

SOAKING UP THE SUN:

THE ROLE OF VITAMIN D AND RACE IN THE PRODUCTION OF INFANT HEALTH

Karen Smith Conway¹
Andrea Kutinova-Menclova²
Jennifer Trudeau¹

Revised November 2011

***Preliminary Draft - Comments Welcome**

Please do not cite without author's permission.

For presentation at 2011 Southern Economic Association Meetings, November 2011

*Acknowledgements: We would like to thank Vladimir Mencl from BlueFern Computing Services at the University of Canterbury for computing assistance. This paper has also benefited from the comments of Donka Mirtcheva, Nancy Reichman and participants in our sessions at the Eastern Economic Association and iHEA Meetings.

¹ University of New Hampshire Department of Economics, McConnell Hall, Durham, NH 03824. Email: karen.conway@unh.edu and jmn5@unh.edu.

² University of Canterbury Department of Economics and Finance, Christchurch, NZ. E-mail: andrea.menclova@canterbury.ac.nz.

I. Introduction

In the last several years, increased attention has been devoted towards eliminating the birth outcome gap between races. Despite increases in prenatal care utilization and expanding coverage of Medicaid in the 1990s, the birth weight gap between black and white infants has yet to be explained in its entirety. Only 40.6% of the gap has been explained by observable differences (i.e. socioeconomic status, prenatal care etc.) across races (Lhila and Long 2011), warranting further research into alternative economic and biological factors. At the same time, Vitamin D has come to the forefront of medical investigation for its influence in protecting against a whole host of negative health outcomes. The link between Vitamin D insufficiency and bone health has been well established in the field (Gallagher and Sai 2010); recent investigations have begun to look at the influence of maternal Vitamin D status on birth outcomes as well. This paper contributes to both strands of research as well as the broader infant health production literature by investigating the effect that sun exposure, presumably via Vitamin D absorption but also possibly through other mechanisms, has on birth outcomes.

Apart from diet and supplementation, Vitamin D is produced in the body via a process of photosynthesis in the skin initiated by UV-B exposure. This process is inhibited by skin pigmentation, clothing/sunblock and high latitude, leading to well established racial/ethnic and geographic/seasonal patterns in vitamin D (in)sufficiency (e.g., Ginde et al. 2009). Our research investigates the connection between sunshine, measured by solar radiation, and birth outcomes to draw inferences on the role of Vitamin D and race in the production of infant health. Solar radiation, also referred to as insolation, encompasses the entire spectrum of light which we perceive as sunlight. A portion of this solar energy consists of UV-B radiation which has the optimal wavelength for photosynthesis of Vitamin D in the skin. Exposure to UV-B radiation by the mother results in the production and storage of Vitamin D in the body which then may be distributed throughout the body or passed directly through the placenta to the infant. Although insolation is a crude measure capturing the total amount of radiation, it serves as an upper bound for UV-B exposure that a mother could obtain during her pregnancy. In addition, compared to Vitamin D blood levels which are frequently used in medical studies and are influenced by many factors such as obesity and diet, it is more likely exogenous to the mother.

Medical evidence on the effects of Vitamin D on pregnancy outcomes has been primarily observational or based on animal studies; very little evidence from randomized controlled trials (RCT) exist (for a review see Brannon and Picciano 2011; Hollis et al. 2011 is the most recent RCT). Human studies typically include a small (<1,000 observations) sample of mothers from a specific geographic location during a short time period, a very limited number of birth outcomes and likely endogenous measures of Vitamin D from only one point during the pregnancy. In contrast, our study uses multiple birth outcomes from the very large, national Natality Detail Files over a long time period (1989-2004) combined with daily weather data on solar insolation and temperature. With our dataset, we can investigate the effects of potential sun exposure measured at many different points during the pregnancy on a wide set of birth outcomes using large, national samples of black and white mothers. We can also focus on *changes over time* in

sun exposure, thereby isolating the effects of sunshine from those of season of birth or geographic location which are likely capturing other factors and are more within the mother's control.

In addition to contributing to economic research on the causes of racial disparities in birth outcomes, the effects of sun exposure and Vitamin D may also help to explain the seasonal variation in birth outcomes observed by Kestenbaum (1987), Lokshin and Radaykin (2009) and others. It could further support recent findings by Buckles and Hungerman (2008) in rejecting the validity of season of birth as an instrumental variable for evaluating educational policies and practices. It also has implications for the recent research that finds detrimental effects of climate change and extreme weather events on birth outcomes (Deschenes et al 2009 and Simeonova 2011, respectively). Sunshine is clearly associated with both temperature extremes and some natural disasters and so its effects could be a confounding factor.

Our research also has implications for the effectiveness of the Medicaid expansions and other policies. The daily recommended levels of Vitamin D for pregnant women were actually *reduced* concurrently with the Medicaid expansions of the 1990s. Estimates of the effect of Medicaid expansions may be confounded, especially by race, if the influence of Vitamin D levels is an important factor in infant health. Moreover, the finding that the Women, Infants and Children (WIC) feeding program is more beneficial for black mothers (e.g., Metcoff et al. 1985, Brien and Swann 2001) may be explained by the program's emphasis on high calcium foods, which aid in the absorption of Vitamin D (Food and Nutrition Service³). We also acknowledge that sun exposure may be associated with additional environmental and behavioral factors that could influence birth outcomes. In particular, sunshine may be both correlated with and an important determinant of the level of air pollutants (e.g., Knittel et al. 2011) which has been found to play an important role in infant health (Currie 2011).

Finally and perhaps significantly for both medical and economic research, we present a conceptual model that helps to clarify the complicated, intertwined roles of maternal characteristics and behaviors, environmental factors, Vitamin D and sun exposure. This framework clarifies concerns in the medical literature about using observed maternal Vitamin D blood levels to estimate causal effects but also points out the possible pitfalls of using meteorological data as an instrumental variable. It further reveals how Vitamin D and sun exposure may be confounding factors in economic models of infant health.

Using birth outcomes data from the Natality Detail Files and daily weather data on temperature and solar insolation, we estimate birth outcome equations incorporating weather effects. Surprisingly, our preliminary results indicate a *negative* relationship between insolation and birth weight across both races. The results are persistent across alternative aggregation

³ <http://www.fns.usda.gov/wic/aboutwic/howwichelps.htm#diet> outcomes; Accessed 08/24/2011.

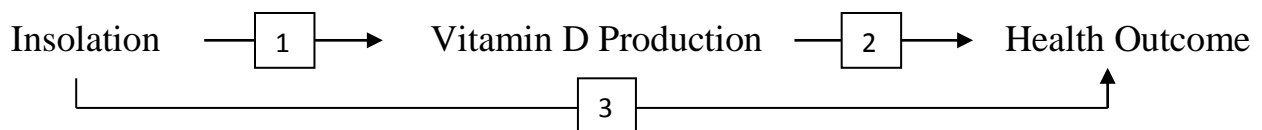
levels: by pregnancy, trimester and month, regardless of weekend effects and nonlinearities; across various sub-samples and robust to alternative fixed-effects specifications. In future research, we plan to explore additional model specifications that are similar to Deschenes et al (2009)'s measures of temperature extremes by creating discrete measures that combine sunshine and temperature sunshine. In this way we can better capture both weather extremes (e.g., the effects of 4 days with 2 hours of sunshine each are different than one with 8 hours and three with none) and the relationship between temperature and sunshine (e.g., sunshine may have a different effect if it occurs on a temperate day rather than a very hot or cold one). More generally, we also plan to both expand the number of birth outcomes considered and investigate alternative mechanisms for sunshine to have an effect on infant health to better understand our results.

The paper first provides background of Vitamin D's effects, solar radiation as a catalyst for Vitamin D creation, and its relationship to pregnancy. Section II summarizes past medical studies and infant health analyses, which we combine to explore the impact of insolation on birth outcomes. Section III outlines the empirical specification of a reduced form infant health production function utilized in the study and is followed by an explanation of the data in Section IV. Section V explores the preliminary results of our empirical analysis. The paper concludes with a discussion of several additional hypotheses for the observed negative relationship between insolation and Vitamin D.

II. Background on Sun Exposure, Vitamin D and Birth Outcomes

Medical research on the determinants, prevalence and health effects of Vitamin D (in)sufficiency has exploded in the last decade. While initially limited primarily to bone health, the role of Vitamin D during pregnancy has been explored in numerous studies, resulting in a large number of review articles in just the last year or so (e.g., Bodnar and Simhan 2010, Brannon and Picciano 2011, Dror and Allen 2010, Lapillonne 2010, Lewis et al. 2010, Ponsoby et al. 2010, and Grayson and Hewison 2011). These reviews typically discuss the determinants and prevalence of Vitamin D deficiency among pregnant women and then proceed to the possible biological mechanisms and empirical evidence regarding the effects of Vitamin D on a host of pregnancy and birth outcomes, sometimes including long-lasting effects into the offspring's adulthood and the potential for fetal 'imprinting.' The main conclusions from these reviews are similar and so we summarize them as a group.

The framework for our study begins with three associations, linking insolation with positive birth outcomes.



Our review is organized around these three linkages, in order, noting the influential role of race along the way. We pay special attention to Gale et al. (2008), the only study to our knowledge to provide evidence on links #1 and 2 with the same data, and to Hollis et al. (2011) and Yu et al. (2009), as the only recent RCT studies of Vitamin D supplementation. However, we start with a brief scientific primer on Vitamin D, its determinants and observed levels in the population, and its possible relationship with race.

a. The science of Vitamin D, its determinants and the role of race

Vitamin D is a fat soluble seco-sterol that acts as an agent in the absorption and transport of calcium in the body. It appears in two forms: ergocalciferol, more commonly referred to as Vitamin D₂ and cholecalciferol, Vitamin D₃. The two forms are unique in their mode of transmission to individuals. Vitamin D₂ is acquired via ingestion of foods such as fish and dairy products or oral supplementation. Dairy products in particular are a good source of Vitamin D as they are often fortified by the manufacturer. However, studies on race and lactase have shown that as much as 70% of the African American population has lactase non-persistence, leaving them susceptible to symptoms of lactose intolerance (Byers and Savaiano 2005), severely inhibiting the consumption of calcium and Vitamin D via dietary measures.

In contrast, Vitamin D₃ is produced in the body via exposure to UV-B radiation and photosynthesis within the skin (link #1 above). The process begins with 7-dehydrocholesterol in the cells of the epidermis which is converted by UV-B into pre-vitamin D₃. The body is able to regulate the amount of vitamin D required, preventing hypervitaminosis D (toxicity) from occurring as a result of sun exposure (Holick 2007). The pre-vitamin D₃ is converted to Vitamin D within the skin, then travels to the kidneys and liver where it is processed into the active form 1,25(OH)₂D, which is circulated throughout the body (Wolpowitz 2006). This form of the vitamin has a more potent impact on serum levels, argued by Armas et al. (2004) to be as much as 3 to 10 times more effective than Vitamin D₂, and is less likely to lead to toxicity because of the way in which it binds to receptors (Moyad 2009). Currently, both D₂ and D₃ supplements are available on the market for over-the-counter consumption.

Similar to the disparities in race across ingestion of vitamin D₂, vitamin D₃ is not photosynthesized consistently across various concentrations of skin pigmentation. Developing out of an evolutionary need, dark and light skin pigmentation results in both favorable and adverse effects. Two theories capture the trade-off between hazardous sun exposure (as observed in the prevalence of skin cancer) and vitamin D deficiencies that has been witnessed in the past 90 years (Rajamakar 2005). The first recognizes dark skin pigmentation as a response to the body's need to protect the skin from harmful UV radiation. The dark-skin pigmentation is a result of extra melanin in the cells which prevents the UV radiation from penetrating to the dermis and damaging DNA (Jablonski 2004). The second argues that fair skin resulted as individuals moved farther from the equator as a function of the need to be more receptive of the sunlight available. Based on the diminished intensity of UV radiation at latitudes farther from

the equator, the human body needed to make the most of the available exposure, building up stock by processing Vitamin D more efficiently (Jablonski 2004). However, with increased mobility of individuals, the once useful traits have begun to impede individuals from accumulating sufficient Vitamin D levels.

Swamy et al. (2011) provides strong evidence that genetic variability in Vitamin D receptors may help explain racial disparities in pregnancy outcomes and that sun exposure may have differential effects by race. Using a sample of 615 pregnant women in Durham, NC, the study shows that differences in allelic frequencies in these receptor genes significantly explain differences in birth weight among black infants only. Conversely, the season of conception – a proxy for sun exposure and link #3 above – is a weakly significant factor for white infants only.

In addition to diet/supplements, UV-B radiation and race, other factors affect the production of Vitamin D as well. Obviously, sun screen, veils and other factors limiting sun exposure (e.g., sedentary lifestyle) may also play a role. Obesity has also been associated with lower levels of Vitamin D (e.g., Manson et al. 2011). These other factors can make isolating the causal effect of Vitamin D difficult as each may have independent health effects as well. While sun exposure is an indirect and approximate measure of Vitamin D absorption, it is exogenous to the mother and free of these types of confounding effects. Its strong relationship with Vitamin D (link #1 above) is well-documented as noted in the next section.

Widespread deficiency and insufficiency of Vitamin D among all groups, but especially among pregnant women and the elderly, has been widely recognized (Ginde et al. 2010, Looker et al. 2011 and above surveys) and African Americans have an especially high prevalence. This tendency has led to calls for increasing the recommended Vitamin D dose for pregnant women from the current 400 IUs to as much as 4,000 IUs (Hollis et al. 2011).

b. Link #1 – Solar insolation and other determinants of Vitamin D

UV-B, the catalyst of the photosynthesizing process, falls between wavelengths of 290-320 nanometers on the electromagnetic spectrum and is one of the most harmful forms of UV radiation (HPS 2009). Researchers recommend individuals get outdoors for a “sensible” 5-30 minutes exposure twice a week, during the midday hours when insolation is direct, so that they can reap the benefits of the sunshine while spending the least amount of time under the sun (Holick 2007). Because of differences in the distance from the sun, the distribution of UV-B radiation is not identical across latitudes and seasons. Additionally, factors such as ozone composition reduce the amount of insolation that reaches the Earth’s surface. Of the insolation that does enter the atmosphere, factors such as dark-skin pigmentation, sun block and clothing coverage further inhibit the absorption of radiation. Variations in skin-pigmentation and geographic location create a significant spread in the length of time required to photosynthesize

Vitamin D. For instance, with clear sky, a fair skinned Caucasian woman at 42.5 degrees latitude in June can achieve sufficient Vitamin D production in 4 minutes at noon; the corresponding time required is 19 minutes for a dark-skinned individual. In December, the required time increases to 70 minutes for fair skinned individuals, with duration for dark-skinned individuals exceeding the length of the day (Webb and Engelsen 2006). This severe discrepancy in Vitamin D synthesis may thus help explain both seasonal and racial disparities in infant health outcomes.

