0.406)
7	-0.137	0.003	0.016	-0.105	-0.082	-2.063***	0.207	0.829**
	(0.130)	(0.038)	(0.015)	(0.065)	(0.260)	(0.671)	(0.541)	(0.410)
6	0.054	0.002	0.003	0.061	-0.404	-1.422**	0.049	0.740*
	(0.128)	(0.037)	(0.015)	(0.064)	(0.256)	(0.661)	(0.533)	(0.403)
5	0.139	0.079**	0.021	0.059	-0.221	-1.654**	-0.382	0.361
	(0.126)	(0.036)	(0.015)	(0.063)	(0.252)	(0.650)	(0.524)	(0.397)
4	0.076	0.056	-0.006	0.04	-0.482**	-1.091	-0.153	0.164
	(0.132)	(0.038)	(0.015)	(0.066)	(0.238)	(0.679)	(0.547)	(0.414)
3	0.088	0.016	0.002	-0.001	-0.128	-1.294*	-0.545	-0.853**
	(0.132)	(0.038)	(0.015)	(0.066)	(0.249)	(0.681)	(0.548)	(0.415)
2	0.057	0.041	-0.006	0.03	-0.127	-1.638**	0.328	-0.337
	(0.129)	(0.037)	(0.015)	(0.064)	(0.240)	(0.662)	(0.534)	(0.404)
1	0.046	-0.02	0.007	0.01	0.106	-0.951	-0.578	-0.741*
	(0.136)	(0.039)	(0.016)	(0.067)	(0.260)	(0.702)	(0.563)	(0.426)
joint test, coefficients on months 1 to 9 equal to 0								
p -value	0.110	0.300	0.870	0.020	0.340	0.080	0.700	0.000
joint test, coefficients on months 1 to 9 are equal								
p -value	0.080	0.260	0.810	0.010	0.450	0.900	0.610	0.000
Mean	1.48%	0.12%	0.02%	0.36%	1.60%	73.68%	49.00%	43.29%
N	256156	256156	256156	256156	68951	123743	256174	255109

Notes: Entries are coefficients on the percent of days overlapping with Ramadan during the nine months preceding birth. Regressions include birth month and birth year dummies. Each outcome is multiplied by 100, so that coefficients are in units of percentage points. Columns 5 and 6 are restricted to men. All regressions on pooled samples of men and women include a dummy for females. Standard errors in parentheses, *significant at 10%; ** significant at 5%; *** significant at 1%

Contents

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 under-nutrition." 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.

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[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).

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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

Gestation Month exposure	*Dependent Variable is Log Live Births (Total, Male Female)*					
	(1)	(2)	(3)	(4)	(5)	(6)
	Arab Sample			Non-Arab Sample		
	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