A strong relationship between measures of season/sunshine/UV-B exposure and vitamin D levels is well established (Reusch et al. 2009, Nesby-O'Dell et al. 2002, Harris and Dawson-Hughes 1998, Gale et al. 2008) and may differ by race. Bodnar et al. (2009) evaluated the differences across season of birth and race of mothers in Pittsburgh, Pennsylvania. They found significant seasonal variation in the sample means of serum Vitamin D levels accounting for a 76% higher prevalence of insufficiency in white infants born in the spring relative to those born in the summer. Black infants born in the spring had only 21% higher prevalence. The lower volatility in Vitamin D levels among black infants suggests that they are less impacted by seasonal variation, likely due to reduced production of Vitamin D via UV-B. A second influential study of mothers in the United Arab Emirates by Narchi et al. (2010) measured the serum Vitamin D levels and recorded participants' recall on dietary and environmental factors such as time spent outdoors, in addition to sun block usage and clothing coverage. They found hypovitaminosis D (deficiency) in 69% of their sample, but no statistical significance associated with sun exposure, likely attributable to the small sample size and little variation in sun exposure. They cite clothing coverage, sun avoidance and dark skin pigmentation as potential sources of the observed deficiencies.

A related paper by Binkley et al. (2007) took an alternate approach to the sunshine and vitamin D status relationship by studying individuals who have ample exposure to sunshine. They looked at pregnant women in Honolulu, Hawaii utilizing sun exposure recall and reflectance colorimetry, measuring variations in skin color, to assess the contributing factors of Vitamin D levels. They found 51% of their 93 females sample fell into the category of vitamin D deficiency and concluded that sun exposure alone does not assure Vitamin D sufficiency and affirmed the significance of skin-pigmentation in the role of Vitamin D synthesis.

Sayers et al. (2009) is particularly relevant for our analysis. Using data from the UK, the authors first established a strong relationship ($R^2=.99$) between eUV (a type of UV radiation) and hours of sunshine and month dummy variables. They then calculated the accumulated, possible eUV exposure during the last 98 days of pregnancy and regressed it on maternal Vitamin D blood levels and found a strong, statistically significant relationship. Based on these findings, the authors argued for using such meteorological data as an instrumental variable for vitamin D status.

The findings by Sayers et al. (2009) are reassuring for us because neither UV-B radiation nor the actual duration of Vitamin D synthesizing hours is available over the sample period for each county observed in our data. For the analysis in this paper, we use solar insolation, a measure of solar energy (expressed in kilowatt-hours/meters²/day). Insolation captures the intensity of the full-spectrum of UV-radiation as it reaches the surface of the Earth. Use of insolation as a proxy for exposure to sunshine is also used by Carson (2009) in his analysis of the impact of insolation on height of US- and African-born black prisoners and their white American counterparts.

To assess the relationship between insolation and the duration of Vitamin D-synthesizing sun exposure, we employ Ola Engelsen's "VitD-ez Duration of Vitamin D Synthesis in Human Skin" calculator⁴ to determine the length of exposure under ideal and worst weather conditions for different dates and geographic locations.⁵ Our site-by-site comparison of the Engelsen measure with observed insolation values (Figure 1) shows reasonably close correspondence. Specifically, the maximum and minimum values of insolation observed in our data track the Engelsen measures under ideal and worst conditions fairly well and exhibit, for the most part, similar seasonal and geographic patterns. Note that seasonal weather patterns likely explain the instances when the two measures do diverge. For example, Whatcom county, Washington shows the observed peak insolation measures occur later in the year than the Engelsen measures. Examining typical weather conditions reveals that July and August experience substantially lower precipitation than May and June, thus explaining the discrepancy.⁶ This exercise therefore lends support to our use of insolation as a proxy for the duration of exposure of Vitamin D-synthesizing sunshine.

c. Link #2 -Vitamin D and pregnancy outcomes

Birth outcomes present a unique opportunity to study the effects of Vitamin D/insolation because pregnancy is a discrete event during which the fetus accumulates health stock via the behaviors of the mother and a set of predetermined characteristics. For this reason, prenatal inputs such as multivitamin regimens, diet and activity contribute to the health status of the baby over the entire course of a pregnancy. Vitamin D has a half-life of 2-3 weeks (Wolpowitz 2006), indicating a rapid decay which if not replenished may lead to short and/or long-term adverse

⁴ Calculator found at <<http://zardozi.nilu.no/~olaeng/fastrt/VitD-ez.html>>.

⁵ The calculator requires data for the month, day, latitude, longitude and a few climate indicators such as sky condition, ozone layer thickness and surface type (e.g., snow cover) and produces an estimate for the duration of Vitamin-D synthesis for that day with those conditions. For our analysis the "ideal" conditions for NYC would be 'thin' ozone layer, cloudless skies, an altitude of 0.5 kilometers and new snow for the months November through April and dry concrete for May through October; and conversely, 'thick' ozone, overcast skies, and old snow for the winter months. Although duration of Vitamin D synthesis hours would be the preferred measurement, we do not have the resources to generate the daily observations given each condition for each of the 458 counties in our sample.

⁶ Average precipitation for Whatcom Falls, WA is obtained from <http://www.weather.com/weather/wxclimatology/monthly/graph/14863:19>. Aside from New York City, the other two counties were selected based on being the highest and lowest latitude counties in the data set.

health outcomes. The vast majority of the existing research on Vitamin D and pregnancy outcomes are medical studies which use small samples of pregnant women and Vitamin D levels measured in the blood at a given point during the pregnancy (e.g., Bodner et al. 2007, Bodner et al. 2010, Gale et al. 2008), although some also estimate Vitamin D status on the basis of dietary intake (Mannion et al. 2006, Scholl and Chen 2009). A strong relationship between maternal and fetal Vitamin D blood levels has been established, and plausible biological mechanisms for Vitamin D to affect specific pregnancy outcomes are outlined in several of the more technical reviews (e.g., Dror and Allen 2010 and Grayson and Hewison 2011).

These studies reveal that Vitamin D status is associated with fertility (indeed, Grayson and Hewison 2011 recommend Vitamin D supplementation as treatment for recurring miscarriage), pre-eclampsia, gestational diabetes, bacterial vaginosis, preterm birth, gestational age and mode of birth (c-section vs. vaginal), as well as maternal and fetal bone health. The evidence for a relationship with birth weight or fetal size, however, is more mixed. For instance, after first establishing a strong correlation between potential UV-B exposure and maternal Vitamin D blood levels (link #1), Gale et al. (2008) find no statistically significant effect of maternal Vitamin D on infant size (link #2). Conversely, Mannion et al. (2006) and Scholl and Chen (2009) find a significant relationship between Vitamin D intake and infant birth weight. These reviews also report that, after birth, associations have been found between maternal vitamin D status and subsequent brain development (schizophrenia, multiple sclerosis), wheezing/asthma and diabetes in the offspring.

However, as Dror and Allen (2010) note: “Any relationship between maternal vitamin D status and birth weight or size is likely to be obscured by multiple confounding factors including maternal ethnicity, pre-pregnancy BMI, weight gain during pregnancy, gestational diabetes, smoking and parental stature” (pp. 467-8). Vitamin D blood levels, while the most direct measure of Vitamin D status, are also very likely affected by other individual characteristics and lifestyle factors that could exert independent effects on birth weight. This concern is echoed by Brannon and Picciano (2011) as well who conclude that the existing evidence for Vitamin D’s effects on birth outcomes lacks causality. In addition, uncertainty remains about the appropriate thresholds for classifying Vitamin D status (Dror and Allen 2010). Our solar insolation measure is less likely associated with these factors, although, as we discuss further below, it too may capture other behavioral (e.g., more physical activity during sunny weather) and environmental (air pollutants) factors.

RCT studies avoid these pitfalls, but to our knowledge, Yu et al. (2009) and Hollis et al. (2011) are the only ones in the last twenty years to study the effects of increased Vitamin D supplementation *in pregnancy*. Both studies found that Vitamin D blood levels were significantly increased with supplementation but found no statistically significant differences in birth weight and other birth outcomes. Limitations of these studies include small sample sizes (Hollis et al has < 400 observations; Yu et al 2009 had 180) and only 1 location in (South

Carolina, a southerly state where Vitamin D deficiency may be less prevalent than in more northern latitudes, and London, respectively).

d. Link #3 – Solar radiation/sunshine and health outcomes

In a review of the low birth weight literature and an exploration of the potential biological and environmental influences on birth weight, Fuller (2000) cited racial disparities in Vitamin D production as a potential influential factor. A prior study by David and Collins (1997) demonstrated that infants of African-born black mothers and white mothers had more similar weight distributions than that of infants of US-born black mothers. Although they did not cite Vitamin D as a reason for this finding, they paved the way for later research by physicians and social scientists alike. Tustin et al. (2004) analyzed the impact of sunshine duration on birth weight and found that increased sunlight exposure by mothers during the first trimester of gestation had a significant positive effect on birth weight. The strength of the study is its analysis of seasonal variations across a small homogeneous population⁷; however, extensions to wider geographic areas and stratification by race would be beneficial for generalizations about the benefits of first trimester sun exposure.

Using historical data and broader health outcomes, Carson (2009) analyzed heights of black and white prisoners of Southern jails in the early 1900s projecting insolation levels based on recent NASA insolation data. He was particularly concerned with the impact of racial differences in Vitamin D synthesis on height differentials, utilizing the measure of insolation. He found that black men were adversely affected by the lack of insolation at higher latitudes and, through an Oaxaca decomposition of the height differential, found 50% of the variation in heights between black individuals born in Africa versus those born in the United States was attributable to insolation.

To our knowledge, our research is the first to study insolation and birth outcomes over a diverse population, geographic region and time span. It also is the first to measure insolation at many points during the pregnancy and to control for seasonal and geographic factors that likely exert independent effects.

III. Conceptual Framework, Empirical Specification and Past Economic Research

To our knowledge, no economic research exists on the role of sun exposure – or Vitamin D – on birth outcomes. The closest is the historical study of Carson (2009), noted above, and the recent research investigating the relationship between season of birth and health outcomes

⁷ Limited to infants born between 1999 and 2003 in Dunedin, New Zealand, at a latitude of 46° South.

(Kestenbaum 1987, Buckles and Hungerman 2008, Lokshin and Radaykin 2010) and that of extreme weather and health outcomes (Deschenes et al 2009 and Simeonova 2011). Season-of-birth research often includes climate differences as one of several possible reasons for seasonal differences in birth outcomes, but has not explored the link directly. Rather, it has used these seasonal differences to question the validity of season of birth as an instrumental variable (Buckles and Hungerman 2008) and/or explore the validity of alternative explanations (Lokshin and Radaykin 2010). Endogenous self-selection is a key explanation as women may plan their pregnancies with regular weather or other seasonal patterns (e.g., holidays, vacations, school year) in mind. Because we control for the month and county of birth and thus focus on variations in weather *over time*, our analyses largely avoid this issue. However, two additional sources of possible selection remain – those of fertility and survival. This strand of research notes how fertility and/or survival of the fetus may be influenced by weather as well and, as noted above, medical research suggests a role for Vitamin D in both. Research on extreme weather has found that exposure to extreme hot temperatures or natural disasters (storms, floods, extreme temperatures, etc.) has a detrimental effect on birth outcomes but has not explored the causal mechanisms at work, including possible sun exposure. Our analyses contribute to these strands of research by directly investigating the role of sunshine in these patterns.

Another particularly relevant line of research is that exploring the effects of air pollutants on infant health. We find this research relevant because air pollution seems likely to play a similar role within the conceptual infant health production model and suffer from similar confounding effects as insolation. The two factors may be directly related as well, as ozone may impede solar insolation (Webb and Engelsens 2006) and sunshine aids in the production of ozone from auto emissions (Knittel et al. 2011). Currie (2011) is a particularly relevant survey of the infant health production literature, with its emphasis on the blurry line between nature and nurture, including fetal ‘imprinting,’ and the specific confounding factors in trying to estimate the causal effects of air pollution, including its correlation with unobserved factors such as economic activity and mothers’ decision to locate in a polluted area. While changes in sun exposure over time seem less likely to suffer from these confounding effects, especially during our time period when the possible benefits of Vitamin D were little known, our results must be interpreted with similar caveats in mind. Moreover, our findings have strong implications for the relationship between air pollution and birth outcomes.

a. Bringing Vitamin D and insolation into the standard infant health production model

Our conceptual framework is firmly grounded in the broader infant health literature and specifically in the standard utility maximization problem of the mother in the vein of Rosenzweig and Schultz (1982). We use this framework to clarify the possible roles of insolation and Vitamin D in the production of infant health, as well as to conceptualize confounding factors that complicate the interpretation of the effects of insolation in our empirical model. However, we leave modeling the effect of sunshine on fertility to future research.

The mother is assumed to maximize utility, U , which is a function of a vector of birth outcomes, H , consumption, C , and individual tastes and characteristics, X :

$$(1) \quad \text{Max } U(H, C, X).$$

Birth outcomes are produced via the structural production function:

$$(2) \quad H = H(D, P, E, Z),$$

where P is a vector of endogenous prenatal inputs and maternal behaviors that the mother chooses subject to her income and time constraints, E is a vector of environmental factors and Z are individual characteristics including the mother's health endowment. We add Vitamin D (D) to this standard production function, noting that the medical literature suggests that it exhibits diminishing marginal returns in improving health outcomes. As is well-known, estimating structural birth outcome equations via OLS leads to biased estimates due to the endogeneity of P ; Knittel et al. (2011), Currie (2011) and others make the case that E may be endogenous as well (because the mother chooses where to live).

During the time period our sample covers, the possible benefits of Vitamin D and sunshine were largely unknown; indeed, considerable concern about the possible toxicity of Vitamin D led to a reduction in the recommended levels for pregnant women aged 23 and over from 15 to 10 μg in 1992 and then for all pregnant women from 10 to 5 μg in 2002⁸(AAP/ACOG 1992 and 2002) We therefore assume that neither Vitamin D nor sun exposure is chosen by the mother with the goal of improving birth outcomes.

Our key variable is potential sun exposure or solar insolation, S , which may enter this model in several ways. The mechanism we have emphasized so far is its critical, positive role in the production of Vitamin D, along with a host of individual characteristics (race, obesity), Z' , and endogenous behaviors (dietary and supplement intake, outdoor exercise), P' :

$$(3) \quad D = D(S, P', Z').$$

⁸ 2002 also marked the transition from a Recommended Daily Amount (RDA) to an Adequate Intake level for Vitamin D and Calcium. This distinction was made on the basis of having "insufficient evidence [...] available to determine an RDA"(AAP/ACOG 2002 and 2007).

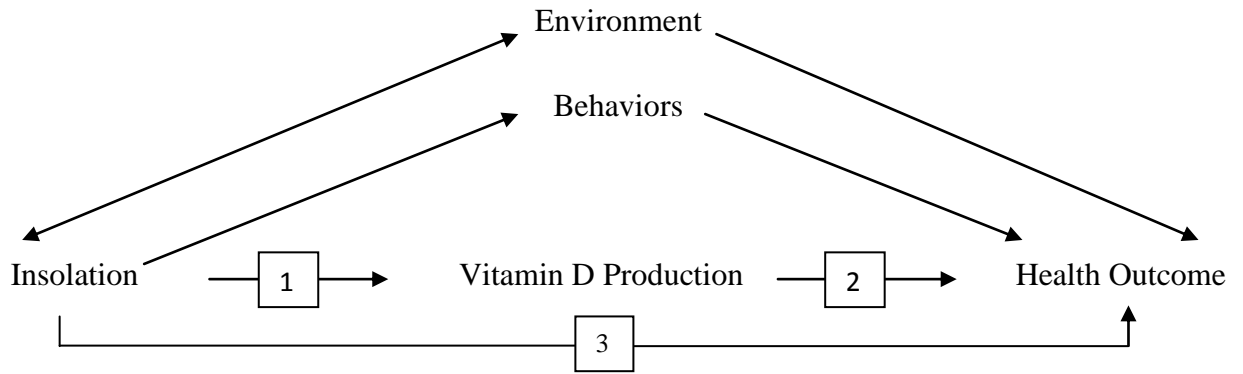
Here again, the medical literature suggests that S has diminishing marginal returns in the production of Vitamin D; indeed, it seems impossible to produce ‘too much’ Vitamin D via UV-B exposure (Wolpowitz and Gilchrest 2006).

There is likely a strong overlap between Z’ and P’ and their counterparts in equation (2) that have independent effects on birth outcomes. This further clarifies the concern with using maternal Vitamin D blood levels to measure the causal effects of Vitamin D; unless one fully specifies all of the characteristics Z and behaviors P in equation (2), the estimated effects capture the indirect effects of those factors as well. Sayers et al. (2009) implicitly make this point by arguing for the use of meteorological data, S, as an instrumental variable for D.

b. Confounding effects in our analyses -- and others

Yet, insolation may have other potential effects as well, especially in a reduced form, birth outcome equation. First, insolation may influence maternal behaviors, P. Sunny weather may make physical activity -- or going outside for a cigarette -- more appealing. These behaviors have direct effects on birth outcomes and also may enhance the impact of environmental toxins (E). Second, as noted above, insolation has a complicated relationship with air pollutants and thus may influence (and be influenced by) environmental factors, E. Finally, insolation may have unknown, independent effects on birth outcomes as a unique element of E.

In sum, while the assumption that insolation is not a choice variable to the mother – especially its change over time – seems reasonable, its reduced form effects on birth outcomes are complicated by its relationships to maternal behaviors and environmental factors. While we have emphasized its relationship with Vitamin D, as in equation (3), we acknowledge that it may be capturing indirect effects via maternal behaviors and environmental factors as well as other possible direct effects of insolation on infant health. Putting these complications in terms of our framework from section II:



As typical in economic birth outcomes research, our empirical analyses employ a reduced form model that evaluates the influence of maternal characteristics and insolation on infant health as measured by birth weight. The reduced form equation is derived by substituting out for P, D and E in equation (2) above:

$$(4) H = H(S, Z', E'),$$

where Z' is $Z \cup Z' \cup X$ and E' are the environmental factors captured by the multitude of fixed effects included in our empirical analyses. In addition to its presumed positive effect via Vitamin D production (links #1 and 2 above), the estimated effect of S in this equation therefore also contains any indirect effects it has via maternal behaviors/inputs P or residual environmental factors $(E - E')$ as well as any direct effects S may have on birth outcomes (link #3 above). A prominent 'residual environmental factor' correlated with insolation and possibly birth outcomes is outdoor temperature (Strand et al. 2011). As discussed in the Data section below, temperature is well recorded in our dataset and so we include it in our empirical specification to mitigate the extent to which environmental factors could be driving our results. We return to the remaining limitations of a reduced form analysis as we interpret our results in section VI.

This framework also helps reveal the possible confounding effect that Vitamin D and insolation may have on existing, reduced form studies of infant health. As noted by Knittel et al. (2011), air pollutants seem likely to exert similar indirect effects on maternal behaviors, such as staying indoors during bad air days or more generally making outdoor activities (and thus sun exposure) less appealing. In addition, if air pollutants and insolation are related, the effects of insolation will be captured in the estimated effects of pollution.

It is also possible that the role of insolation and Vitamin D may confound the estimated effect of the Medicaid expansions on infant health outcomes. Studies have shown that although successful in reducing the levels of infant mortality for medically high-risk mothers, the impact

of Medicaid expansions on rates of low-birth weight among babies is ambiguous (Epstein and Newhouse 1998, Baldwin et al. 1998) across state lines and races (Miller 2003, Dubay et al. 2001). During the period of this study (1989-2004), the literature released from the American Congress of Obstetrics and Gynecology (ACOG) reported significant decreases in the daily recommended intake of Vitamin D (see Figure 2), across all age ranges and without differentiation across race. Additionally, whereas in 1988 ACOG advised women at higher latitudes to be aware of the restricted synthesis of Vitamin D during the winter, this advisory was excluded in each of the following editions (1992, 1997, 2002), and replaced with a warning about toxicity of high levels of consumption. In terms of the model above, the typically assumed mechanism for Medicaid to have an effect is through the reduced cost and improved access to prenatal inputs (P). The simultaneous change in the recommendations, however, reduced D in equation (2) as well. Moreover, these changed recommendations likely had a different impact depending on the mother's race and other characteristics, geographic location, season of birth, and access to prenatal care.

The WIC program operates in a similar way as Medicaid, by improving access to prenatal inputs. With its special emphasis on calcium-rich foods which aid in the absorption of Vitamin D, WIC's effect on birth outcomes likely varies by the mother's Vitamin D status, thereby explaining the stronger effects observed for blacks (Brien and Swann 2001). Moreover, it suggests differential effects by region, season and other maternal characteristics.

c. Empirical specification

To isolate the reduced form effect of insolation on birth outcomes from other factors associated with season and geographic location, our primary empirical specification is:

$$(5) H_{icmt} = \beta W_{cmt} + \delta Z_{icmt} + \theta_t + \gamma_{cm} + \varepsilon_{icmt}$$

where subscript i indexes each individual infant, c , county of birth, m , month of birth and t , year of birth. The dependent variable of interest, birth outcomes, is given as vector H . Vector W includes weather indicators, insolation (S from equation (4)) and temperature for different aggregation levels over the pregnancy -- full pregnancy, trimester or month. We also explore other variants, such as allowing for a quadratic form of insolation and temperature or a differential effect of insolation and temperature on weekend days. Variable z (a set of proxies for Z from equation (4)) denotes the maternal and infant health characteristics that have been demonstrated to influence birth weight in the existing literature. These factors include infant's gender, whether first born to mother, and mother's age, education and marital status. The final two vectors are full sets of year fixed effects, denoted by θ , and county*month fixed effects, denoted by γ . Year fixed effects capture any time effects common to all counties, such as business cycles or overall changes in policies or ACOG recommendations. County*month fixed effects capture both the time-invariant

unobservable characteristics of each county (e.g., health care and public welfare systems, environmental variables E' from equation (4), etc.) as well as any regular seasonal variation unique to the county (e.g., the tendency of mothers to avoid late pregnancy during the hottest months could be stronger in hotter climates). We estimate several variants of this baseline set of fixed effects, ranging from the less restrictive, typical set (state and year fixed effects only) to one that also captures factors that vary over time by each state, such as the Medicaid expansions and welfare reform (accomplished by replacing the year fixed effects with state*year fixed effects). Each observation is subject to a random error, ϵ , exclusive to a given infant i , in county, c , at time mt .

We also estimate equation (5) using county/month/year aggregate data to avoid the exaggerated statistical significance that arises when using a very large dataset like ours (the Natality Detail Files described in the next section) combined with a regressor that can only vary over county/month/year. Such equations are estimated with generalized least squares to adjust for the different number of observations used to create each cell.

IV. Data

Data on maternal health characteristics and inputs as well as infant health outcomes are drawn from the Natality Detail Files (NDF) for the years 1989-2004⁹. The Centers for Disease Control (CDC) publicly provide data for counties of populations greater than 100,000 with 100 or more reported births per year. The NDF supplies infant health indicators: birth weight, gender, gestation; maternal characteristics such as age, education and marital status; and health inputs including smoking, prenatal care and parity. Although one could argue that there exist more sophisticated surveys such as National Health and Nutrition Examination Survey, that provide indicators on supplementation and outdoor activity, the strength of the Natality Detail Files are the geographic identifiers for state, county and metropolitan area which can be merged with insolation data to observe the relationship between infant health outcomes and exposure to a unique environmental factor – and over a long period of time. Existing studies on Vitamin D and infant and maternal health are typically restricted to small cities or regions (Park and Johnson 2005) with sample sizes less than 200 (Narchi et al. 2010, Binkley et al. 2007), or fail to address the seasonal and/or regional variations that contribute to variations in Vitamin D levels (Ginde et al. 2009).

The samples of this analysis are restricted to full term¹⁰ singleton births of non-Hispanic black or white mothers. A random sample of the white births was taken to equate the sample

⁹ Terminal year selected based on cessation of CDC's distribution of geographic identifiers on any publicly available data.

¹⁰ Full term refers to those infants whose gestation is recorded as 37 to 42 weeks. In future analyses, we plan to explore the role of insolation in preterm births as well.

sizes. We also limit the sample to observations with birth weight between 800 and 5,000 grams (or 1 lb 12 oz. and 11 lbs respectively), mothers' aged 19 to 44, and eliminate Hawaii and Alaska. These restrictions, plus addressing coding concerns in the Natality Detail Files with respect to maternal education¹¹, yield sample sizes of 4,078,468 black infants and 5,816,572 white infants. The sample is stratified by race as typical in the majority of infant health studies evaluating the birth weight gap, and in particular to this analysis because of the biological differentiation in Vitamin D synthesis for dark and fair skinned individuals.

Our primary dependent variable is a continuous measurement of birth weight. It serves as a linear indicator of infant health with a poor health outcome identified by low birth weight. As noted by the sample selection process above, the first cut of the NDF data restricts the sample to the "full term" length of gestation ranging between 37 and 42 weeks, to limit the effect of preterm birth and the need to adjust for gestation. For those full term infants, the mean birth weight for white infants was 212.58 grams heavier than for black infants (Table 1). Figure 4 shows the graphical representation of the distributions of birth weight depicting the higher mean for white infants.

Of particular concern in the sample are the infants who fall into the categories of low birth weight (1500 - 2500 grams) and very low birth weight (<1500 grams). As a secondary analysis of the continuous birth weight measure, two dichotomous variables are also included in the data set to look at the probability of infants falling into the low and very-low birth weight categories. 1.8% and 0.029% of all white births fall into the low and very low birth weight categories respectively, compared to 4.74% and 0.095% of black births. However, across races the picture is very different. For the low-birth weight population, 68 % of the sample births are black and 73% of all very-low birth weight babies.

The summary statistics for the control variables mentioned above (age, education, marital status, parity and gender) are summarized in Tables 1. On average, white mothers were two years older than black mothers reporting a mean age of 26 years. Additionally, white mothers were more than twice as likely to be married, with 83.8% of the respondents reporting being married versus 37.5% of black mothers. Education is bracketed into four categories: some high school, completed high school, some college and completed college, for this study. Although the distribution is similar across the ranges of education, white women were more likely to have some college education and less likely to have not completed high school than black mothers. Across both samples, 51% of all births were male, but black mothers had more previous children on average, with only 32% of black infants reported as the first born for their mothers compared to 41% of all white birth.

¹¹ Missing values in the education records were cited by Baughman and Dickert-Conlin (2008) as being an issue. 322,706 observations were dropped from the black sample and 317,807 observations from the white sample dropped across 17 unique state/year combinations flagged in the NDF documentation.

Latitudes and longitudes were acquired for each county available in the NDF and then matched with weather measurements from NASA's Atmospheric Science Data Center over the period July 1, 1983 through June 30, 2006. Employing the strategy of Carson (2009), measurements of insolation on a horizontal surface and maximum temperature were recorded for the 460 counties across 46 continental states and the District of Columbia¹². The level at which the data is reported by NASA is for each 1° latitude by 1° longitude, over which multiple counties in the dataset may fall into or straddle between. The relationship between county border and latitude/longitudes can be found in Figure 3 of the Appendix. The NASA data is merged with the NDF data by computed conception date (based on a fixed gestation of 280 days) and county FIPS code.

The main exogenous variable of interest in this study, insolation, represents the amount of solar energy (as measured in kilowatt-hours/meters squared/day) that reaches the surface of the earth. Insolation is sensitive to variations in latitude and season as well as weather characteristics such as cloudiness and ozone coverage. Since the energy measurement captures more than just the energy derived from UV-B, the measurement provides the upper bound of potential exposure.

In order to capture the variability of the insolation measurement, aggregations by full term pregnancy, trimester and month are used to examine the impact of potential maternal exposure to sunshine. The aggregation is a moving average over a 280, 93 and 31 day period for the full term, trimester and month respectively. Patterns in the monthly aggregations most closely mimic the trend in the daily data with a peak in July. The peak average insolation for the other measures lag behind the monthly high as to be expected. The trimester with the highest insolation average ends in August. If for instance, the first trimester plays the most influential role in the production of infant health as found by Tustin, Gross and Hayne (2004), mothers giving birth in February gained the most benefit from the summer sunshine. In contrast, if insolation matters equally throughout the pregnancy, then mothers giving birth in November benefit most, as they have the highest average exposure to insolation. We also control for weekend effects within each level of aggregation. We hypothesize that women may have a greater opportunity to go outdoors during the weekend when they are likely to have more free time. More generally, patterns of behavior seem likely to diverge between weekdays (typical workdays and school days) and weekends. Therefore, the average level of insolation on weekends may have an additional impact on the production of Vitamin D and subsequently infant health.