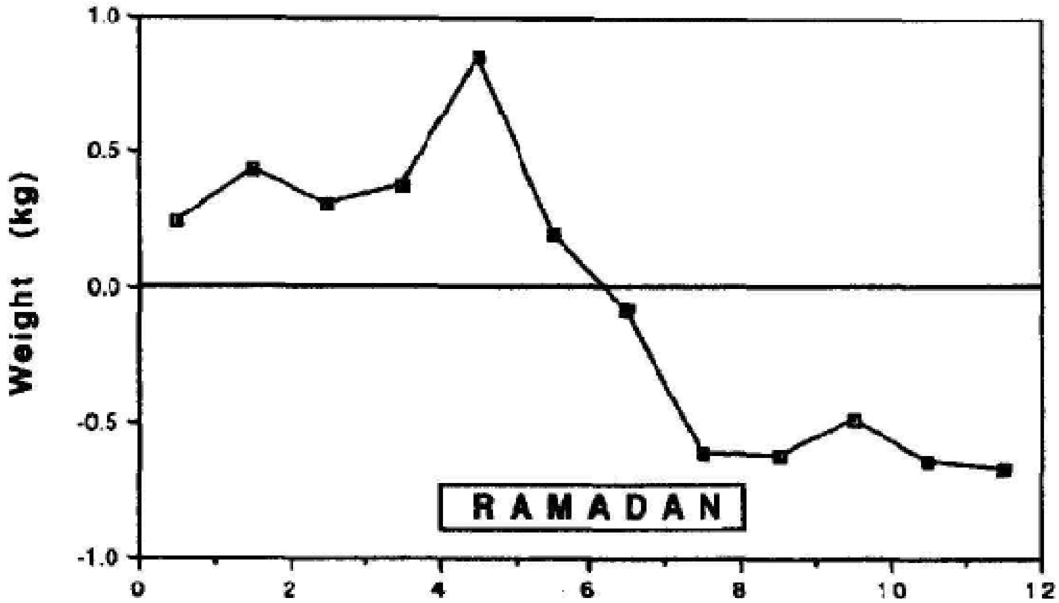
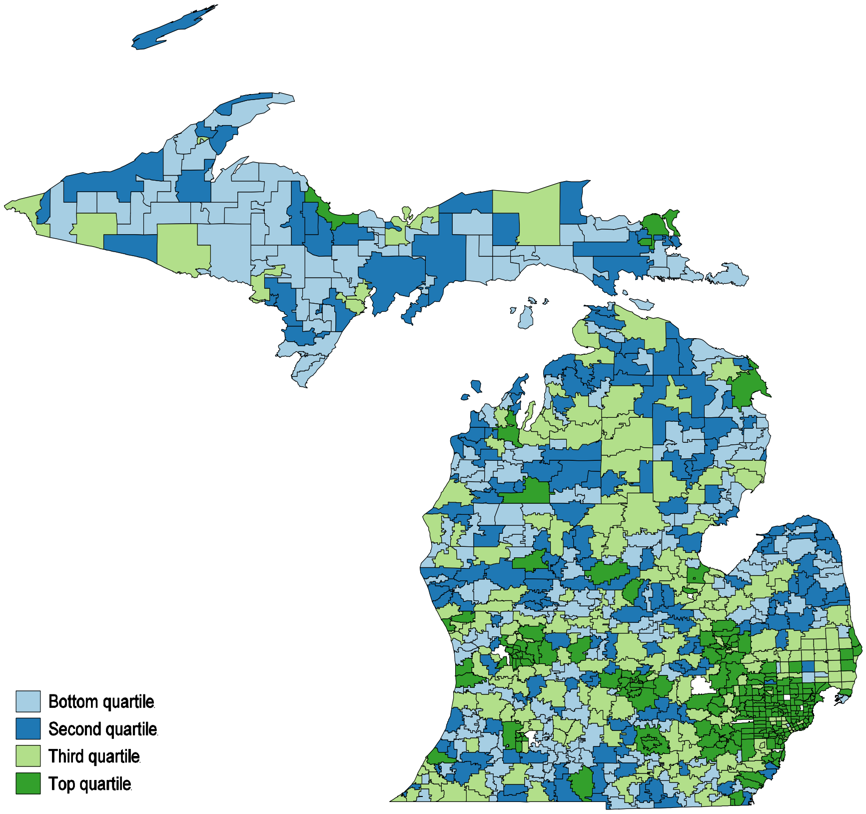


Fig. 8.5. Weight change in Gambian women during 3 months around the fast of Ramadan, expressed relative to mean weight for the other 9 months of the year. Each point has a standard error of about 0.15 kg. The data are adjusted for calendar month and year of measurement, and stage of pregnancy/lactation,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

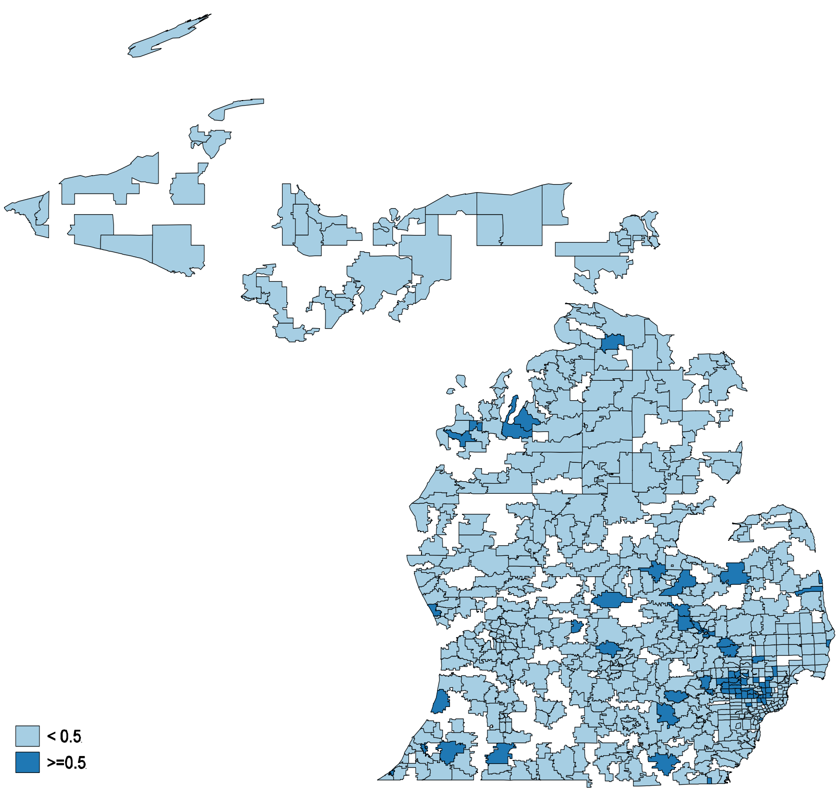
Source: Cole (1993)