Notable in each of the figures found in the Appendix is the seasonal variation in insolation. We recognize that insolation is not the only factor that could cause a seasonal effect on birth outcomes, and so we employ county*month fixed effects as a control. For example, a

¹² Idaho and Wyoming are excluded from the sample based on insufficient population sizes in the Natality Detail Files.

possible concern with regards to month effects is selection by mothers. The county*month dummies will therefore serve to capture variations across selection into pregnancy and those common characteristics across women giving birth during the same season (Buckles and Hungerman 2008). This specification thus identifies the effects of insolation solely from its variation over time for each county and month.

It is therefore important to look at the variation across locations and, especially, over time. In general there is an inverse relationship between latitude and insolation, with higher latitudes experiencing lower levels of insolation. Particularly during winter months, when the angle at which radiation strikes the surface is flatter making the distance the radiation must travel longer, insolation is restricted. Variations across different climates, such as inland desert versus coastal climates, can also be seen in the measurements. Figure 5 shows four counties from different latitudes across the US. The graph indicates that as one moves from the northernmost county, Whatcom, WA to Cameron, TX the levels of insolation increase. The exception in this particular graph is given by Clark, NV, the sample county with the highest mean insolation, but a mid-range latitude. Based on the desert climate of Nevada, this result is not surprising and serves to further underscore the variation in insolation across counties of our sample.

With this primary model, if there was no variation in insolation across the years in the sample, we would not be able to identify an effect of insolation on infant health. Figures 6a-d address this concern by reporting the maximum and minimum observed 9-month moving average of insolation for these counties during our sample (1989-2004). They demonstrate the variation in insolation not captured by the county*month dummies. In a complementary analysis regressing temperature, county*month and year fixed effects against insolation yields an R^2 measurement of 0.96, leaving 4.0% of the variation in insolation to identify its effect on birth weight. This small level of variation is what leads us to also estimate models with fewer seasonal/geographic controls. In this way, we can establish a range of possible estimates of the effects of insolation.

In addition to the variable of interest, temperature is included as another explanatory variable. Maximum temperature per day is employed as the temperature variable because it likely more closely approximates the temperature during the day. Minimum temperatures on the other hand, tend to occur at night and are thus irrelevant to the effects of insolation (or behaviors related to it, such as the desirability of outdoor activities). The same moving average and weekend effect aggregations are applied to the temperature variables for consideration in the models as well as nonlinear effects and interactions between insolation and temperature in order to account for the decision to stay indoors when it's particularly hot or cold¹³.

¹³ Summary statistics for temperature and insolation by county are not reported in this paper, but are available upon request to the authors.

V. Preliminary Results

Regression results for the full sample (Tables 2a and b) and samples aggregated at the county level (Tables 3a and b) are reported in the appendix. The results are contrary to our anticipated hypothesis of the relationship between insolation and birth weight. The standard model of our analysis, looking at the average insolation and temperature across an entire pregnancy, finds a statistically significant negative impact of insolation on birth weight for both races. The negative result is persistent across all three levels of aggregation, with a statistically significant influence in the full pregnancy and third trimester for both races. However, the magnitude of each estimate does not indicate a differential effect favoring one race or the other, with a large magnitude for white mothers in the full pregnancy specification, but larger for black mothers in the trimester model. The county/month/year-aggregated data produces a similar result.

If the model is capturing the unique effect of insolation, which is believed to have an asymmetric effect across races, we would anticipate that one race would have consistently smaller parameter estimates. Two competing effects of the racial disparity in Vitamin D production make it uncertain a priori whether our results should show larger effects for black or white mothers. Insolation could have less effect for black mothers because their higher level of skin pigmentation makes it more difficult to convert insolation into Vitamin D (i.e., the insolation \rightarrow Vitamin D relationship is weaker). Alternatively, because black women are consistently found to be more likely Vitamin D deficient, the marginal effect of insolation/Vitamin D on their infant's birth weight could be larger (i.e., the Vitamin D \rightarrow infant health relationship could be stronger). In either case, we would not anticipate a negative relationship between insolation and birth weight for either race.

Turning to alternative specifications, we find that the results are robust (see Tables 4a and b). The first alternative specification is a non-linear model incorporating two interaction terms between insolation and temperature and temperature squared. Accounting for the full effect of insolation in the model, we still find that the effect of insolation is negative across races given average temperatures exceeding 45°F and 40°F for the white and black samples respectively. Similarly in the weekend effects model, we find that although black women benefit from higher weekend insolation, the effect does not offset the negative impact of average insolation over the entire pregnancy. Looking at the probability of having a low birth weight infant, we find no statistically significant effect of insolation, although the coefficient sign continues to suggest a detrimental effect.

Testing of sub-sample populations did not produce different results either. Looking independently at the effects of insolation during the winter versus the summer, we find that the negative result persists, although statistically significant only in January for white mothers and July for black mothers. In unreported results, we next limit the samples to different geographic

regions, omitting California, and other variations; the negative effect persists. We considered that perhaps pleasant weather encouraged more smoking, with the growing prevalence of indoor smoking bans; our insolation estimates could therefore be biased downward via its indirect effects on smoking. (Of course, the same logic applies to healthy behaviors such as exercise.) To explore this further, we limit the sample to non-smokers, but the results remain negative.

We employed a falsification test by using the insolation measures for one year after the birth of the infant (i.e., a one-year lead). If insolation's effect is accurately captured in the model we should find no effect of future insolation on the birth weight of the baby. This is not the case, however. As has been consistent in our results, we find that the measure of future insolation is negatively related to the birth weight of infants across each sample. This result further serves to demonstrate that the model does not effectively capture the impact of variations in insolation on birth weight. However, in one sense, the falsification test results are reasonable because we find that future insolation is strongly positively correlated with the current insolation measure, even after controlling for temperature, and county*month and year fixed effects, perhaps due to the overall dimming of global radiation (Stanhill and Cohen 2001). This persistence in insolation patterns over time requires additional exploration but explains why future insolation could be found to have an impact.

Finally, in Table 6 we report estimates from the county/month/year-level data with a range of specifications for seasonal and geographic effects. We re-estimate the above models alternatively including 1) state and year fixed effects only (as many studies that use the NDF do), 2) state, month and year fixed effects, 3) state*year and state*month fixed effects, 4) state*year, state*month and county fixed effects and 5) county*month and state*year fixed effects. The negative effect of insolation is stronger the fewer fixed effects are included, and it becomes statistically insignificant in the richest models. The coefficient signs also diverge by race in these richest models, becoming positive for blacks – an interesting result that requires further exploration. Nonetheless, the vast majority of estimated insolation coefficients remain negative.

VI. Discussion and Future Directions

Despite controls for socio-economic status, maternal behaviors during pregnancy and Medicaid expansions, the birth weight gap persists between races. Alternative biological and economic factors that impact infant health deserve attention in this growing literature. Addressing the asymmetric effect of UV-B radiation on the production of Vitamin D between black and white mothers, this paper investigates the relationship between insolation and birth weight. Persistent negative results suggest that the relationship is not clearly defined in our current specification. We offer several hypotheses that could explain the surprising results and that we plan to pursue in future research.

Major determinants in the daily fluctuations in the measurement of insolation are climate, ozone and also air pollution. Recent research by Bharadwaj and Eberhard (2008) and Currie et al. (2008) link increases in air pollution with adverse infant health outcomes such as low birth weight and preterm birth. Insolation could therefore be capturing the effects of air pollution. Interestingly, the relationship between air pollution and insolation is unclear. Air pollution seems likely to be associated with haze, which would decrease insolation – thus biasing its coefficient *upward*. However, rainfall is also known to reduce air pollutants in the hours and even days afterward, and rainfall and insolation seem likely negatively related. Controlling for air pollution (or rainfall) in the model would allow us to tease out the effects of insolation from air pollution. An IV specification in which rainfall serves as an instrumental variable for air pollution, as in Bharadwaj and Eberhard 2008, could be a feasible alternative as well.

A second hypothesis is that the selection bias caused by restricting the sample to full term births (37-42 weeks gestation) is obscuring the true effects of insolation. Currently the model only considers the effect of Vitamin D in producing infant health by increasing the weight of full-term infants. However, it is also possible that Vitamin D affects infant health by extending the length of gestation. As a result, low birth weight babies, who otherwise would have been preterm and omitted from the sample without the additional Vitamin D from insolation, could be driving the results. By including the viable preterm births (26-36 weeks gestation), we can explore additional impacts that insolation may have for different types of birth outcomes, including the probability of preterm birth. Furthermore, this would serve to better represent the population of black infants who are more likely to be delivered preterm (Fuller 2000, Lhila and Long 2011).

A third consideration is to employ a hybrid model incorporating some of the influential choice variables of the mother. Since we assume that insolation is exogenous to the decisions of the mother during this study (e.g., women are not more likely to seek prenatal care because they are worried about reduced sunshine/Vitamin D), the concern of bias resulting from structural models is less troubling. In particular, prenatal care could be added to the model. To the extent that prenatal care is associated with prenatal vitamin intake – including Vitamin D -- the effects of insolation could depend upon the level of prenatal care received.

A final hypothesis is that the relationship between insolation and Vitamin D must be considered in concurrence with a Vitamin D “stock” variable. So far we have considered the effects of the insolation exposure of the mother during the pregnancy; however, we have not considered the effect of past insolation/Vitamin D on the mother’s health endowment, which also factors into the infant health production function. In a study on birth weights of infants born to mothers born in the US versus Africa, David and Collins (1997) found that for a sample of Illinois infants, the distribution of weights of babies born to white mothers and African-born black mothers were more closely related than those of US-born black mothers. They argued that

this refuted the belief that there was a genetic difference driving the birth weight gap between infants of black and white US born mothers; however, they did not address Vitamin D in their analysis. Based on their research it might be the case that the maternal health endowment acquired in the exposure from youth altered the relationship with birth weight. The same notion was described in Carson's analysis in which he found the heights of black African-born prisoners to be closer to that of white prisoners than those US-born black prisoners (Carson 2009). One approach is to incorporate a "stock" variable, such as the average insolation in the 2 or 3 years prior to the conception of the child. Still another is to include the effects of being foreign born, which although not specific to region in the NDF could provide further distinction of maternal endowment of Vitamin D.

In spite of the positive health benefits seen from sustaining sufficient Vitamin D levels, this study failed to find a positive relationship between insolation and birth weight. Based on the wealth of literature on the biological advantage of fair skin for the production of Vitamin D in the body along with the greater Vitamin D deficiency observed in the black population, the inconsistent results of the differential effect by race are also puzzling. In order to dismiss this factor as influential in infant health, further research is warranted in the subject to tease out the independent effects of insolation.

References

- American Academy of Pediatrics and the American College of Obstetricians and Gynecologists. (1983). *Guidelines for Perinatal Care*. (1st ed.). Elk Grove Village, IL: 166-177.
- AAP/ACOG. (1988). *Guidelines for Perinatal Care*. (2nd ed.). Elk Grove Village, IL: 193-196.
- AAP/ACOG. (1992). *Guidelines for Perinatal Care*. (3rd ed.). Elk Grove Village, IL: 177-181.
- AAP/ACOG. (1997). *Guidelines for Perinatal Care*. (4th ed.). Elk Grove Village, IL: 281-283.
- AAP/ACOG. (2002). *Guidelines for Perinatal Care*. (5th ed.). Elk Grove Village, IL: 79-83.
- Armas, Laura and Bruce W. Hollis, Robert P. Heaney. (2004). "Vitamin D₂ is much less effective than vitamin D₃ in humans." *The Journal of Clinical Endocrinology and Metabolism* 89(11): 5387-5391. doi: 10.1210/jc.2004-0360
- Arab, Lenore, Alicia Carriquiry, Susan Steck-Scott and Mia M. Gaudet. (2003). "Ethnic differences in the nutrient intake adequacy of premenopausal US women: results from the third national health examination survey." *Journal of the American Dietetic Association*. 103(8): 1008-14. doi:10.1016/S0002-8223(03)00474-7
- Baldwin, Laura-Mae, Eric H. Larson, Frederick A. Connell, Daniel Nordlund, Kevin C. Cain, Mary Lawrence Cawthon, Patricia Byrns and Roger A. Rosenblatt. (1998). "The effect of expanding medicaid prenatal services on birth outcomes." *American Journal of Public Health*. 88(11):1623-1629.
- Baughman, Reagan and Stacy Dickert-Conlin. (2003). "Did Expanding the EITC Promote Motherhood." *The American Economic Review*. 93(2):247-251. doi:10.1257/000282803321947137
- Bharadwaj, Prashant and Eberhard, Juan. (2008, August). "Atmospheric Air Pollution and Birth Weight." Available at SSRN: <http://ssrn.com/abstract=1197443>
- Binkley, N. and R. Novotny, D. Krueger, T. Kawahara, Y.G. Daida, G. Lensmeyer, B.W. Hollis, M.K. Drezner. (2007). "Low vitamin D status despite abundant sun exposure." *The*

- Journal of Clinical Endocrinology and Metabolism*.92(6): 2130–2135. doi: 10.1210/jc.2006-2250
- Bodnar, Lisa M. and Hyagriv N .Simhan, Robert W. Powers, Michael P. Frank, Emily Cooperstein, James M. Roberts. (2009). “High prevalence of vitamin D insufficiency in black and white pregnant women residing in the northern united states and their neonates.” *The Journal of Nutrition*.137(2): 447-452.
- Bodnar, Lisa M., Janet M. Catov, Hyagriv N. Simhan, Michael F. Holick, Robert W. Powers and James M. Roberts. (2007). “Maternal vitamin D deficiency increases the risk of preeclampsia.” *The Journal of Clinical Endocrinology and Metabolism*. 92(9): 3517-22.
- Bodnar, Lisa M., Janet M. Catov, Joseph M. Zmuda, Margaret E. Cooper, Meredith S. Parrott, James M. Roberts, Mary L. Marazita, and Hyagriv N. Simhan. (2010). “Maternal serum 25-hydroxyvitamin D concentrations are associated with small-for-gestational age births in white women.” *Journal of Nutrition*. 140(5): 999-1006. doi: 10.3945/jn.109.119636
- Bodnar, L. M., & Simhan, H. N. (2010). “Vitamin D may be a link to black-white disparities in adverse birth outcomes.” *Obstetrical gynecological survey*, 65(4), 273-284. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/20403218>
- Brannon, Patsy M., and Mary Frances Picciano. (2011). “Vitamin D in Pregnancy and Lactation in Humans,” *Annual Review of Nutrition*, 31: 89-115.
- Brien, Michael J. and Christopher A Swann. (2001). “Prenatal WIC Participation and Infant Health: Selection and Maternal Fixed Effects,” Manuscript, UNC Greensboro Department of Economics.
- Buckles, Kasey and Daniel M. Hungerman. (2008). “Season of Birth and Later Outcomes: Old Questions, New Answers.” (NBER Working Paper No. 14573) Accessed May 10, 2010 < <http://www.nber.org/papers/w14573>>.
- Byers, Katherine G. and Dennis Savaiano. (2005). “The Myth of Increased Lactose Intolerance in African-Americans.” *Journal of the American College of Nutrition*. Vol. 24, No. 90006, 569S-573S.
- Carson, Scott Alan, (2009). Geography, Insolation and Vitamin D in 19th Century US African-American and White Statures. *Explorations in Economic History*. 46(1): 149-159.
- Currie, Janet, Matthew Neidell and Johannes F. Schmeider. (2009)“Air Pollution and Infant Health: Lessons from New Jersey.” *Journal of Health Economics*. 28(3): 688-703.
- David, RJ and JW Collins. (1997) “Differing Birthweight Among Infants of US-born Blacks, African-born Blacks and US-born Whites.” *New England Journal of Medicine*, 337: 1209-1214.
- Deschenes, Olivier, Michael Greenstone and Jonathan Guryan. (2009). “Climate Change and Birth Weight.” *American Economic Review: Papers & Proceedings*, May, 99(2): 211-7.
- Dror, Daphna K. and Lindsay H. Allen. (2010). “Vitamin D inadequacy in pregnancy: biology, outcomes and interventions,” *Nutrition Reviews*. 68(8): 465-77.
- Dubay, Lisa and Ted Joyce, Robert Kaestner, Genevieve M. Kenney. (2001) “Changes in Prenatal Care Timing and Low Birth Weight by Race and Socioeconomic Status: Implications for the Medicaid Expansions for Pregnant Women.” *HSR: Health Services Research*. 36(2).
- Engelsen, Ola. “VitD-ez Duration of Vitamin D Synthesis in Human Skin.” (2005) 15 Jan. 2011. < <http://zardozi.nilu.no/~olaeng/fastrt/VitD-ez.html>>.

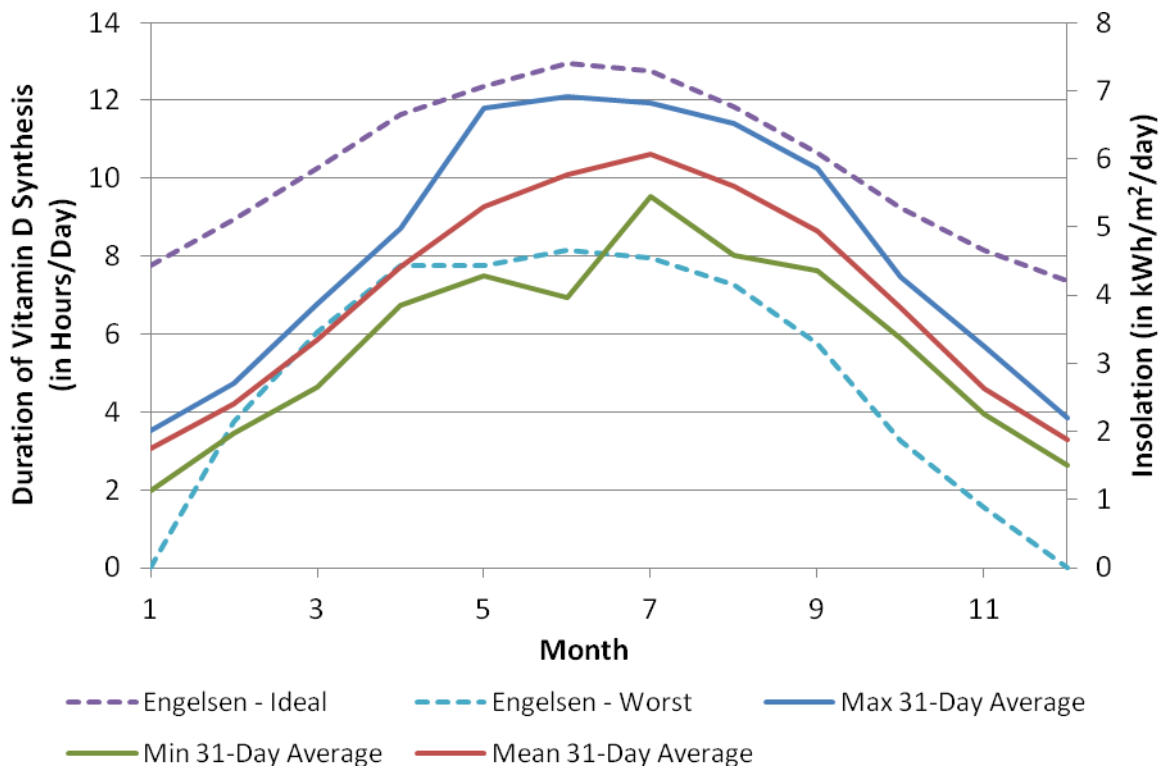
- Epstein, Arnold M. and Joseph P. Newhouse. (1998) "Impact of Medicaid Expansion on Early Prenatal Care and Health Outcomes." *Health Care Financing Review*. 19(4): 85-99.
- Food and Nutrition Service. "Women, Infants and Children." 1/28/201. Web. 14 Feb 2011. <<http://www.fns.usda.gov/wic/>>.
- Fuller, Kathleen E. (2000) "Low Birth-Weight Infants: The Continuing Ethnic Disparity and the Interaction of Biology and Environment." *Ethnicity and Disease*. 10: 432-445.
- Gale, CF, SM Robinson, NC Harvey, MK Javaid, B Jiang, CN Martyn, KM Godfrey, C Cooper and The Princess Anne Hospital Study Group. (2008). "Maternal vitamin D status during pregnancy and child outcomes," *European Journal of Clinical Nutrition*. 62(1): 68-77.
- Gallagher, J Chris and Adarsh J Sai. (2010) "Vitamin D Insufficiency, Deficiency, and Bone Health," *The Journal of Clinical Endocrinology and Metabolism*, 95(6): 2630-3.
- Ginde, Adit A, Mark Liu, and Carlos Carmago. (2009) "Demographic Differences and Trends of Vitamin D Insufficiency in the US Population, 1988-2004." *Archives of Internal Medicine*. 169(6):626-632.
- Grayson, Rebekah and Martin Hewison. (2011). "Vitamin D and Human Pregnancy," *Fetal and Maternal Medicine Review*. 22(1): 67-90.
- Harris, Susan S. and Bess Dawson-Hughes. (1998). "Seasonal Changes in Plasma 25-hydroxyvitamin D concentrations of young American black and white women," *American Journal of Clinical Nutrition*. 67(6): 1232-6.
- Health Physics Society. (2009). "Pregnancy and Radiation Exposure." May 10, 2010. <<http://hps.org/publicinformation/ate/faqs/pregnancyandradiationexposure.html>>.
- Holick, Michael F. "Vitamin D Deficiency." *The New England Journal of Medicine*. Vol 357 Issue 3. July 19, 2007.
- Hollis, Bruce W., Donna Johnson, Thomas C. Hulsey, Myla Ebeling and Carol L. Wagner, "Vitamin D supplementation during Pregnancy: Double blind, randomized clinical trial of safety and effectiveness." *Journal of Bone and Mineral Research* published online June 2011.
- Jablonski, Nina J. (2004) "The Evolution of Human Skin and Skin Color." *Annu. Rev. Anthropol.* 33:585-623.
- Kestenbaum, Bert, "Two Findings from the Decennial Census," *Social Biology*, 1987, 34, pp. 244-48.
- Knittel, Christopher R., Douglas L. Miller, and Nicholas J. Sanders, "Caution, Drivers! Children Present: Traffic, Pollution and Infant Health," *NBER Working Paper #17222*, July 2011.
- Lapillonne, Alexandre. 2010. "Vitamin D Deficiency during Pregnancy May Impair Maternal and Fetal Outcomes," *Medical Hypotheses*, 74, pp. 71-75.
- Lewis, Sharon, Robyn M. Lucas, Jane Halliday and Anne-Louise Ponsonby, "Vitamin D deficiency and pregnancy: From preconception to birth," *Molecular Nutrition Food Res*, 2010, 54, pp. 1092-1102.
- Lhila, Aparna and Sharon Long. (2011) "What is driving the black-white difference in low birthweight in the US?" *Health Economics*. <<http://onlinelibrary.wiley.com/doi/10.1002/hec.1715/pdf>>.
- Lokshin, Michael and Sergiy Radyakin, "Month of Birth and Children's Health in India," The World Bank, Policy research WP #4813, January 2009.
- Looker, Anne C.; Christine M. Pfeiffer, David A. Lacher, Rosemary L. Schleicher, Mary Frances Picciano, and Elizabeth A. Yetley. 2008. "Serum 25-Hydroxyvitamin D Status of the US Population: 1988-1994 versus 2000-2004," *Am J Clin Nutr*, 88:6, pp. 1519-1527.

- Mannion, Cynthia A., Katherine Gray-Donald, and Kristine G. Koski, "Association of low intake of mile and vitamin D during pregnancy with decreased birth weight," *CMAJ (Canadian Medical Association Journal)*, April 25, 2006, 174(9), pp. Online-1-5.
- Manson, JoAnn E., Susan T. Mayne and Steven K. Clinton, "Vitamin D and Prevention of Cancer – Ready for Prime time?" *The New England Journal of Medicine*, April 14, 2011, 364(15), pp. 1385-87.
- Metcoff, Jack et al. (1985) "Effect of Food Supplementation (WIC) during Pregnancy on Birth Weight." *The American Journal of Clinical Nutrition*. 41:933-947.
- Miller, Douglas L. (2003) "What underlies the black-white infant mortality gap? The importance of birthweight, behavior, environment, and health care." (Working Paper) Retrieved 16 May 2010.
<<http://www.econ.ucdavis.edu/faculty/dlmiller/workingpapers/IMRgap.PDF>>.
- Moore, Carolyn, Mary M. Murphy, Debra R. Keast, and Michael F. Holick, "Vitamin D Intake in the United States," *Journal of the American Dietetic Association*, 2004, 104, pp. 980-83.
- Moyad, Mark A. (2009) "Vitamin D2 and/or Vitamin D3." *Dermatology Nursing*. 21(1).
- Mulligan, Megan L., Shalil K. Felton, Amy E. Riek, and Carlos Bernal-Mizrachi, "Implications of Vitamin D Deficiency in pregnancy and lactation," *American Journal of Obstetrics and Gynecology*, May 2010, 202, pp. 429.e1-e9.
- Narchi, H, et al. (2010) "Maternal vitamin D status throughout and after pregnancy." *Journal of Obstetrics and Gynecology*, Feb. 2010, 30(20) pp 137-142.
- NASA Atmospheric Science Data Center. "Meteorology and Solar Energy: Daily Data (1983-2006)." Accessed February 5, 2010.
- National Center for Health Statistics. "Natality Detail Files 1989-1999 (Public Use)." Accessed February 21, 2010.
- Nesby-O'Dell, Shanna; Kelley S Scanlon, Mary E Cogswell, Cathleen Gillespie, Bruce W Hollis, Anne C Looker, Chris Allen, Cindy Dougherty, Elaine W Gunter, and Barbara A Bowman. 2002. "Hypovitaminosis D Prevalence and Determinants among African American and White Women of Reproductive Age: Third National Health and Nutrition Examination Survey, 1988–1994," *Am J Clin Nutr*, 76, pp. 187–92.
- Ponsoby, Anne-Louise, Robyn M. Lucas, Sharon lewis, and Jane Halliday, "Vitamin D status during pregnancy and aspects of offspring health," *Nutrients*, March 2010, 2, pp. 389-407.
- Rajakumar , Kumaravel and Stephen B. Thomas. "Reemerging Nutritional Rickets: A Historical Perspective." *Arch Pediatric Adolesc Med* 2005; 159.
- Reusch, J; H. Ackermann, and K. Badenhoop. 2009. "Cyclic Changes of Vitamin D and PTH are Primarily Regulated by Solar Radiation: 5-Year Analysis of a German (50 degrees N) Population," *Horm Metab Res*, 41:5, pp: 402-7.
- Rosenzweig, Mark R., and T. Paul Schultz. (1982). "The behavior of mothers as inputs to child health: The determinants of birth weight, gestation, and rate of fetal growth." *Economic Aspects of Health*, edited by Victor R. Fuchs. Chicago: University of Chicago Press, pp. 53-85.
- Sayers, Adrian, Kate Tilling, Barbara J. Boucher, Kate Noonan, and Jon H. Tobias, "Predicting ambient ultraviolet from routine meteorological data; its potential use as an instrumental variable for vitamin D status in pregnancy in a longitudinal birth cohort in the UK," *International Journal of Epidemiology*, June 29, 2009, pp. 1-8.