Figure A2: Michigan Arab Population by Zipcode

Panel A: Quartiles of the Arab Population Level

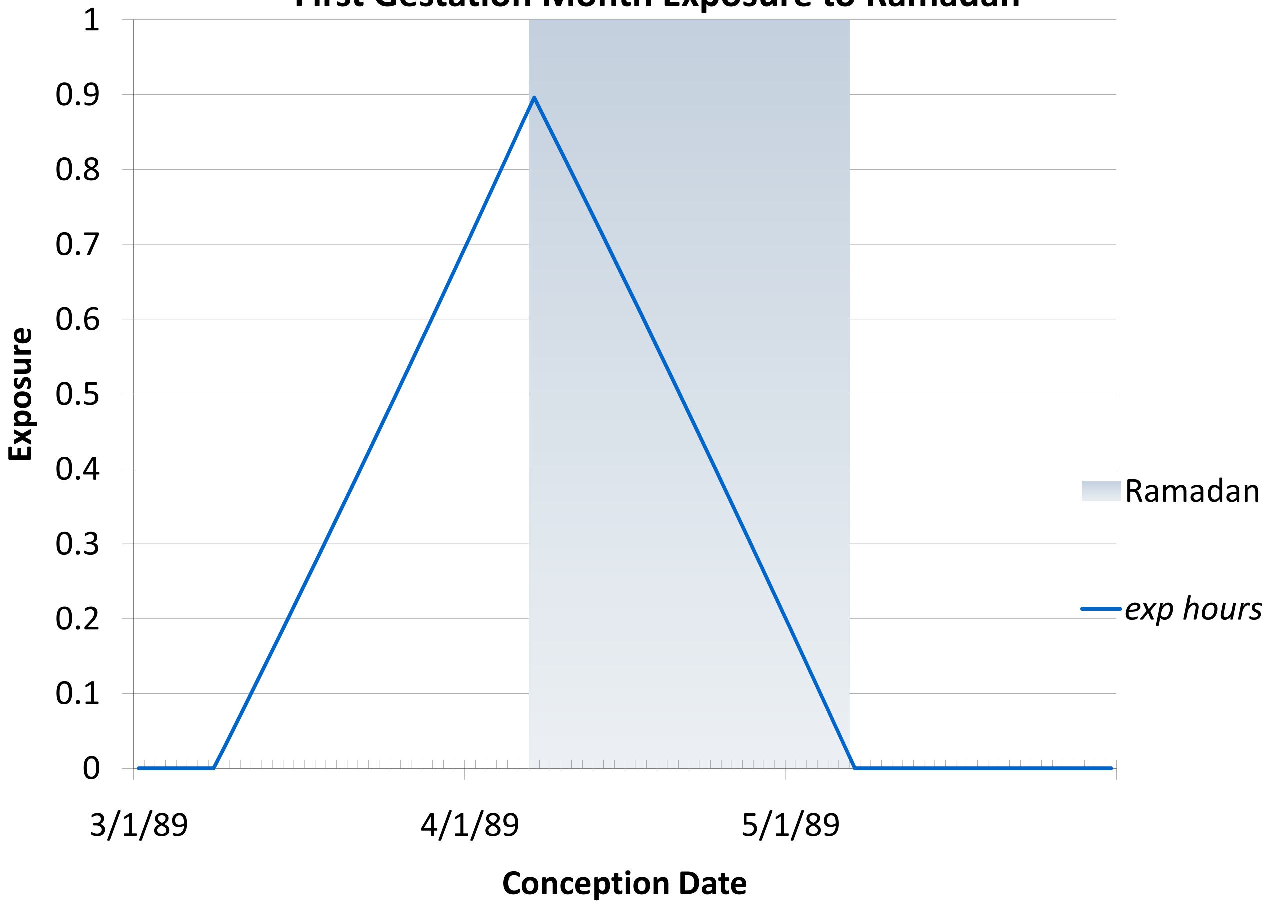


Panel B: Ratio of the Chaldean to Arab Population



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

Figure A3:
First Gestation Month Exposure to Ramadan



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