- Scholl, Theresa O. and Xinhua Chen, "Vitamin D intake during pregnancy: Association with maternal characteristics and infant birth weight," *Early Human Development*, 2009, 85, pp. 231-4.
- Simeonova, Emilia. (2011). "Out of Sight, Out of Mind? Natural Disasters and Pregnancy Outcomes in the USA," *CESifo Economic Studies*, 57(3): 403-31.
- Stanhill, Gerald and Shabtai Cohen. (2001). "Global dimming : a review of the evidence for a widespread and significant reduction in global radiation with discussion of its probable causes and possible agricultural consequences." *Agricultural and Forest Meteorology*, 107, pp. 255-78.
- Strand, Linn B., Adrian G. Barnett, and Shilu Tong. 2011. "The Influence of Season and Ambient Temperature on Birth Outcomes: A Review of the Epidemiological Literature," *Environmental Research*, 111:3, pp. 451-62.
- Swamy, Geeta K., Melanie E. Garrett, Marie Lynn Miranda, and Allison E. Ashley-Koch, "Maternal Vitamin D Receptor Genetic Variation Contributes to Infant Birthweight among Black Mothers," *American Journal of Medical Genetics*, 2011, pp. 1264-71.
- Terushkin, Vitaly; Anna Bender, Estee L. Psaty, Ola Engelsen, Steven Q. Wang, and Allan C. Halpern. 2010. "Estimated Equivalency of Vitamin D Production from Natural Sun Exposure versus Oral Vitamin D Supplementation across Seasons at Two US Latitudes," *J Am Acad Dermatol*, 62:6, pp. 929.e1-9.
- Tustin, Karen, Julien Gross and Harlene Hayne. (2004) "Maternal Exposure to First-Trimester Sunshine is Associated with Increase Birth Weight in Human Infants." *Developmental Psychobiology*, 45:221-230.
- Webb, Ann and Ola Engelsen. "Calculated Ultraviolet Exposure Levels for a Healthy Vitamin D Status." *Photochemistry and Photobiology*, 2006, 82:1697-1703.
- Wolpowitz, Deon and Barbara A. Gilchrest. "The vitamin D questions: How much do you need and how should you get it?" *Journal of the American Academy of Dermatology*. Vol 54, Issue 2. (Feb 2006) pp. 301-317.
- Yu, C.K. H., L. Sykes, M. Sethit, T.G. Teoh, and S. Robinson. (2009). "Vitamin D Deficiency and Supplementation during Pregnancy," *Clinical Endocrinology*, 70(5): 685-90.

Figure 1. Comparison of Engelsen’s Duration of Vitamin D Synthesizing Hours and Insolation

A. New York City



- Note: 1) Secondary axis refers to max, min and mean 31-day moving averages of insolation for the 15th of each month over the period 1989-2004.
- 2) Engelsen’s measurement calculates “ideal” conditions based on ‘thin’ ozone layer, cloudless skies, an altitude of 0.5 kilometers and new snow for the months November through April versus dry concrete for May through October; and conversely, ‘thick’ ozone, overcast skies, and old snow for the winter months.
- 3) The two following graphs are for counties of the highest and lowest latitudes from the sample: Whatcom, WA and Cameron, TX.

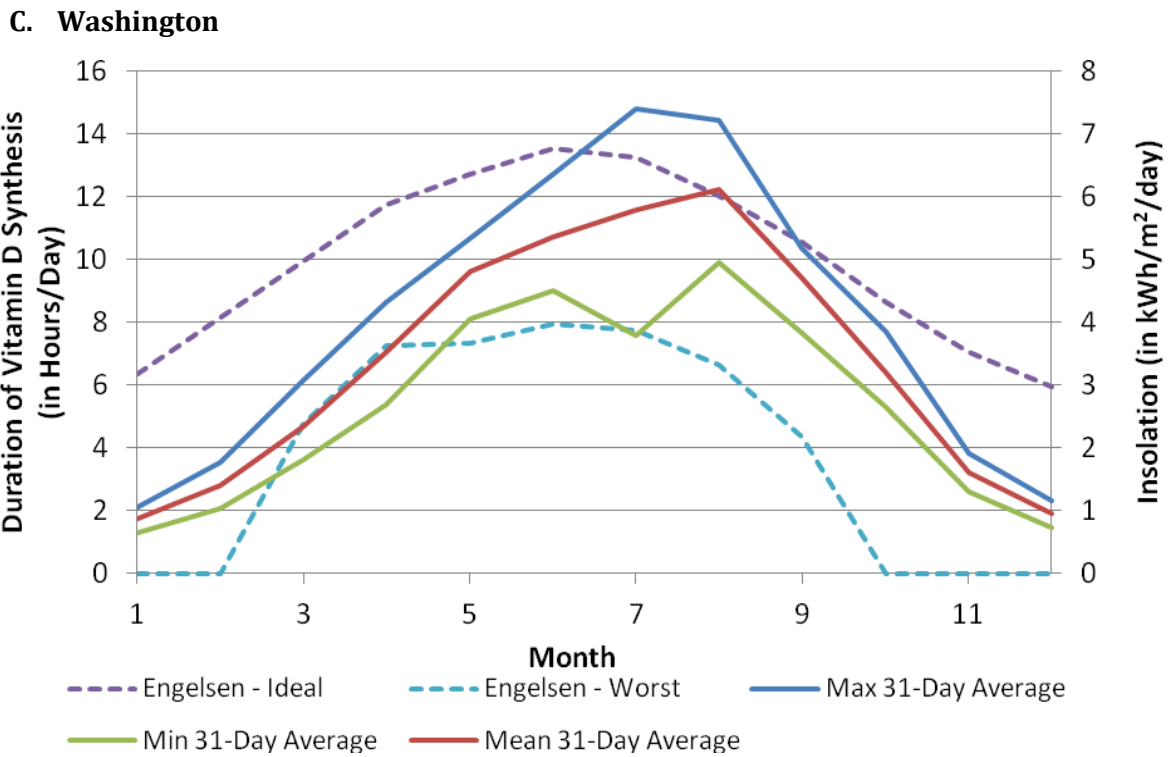
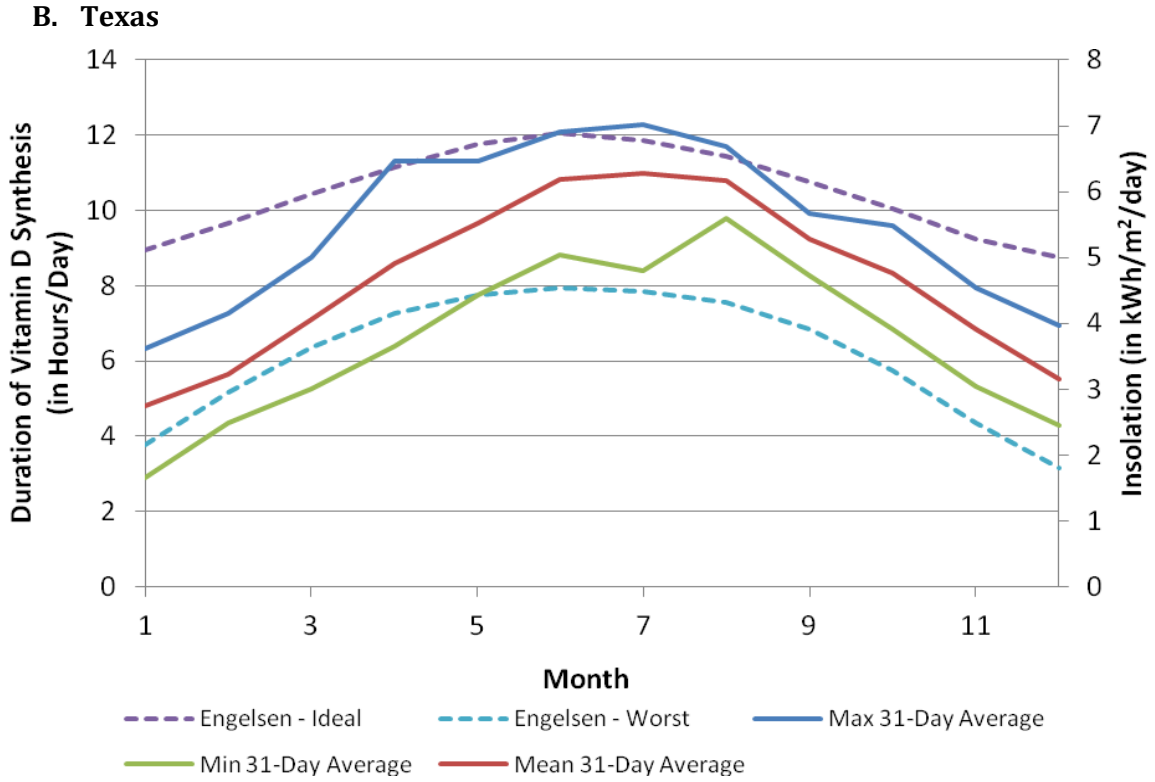


Figure 2. ACOG Recommendations for Daily Vitamin D Intake

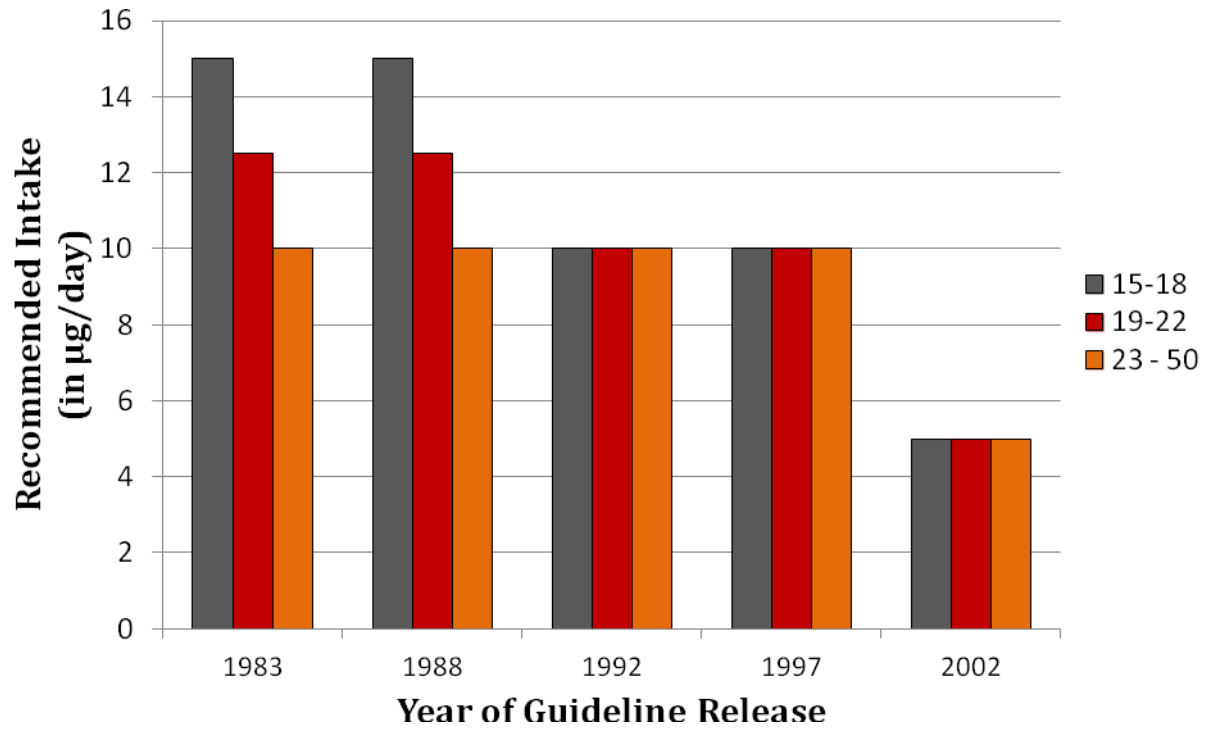
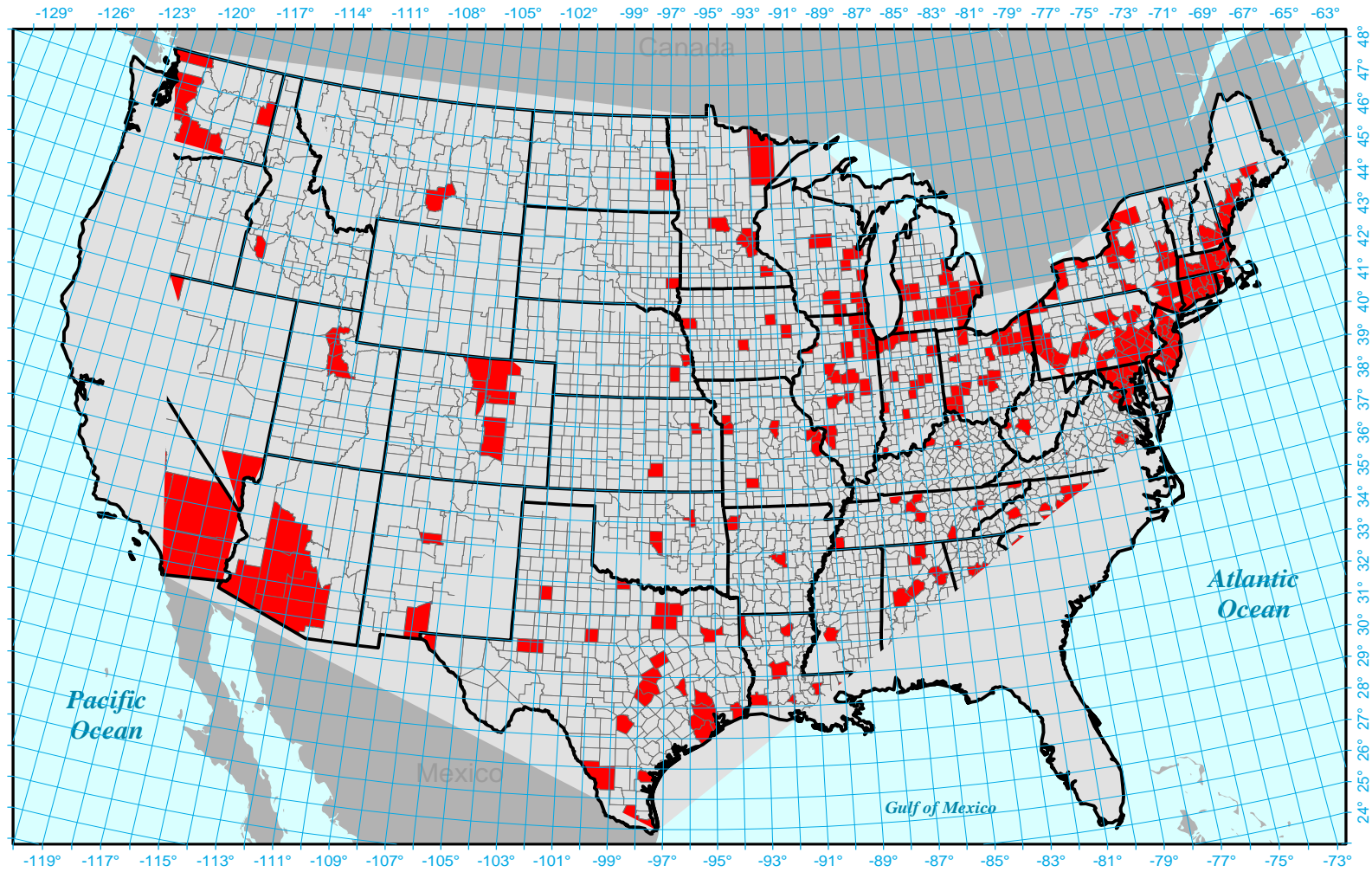


Figure 3. Geographical Distribution of Natality Data



Note: 1) The figure displays 458 counties across 26 states for which vital statistics birth data is matched with insolation measures.

The sample is restricted to counties with populations in excess of 100,000 individuals and with more than 100 births in each year.

2) Latitudes and Longitudes depict the level of specification of the insolation data which is only available at the level of each $1^\circ \times 1^\circ$ cell.

Figure 4: Distribution of Birth Weights for Black and White Infants (1989-2004)

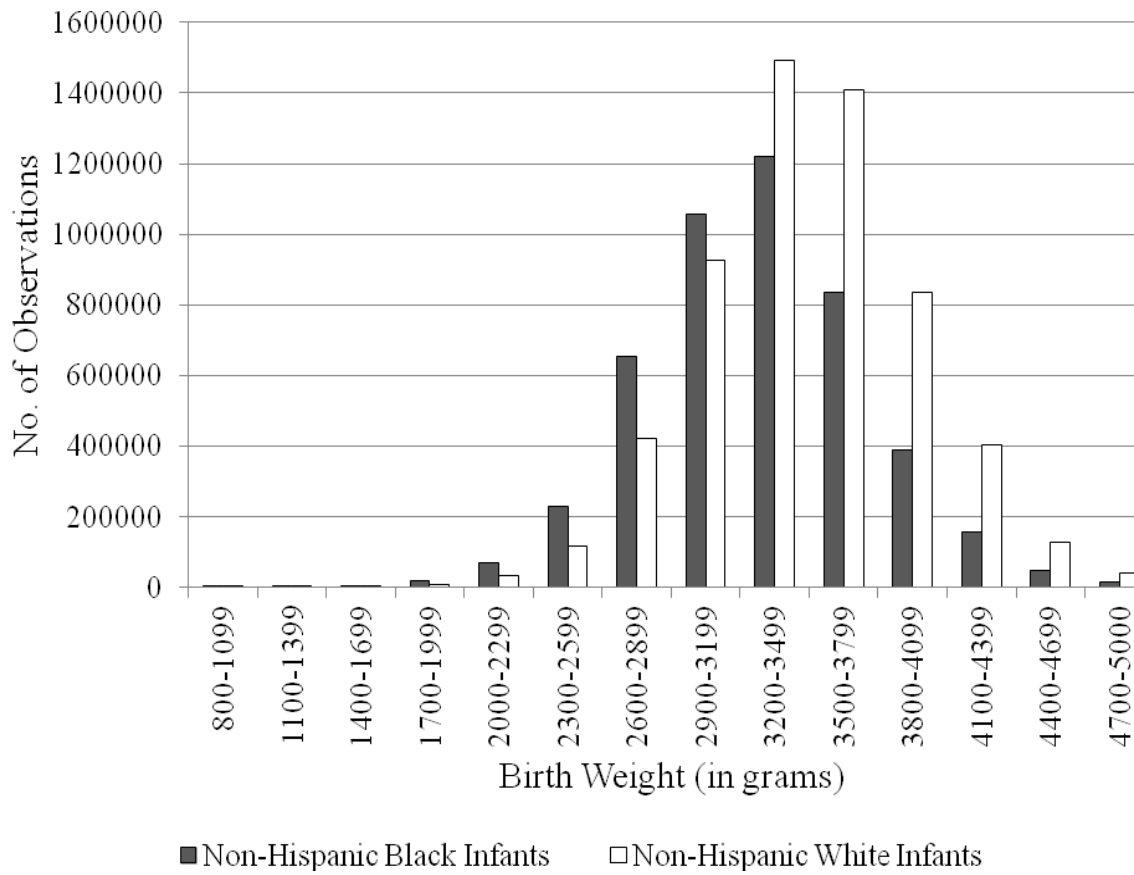
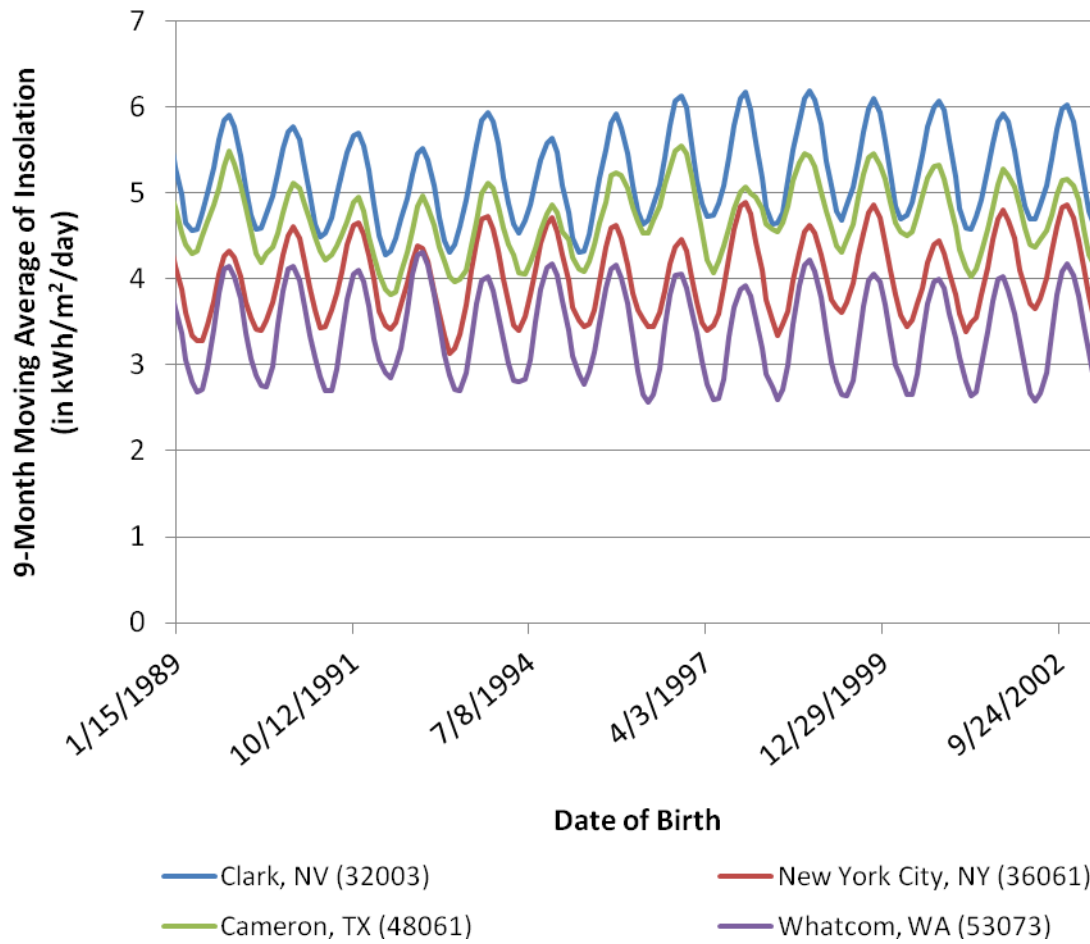


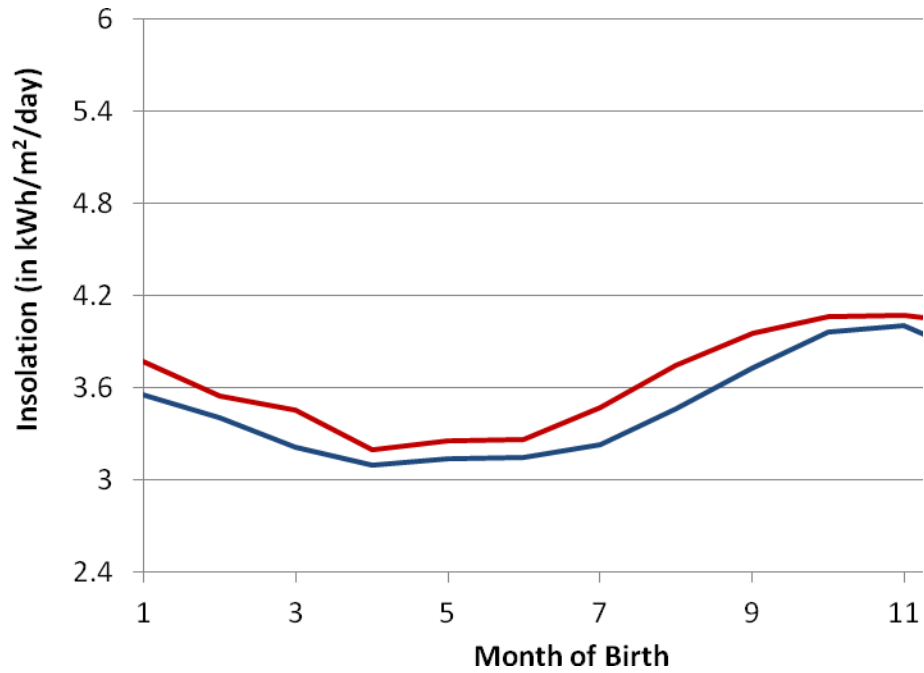
Figure 5. County Variation in Insolation Measures Over the Period 1989-2004



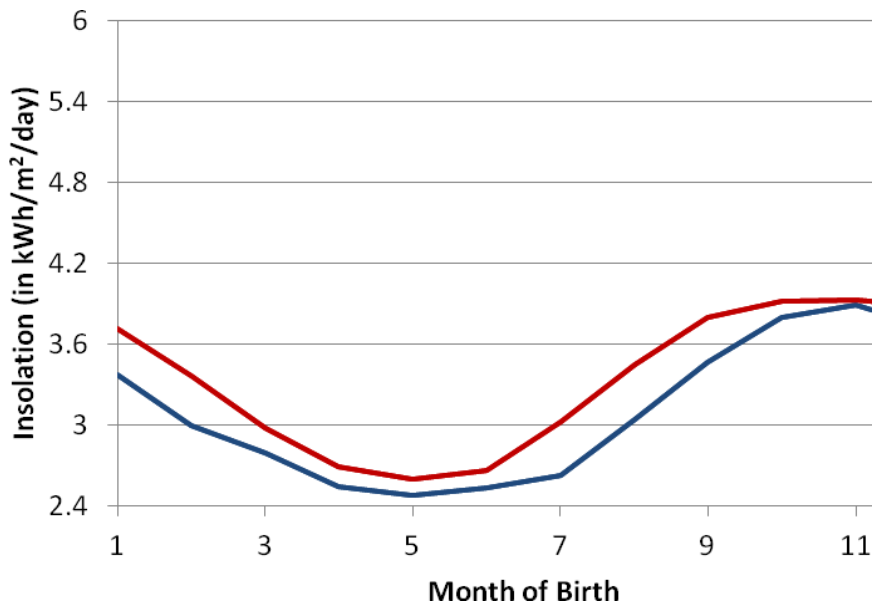
Note: 1) 9-month moving average insolation is depicted in the graph. Shorter aggregations by month or trimester depict a similar trend but with a larger variance.

Figure 6. Variations in Insolation: Maximum and minimum levels by county

A. New York City, NY

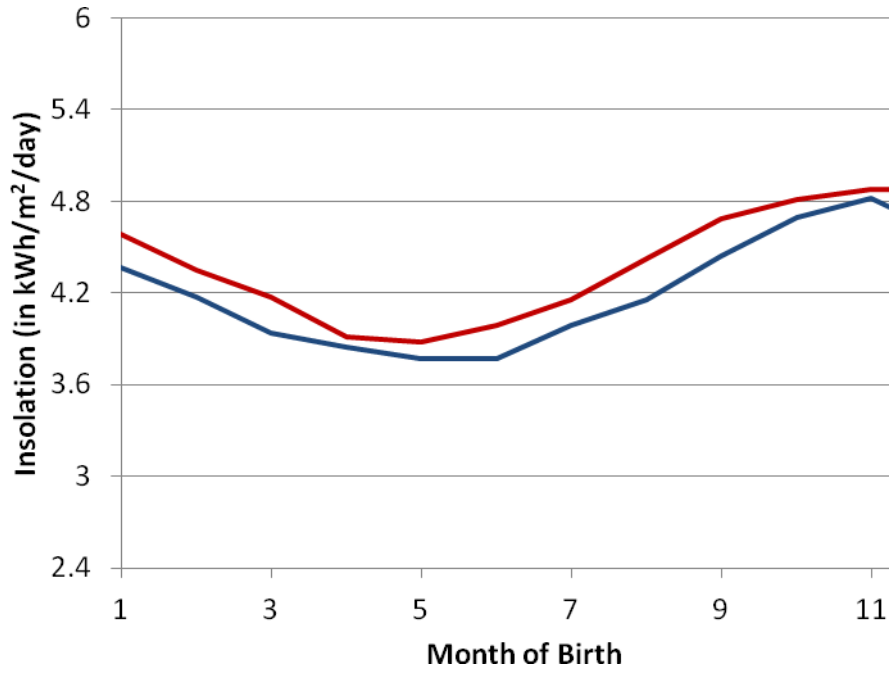


B. Whatcom, WA



Note: 1) Blue denotes minimum and Red denotes the maximum 9-month average of insolation given birth in each month.

C. Cameron, TX



D. Clark, NV

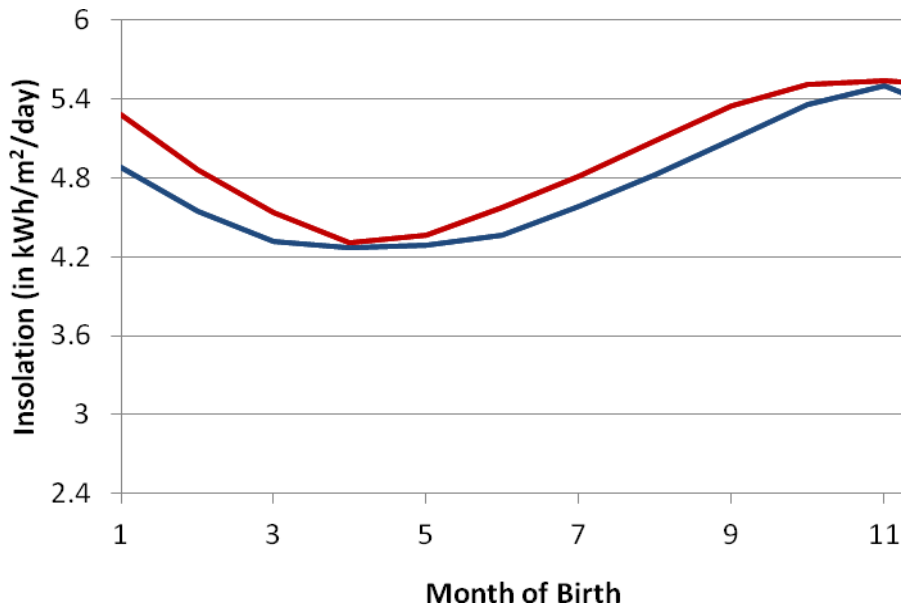


Table 1. Summary Statistics

A. White Mothers

	Mean	Std. Dev.
Maternal Characteristics		
Age	28.86	5.36
Some High School	0.08	0.26
Completed High School	0.3	0.46
Some College	0.25	0.43
Completed College	0.35	0.48
Marital Status	0.84	0.37
Smoker	0.14	0.35
Infant Characteristics		
Male	0.51	0.49
First Born	0.41	0.49
Dependent Variable		
Birth Weight	3489.058	471.42
Observations	5816572	
Smoke Observations	4801852	

B. Black Mothers

	Mean	Std. Dev.
Maternal Characteristics		
Age	26.4	5.53
Some High School	0.17	0.38
Completed High School	0.41	0.49
Some College	0.26	0.44
Completed College	0.13	0.34
Marital Status	0.38	0.48
Smoker	0.12	0.32
Infant Characteristics		
Male	0.51	0.49
First Born	0.32	0.47
Dependent Variable		
Birth Weight	3276.475	479.54
Observations	4707786	
Smoke Observations	4078468	

Table 2. Basic Insolation/Temperature Models for full samples

A. White Sample

		Insolation			Temperature		
		Full Pregnancy	Trimester	Monthly	Full Pregnancy	Trimester	Monthly
Full Pregnancy		-5.274*** (-3.44)			-0.031 (-0.18)		
1st Trimester /	Mon 1		-2.254** (-2.43)	-1.406** (-2.51)		-0.091 (-0.89)	0.122* (1.95)
	Mon 2			0.018 (0.03)			-0.117* (-1.88)
	Mon 3			-0.753 (-1.31)			-0.093 (-1.49)
2nd Trimester /	Mon 4		-1.056 (-1.13)	-0.240 (-0.42)		-0.064 (-0.63)	-0.069 (-1.11)
	Mon 5			-0.729 (-1.29)			0.092 (1.49)
	Mon 6			-0.232 (-0.41)			-0.086 (-1.39)
3rd Trimester /	Mon 7		-2.110** (-2.32)	-0.760 (-1.36)		0.125 (1.22)	0.084 (1.35)
	Mon 8			-0.430 (-0.77)			0.028 (0.45)
	Mon 9			-0.777 (-1.4)			0.01 (0.17)
Observations		5816572	5816572	5816572			
F-Stat		9908.55***	8541.98***	6042.27***			
R-Squared		0.0489	0.0489	0.0489			

Note: 1) ***, **, * imply significance at 1%, 5%, and 10% levels respectively; values given in parentheses are t-statistics.

B. Black Sample

		Insolation			Temperature		
		Full Pregnancy	Trimester	Monthly	Full Pregnancy	Trimester	Monthly
Full Pregnancy		-4.930*** (-2.83)			0.356* (1.66)		
1st Trimester /	Mon 1		-0.237 (-0.23)	-0.332 (-0.53)		-0.13 (-1.07)	0.163** (2.27)
	Mon 2			-0.267 (-0.42)			-0.142** (-1.98)
	Mon 3			0.554 (0.87)			-0.127* (-1.75)
2nd Trimester /	Mon 4		-0.919 (-0.88)	-0.77 (-1.21)		0.324*** (2.62)	0.128* (1.77)
	Mon 5			-0.314 (-0.5)			0.031 (0.43)
	Mon 6			-0.15 (-0.24)			0.193*** (2.63)
3rd Trimester /	Mon 7		-3.865*** (-3.76)	-0.723 (-1.16)		0.19 (1.54)	0.193*** (2.66)
	Mon 8			-1.393** (-2.24)			0.092 (1.27)
	Mon 9			-1.624*** (-2.61)			-0.104 (-1.44)
Observations		4707786	4707786	4707786			
F-Stat		6449.49***	5275.96***	3732.52***			
R-Squared		0.038	0.038	0.038			

Note: 1) ***, **, * imply significance at 1%, 5%, and 10% levels respectively; values given in parentheses are t-statistics.

Table 3. Basic Insolation/Temperature Models for county/month/year- level data

A. White Sample – County Level

		Insolation			Temperature		
		Full Pregnancy	Trimester	Monthly	Full Pregnancy	Trimester	Monthly
Full Pregnancy		-4.926*** (-3.14)			-0.057 (-0.32)		
1st Trimester /	Mon 1		-2.039** (-2.15)	-1.433** (-2.50)		-0.086 (-0.81)	0.125* (1.95)
	Mon 2			0.12 (0.21)			-0.114* (-1.79)
	Mon 3			-0.614 (-1.05)			-0.093 (-1.45)
2nd Trimester /	Mon 4		-1.088 (-1.14)	-0.207 (-0.35)		-0.077 (-0.73)	-0.072 (-1.13)
	Mon 5			-0.755 (-1.30)			0.084 (1.33)
	Mon 6			-0.267 (-0.46)			-0.089 (-1.40)
3rd Trimester /	Mon 7		-1.927** (-2.07)	-0.756 (-1.32)		0.106 (1.01)	0.074 (1.16)
	Mon 8			-0.387 (-0.68)			0.025 (0.39)
	Mon 9			-0.644 (-1.13)			0.005 (0.09)
Observations		80610	80610	80610			
F-Stat		226.60***	195.43***	138.60***			
R-Squared		0.421	0.421	0.421			

Note: 1) Individual Observations are aggregated to county /month/year cells, the level of variation in insolation and temperature in our data..

2) ***, **, * imply significance at 1%, 5%, and 10% levels respectively; values given in parentheses are t-statistics.

B. Black Sample – County Level

		Insolation			Temperature		
		Full Pregnancy	Trimester	Monthly	Full Pregnancy	Trimester	Monthly
Full Pregnancy		-4.781*** (-2.68)			0.333 (1.51)		
1st Trimester /	Mon 1		-0.126 (-0.12)	-0.346 (-0.54)		-0.14 (-1.13)	0.159** (2.16)
	Mon 2			-0.241 (-0.37)			-0.142* (-1.94)
	Mon 3			0.646 (1.00)			-0.130* (-1.76)
2nd Trimester /	Mon 4		-0.910 (-0.85)	-0.729 (-1.12)		0.319** (2.52)	0.130* (1.75)
	Mon 5			-0.319 (-0.50)			0.026 (0.35)
	Mon 6			-0.167 (-0.26)			0.190** (2.53)
3rd Trimester /	Mon 7		-3.829*** (-3.64)	-0.765 (-1.20)		0.181 (1.44)	0.188** (2.53)
	Mon 8			-1.371** (-2.16)			0.096 (1.29)
	Mon 9			-1.567** (-2.47)			-0.111 (-1.50)
Observations		74177	74177	74177			
F-Stat		157.75***	136.52***	97.27***			
R-Squared		0.339	0.34	0.34			

Note: 1) Individual Observations are aggregated to to county /month/year cells, the level of variation in insolation and temperature in our data.

2) ***, **, * imply significance at 1%, 5%, and 10% levels respectively; values given in parentheses are t-statistics.

Table 4: Alternative Specifications for full samples

A. White Sample

	Non-Linearities	Weekend Effects	January Only	July Only	Non Smokers Only	Low Birth Weight Dummy	Falsification Test
Insolation	30.616*** (2.69)	-4.532** (-2.25)	-21.89*** (-2.77)	-5.006 (-0.70)	-6.136** (-2.550)	0.0007 (1.49)	-3.757** (-2.49)
Temperature	1.378*** (3.54)	-0.114 (-0.33)	3.39** (2.28)	3.066*** (2.58)	0.039 (0.10)	0.00002 (0.31)	0.536*** (3.22)
Weekend Insolation		-0.858 (-0.60)	8.109 (1.47)	-3.698 (-0.71)	-1.152 (-0.69)		
Weekend Temperature		0.083 (0.270)	-2.009* (-1.7)	-2.524** (-2.29)	0.355 (1.00)		
Temp*Insolation	-0.672** (-2.49)						
Tempsq*Insolation	0.002 (1.49)						
No. Observations	5816572	5816572	456422	511892	4119636	5816572	5816572
F-Statistic	9175.3***	9174.6***	711.46***	825.17***	5676.61***	1170.52***	9908.43***
R-Squared	0.0489	0.0489	0.0478	0.0499	0.0451	0.0067	0.0489

Note: 1) All models control for mother’s age, education, marital status, whether infant is firstborn or male, year and county*month fixed effects. Full results available upon request.

2) All models employ 280-day moving average insolation and temperature variables.

3) ***, **, * imply significance at 1%, 5%, and 10% levels respectively; values given in parentheses are t-statistics.

B. Black Sample

	Non-Linearities	Weekend Effects	January Only	July Only	Non Smokers Only	Low Birth Weight Dummy	Falsification Test
Insolation	41.660*** (2.83)	-14.675*** (-6.48)	-13.985 (-1.52)	-25.563*** (-3.240)	-9.423*** (-3.66)	0.0009 (1.12)	-6.154*** (-3.62)
Temperature	1.769*** (3.69)	0.93** (2.22)	4.745*** (2.72)	1.632 (1.12)	0.496 (1.04)	-0.0002* (-1.83)	1.609*** (7.66)
Weekend Insolation		11.076*** (6.96)	8.031 1.31	-0.657 (-0.011)	7.362*** (4.07)		
Weekend Temperature		-0.525 (-1.39)	-3.070** (-2.13)	-0.45 (-0.33)	-0.759* (-1.78)		
Temp*Insolation	-1.017*** (-2.95)						
Tempsq*Insolation	0.005** (2.48)						
No. Observations	4707786	4707786	397874	416599	3603164	4707786	4707786
F-Statistic	5666.61***	5668.09***	458.93***	518.78***	4256.54***	1288.42***	6121.59***
R-Squared	0.038	0.038	0.0365	0.039	0.037	0.0091	0.038

Note: 1) All models control for mother’s age, education, marital status, whether infant is firstborn or male, year and county*month fixed effects. Full results available upon request.

2) All models employ 280-day moving average insolation and temperature variables.

3) ***, **, * imply significance at 1%, 5%, and 10% levels respectively; values given in parentheses are t-statistics

Table 5: Alternative Specifications for County Level data

A. White Sample – County Level

	Non-Linearities	Weekend Effects	January Only	July Only	Non Smokers Only	Low Birth Weight Dummy	Falsification Test
Insolation	30.812*** (2.65)	-4.123** (-2.00)	-22.105*** (-2.73)	-4.92 (-0.68)	-6.099** (-2.48)	0.0006 (1.37)	-3.817** (-2.47)
Temperature	1.327*** (3.33)	-0.229 (-0.64)	2.2 (1.44)	3.111*** (2.60)	0.036 (0.09)	0.00002 (0.37)	0.574*** (3.36)
Weekend Insolation		-0.97 (-0.66)	8.6 (1.52)	-3.373 (-0.64)	-1.106 (-0.65)		
Weekend Temperature		0.174 (0.55)	-0.97 (-0.80)	-2.539** (-2.28)	0.363 (1.00)		
Temp*Insolation	-0.679** (-2.46)						
Tempsq*Insolation	0.002 (1.52)						
No. Observations	80610	80610	6710	6720	72598	80610	80610
F-Statistic	210.47***	209.83***	17.37***	19.57	264.38***	18.31***	226.59
R-Squared	0.421	0.421	0.391	0.447	0.408	0.118	0.0421

- Note: 1) Individual Observations are aggregated to county level where variation in insolation measurements occur for these models.
- 2) All models control for mother’s age, education, marital status, whether infant is firstborn or male, year and county*month fixed effects. Full results available upon request.
- 3) All models employ 280-day moving average insolation and temperature variables.
- 4) ***, **, * imply significance at 1%, 5%, and 10% levels respectively; values given in parentheses are t-statistics.

B. Black Sample – County Level

	Non-Linearities	Weekend Effects	January Only	July Only	Non Smokers Only	Low Birth Weight Dummy	Falsification Test
Insolation	43.257*** (2.87)	-14.386*** (-6.21)	-13.39 (-1.41)	-25.698*** (-3.20)	-9.401*** (-3.58)	0.0009 (1.11)	-5.917*** (-3.40)
Temperature	1.757*** (3.58)	0.853** (1.99)	4.12** (2.27)	1.598 (1.08)	0.408 (0.84)	-0.0002* (-1.79)	1.621*** (7.55)
Weekend Insolation		10.887*** (6.69)	7.648 (1.21)	-0.53 (-0.09)	7.482*** (4.06)		
Weekend Temperature		-0.47 (-1.22)	-2.568* (-1.72)	-0.494 (-0.35)	-0.672 (-1.55)		
Temp*Insolation	-1.063*** (-3.01)						
Tempsq*Insolation	0.005*** (2.59)						
No. Observations	74177	74177	6176	6218	65050	74177	74177
F-Statistic	146.48***	147.84***	13.35***	17.94***	135.79***	56.37	159.86***
R-Squared	0.339	0.34	0.336	0.362	0.304	0.152	0.34

- Note: 1) Individual Observations are aggregated to county level where variation in insolation measurements occur for these models.
- 2) All models control for mother’s age, education, marital status, whether infant is firstborn or male, year and county*month fixed effects. Full results available upon request.
- 3) All models employ 280-day moving average insolation and temperature variables.
- 4) ***, **, * imply significance at 1%, 5%, and 10% levels respectively; values given in parentheses are t-statistics.

Table 6: Alternative Fixed Effects Specifications

	White		Black	
	Insolation	Temperature	Insolation	Temperature
1) State and Year	-19.634*** (-20.59)	0.986*** (10.91)	-21.897*** -9.49	1.472*** 6.71
2) State, Month, Year	-30.445*** (-22.24)	1.176*** (10.17)	-25.383*** -7.67	1.594*** 5.66
3) State*Month, State*Year	-36.651*** (-23.57)	1.577*** (11.62)	-27.752*** -7.39	1.687*** 5.09
4) State*Month, State*Year, County	-2.544 (-0.99)	-0.52 (-1.61)	4.614 0.73	0.181 0.23
5) County*Month, State*Year	-3.751 (-1.39)	-0.361 (-0.97)	2.307 0.35	0.163 0.18