The Impacts of Temperature Shocks on Birth Weight in Vietnam

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Kien Le & My Nguyen[1]

Abstract

This paper investigates the extent to which in-utero exposure to temperature shocks affects birth weight outcomes in Vietnam. Exploiting the variations across districts and conception timing within districts, we show that a one standard deviation increase in temperature relative to the local norm (approximately 0.52 degree Celsius) during the first trimester of pregnancy reduces the child's weight at birth by 67 grams or 2.2%. Our heterogeneity analysis suggests that infants living in rural areas, born to poor and low-educated mothers are especially vulnerable to temperature shocks.

JEL codes: I15, J13, O15, Q54

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1 Introduction

Temperature has been rising across the globe with the period of 2000-2009 being the warmest decade since the beginning of modern measurement in the 1850s (World Meteorological Organization, 2013). The increase in temperature has been shown to tremendously affect various socio-economic aspects. For example, temperature hikes are reported to decrease agricultural yield and agricultural output (Guiteras, 2009; Feng et al., 2010; Schlenker and Lobell, 2010; Dell et al., 2012). Several studies document labor productivity losses due to temperature shocks (Niemela et al., 2002; Seppanen et al., 2003). There is also evidence that temperature shocks affect impulsivity and aggression, thus leading to increased criminal activities (Jacob et al., 2007; Ranson, 2014).

In this paper, we investigate how in-utero exposure to temperature shocks affects birth weight in Vietnam. We contribute to the literature in four ways. First, we quantify the less visible cost of temperature shocks to human development. Second, in examining the association between fetal exposure to temperature shocks and early childhood development, we also connect the epidemiology literature with issues of climate change. Third, the study can be useful to Vietnamese policymakers because the country is among the most affected ones by climate change. Fourth, we add to the debate on the relative seriousness of exposure timing by presenting evidence for the significance of the first trimester.

In the analysis, we employ the data from the Vietnam Multiple Indicator Cluster Survey (MICS) for rich information on birth cases and the Meteorological and Hydrological Administration of Vietnam's temperature records of 70 weather stations across the country. In terms of identification, we exploit both the variations across districts and within districts in the average temperature to identify the impacts of temperature shocks on birth weight outcomes.

Our study reaches the following findings. First, we present compelling evidence that a one standard deviation increase in temperature relative to the local norm (approximately 0.52 degree Celsius) during the first trimester of pregnancy reduces the child's weight at birth by 2.2% or 67 grams. Second, our nonlinear analyses show that the impacts of rising temperature started to kick in around 28°C during the first trimester. Third, exploring the heterogeneous effects of temperature, we detect the vulnerability to temperature shocks of children from disadvantaged backgrounds. In particular, the birth weight of those living in rural areas, being poor, and born to low educated mothers are 2.8, 3.3, and 2.84% (or 89, 98, and 85 grams) lower in response to a one standard deviation increase in temperature. Meanwhile, the effects of interest are both statistically and economically smaller for those living in urban areas, being non-poor, and born to highly educated mothers.

Our study highlights the injurious repercussions of temperature shocks on early human capital formation. To the extent that poor infant health imposes long-lasting consequences over the life cycle such as lower educational attainment, labor productivity, and earnings, our findings imply the substantial cost of temperature shocks from both private and social perspectives. Given that 70% of the country's population live in rural areas and the geographic area lies in the disease conducive tropical zone, Vietnam is among the most vulnerable countries to climate change. According to FAO's projection, the annual mean temperatures in Vietnam might increase from 0.8 to 1.3 degrees Celcius by 2050 (FAO, 2011). Therefore, the study calls for immediate actions by Vietnamese policymakers to curtail the costs of climate change.

The paper proceeds as follows. Section 2 presents the literature review. Section 3 describes our data. Section 4 outlines the empirical methodology. Section 5 reports estimating results. Section 6 concludes the study.

2 Literature Review

Our quantitative analysis of the effects of temperature shocks is guided by the theory of Corman et al. (1987) where infant health can be influenced by maternal health and health inputs during the prenatal period (e.g. nutrition, vitamin supplement, medical services...). Temperature shocks have been shown to affect both maternal health and health inputs during pregnancy.

Regarding maternal health, there are three ways temperature shocks can impair the health of pregnant women. First, temperature shocks could generate excessive stress on the mothers, which might worsen birth outcomes (Basu et al., 2018). Specifically, heat stress can raise the risk of preterm birth through the release of labor-inducing hormones (Basu et al., 2010; Carolan-Olah and Frankowska, 2014). Excessive stress might also activate the release of norepinephrine and cortisol, which is damaging to fetal growth (Gluckman and Hanson, 2004). Second, temperature shocks can also deteriorate the physical health of mothers by facilitating the growth and survival of infectious agents (Bandyopadhyay et al., 2012; Levy et al., 2016; Endo and Eltahir, 2020). The affliction of infectious diseases during pregnancy is documented to raise the incidence of low birth weight (Umbers et al., 2011). Third, temperature shocks can devastate maternal health by increasing the labor demand for women which forces them to expend more energy (Grace et al., 2017; MacVicar et al., 2017). Doing physically demanding work during pregnancy is reported to aggravate newborns' health (Rao et al., 2003).

As for health inputs during the prenatal period, temperature shocks could alter the consumption of health inputs via the impacts on household incomes, thus affecting birth outcomes. In particular, fluctuations in temperatures are reported to decrease agricultural yield and agricultural output, thus depressing agricultural incomes (Guiteras, 2009; Feng et al., 2010; Schlenker and Lobell, 2010; Dell et al., 2012; Kubik and Maurel, 2016). Lower incomes decrease household ability to acquire health inputs such as food supplies, medical services, vaccines, and vitamin supplements. Insufficient nutrition and care during the intrauterine period are likely to hurt fetal development and worsen birth outcomes (Tayebi et al., 2013; Woldeamanuel et al., 2019).

Empirically, our analysis can be related to two groups of studies. The first group focuses on the impacts of intrauterine shocks on birth outcomes. A study by Camacho (2008) concludes that landmine explosions during pregnancy induce Colombian women to give birth to lightweight infants. In the context of Spain, Quintana-Domeque and Rodenas-Serrano (2017) show that in-utero exposure to terrorism decreases the weight at birth of newborns and increases the complications during the pregnancy or labor. Almond and Mazumder (2011) uncover the deteriorating impacts on birth weight among Arab mothers who practice fasting during pregnancy. Intrauterine exposure to other adverse events such as pandemics or natural disasters can also decrease gestational length and birth weight (Simeonova, 2011; Dorelien, 2019). Despite the consensus on the negative association between infant health and intrauterine exposure to negative shocks, the relative significance of the exposure timing is still an ongoing debate. While some studies highlight the importance of the first trimester (Camacho, 2008; Quintana-Domeque and Rodenas-Serrano, 2017), others point to the role of the second trimester (Almond and Mazumder, 2011) or the equal importance of all three trimesters (Dorelien, 2019).[2]

The second stream of empirical related to our paper explores the association between temperature shocks and child health. In the context of 30 Sub-Saharan countries, Baker and Anttila-Hughes (2020) documents the child growth and development effects of increased temperatures. The authors find that hiking temperatures depress child's weight-for-age and height-for-age. They

[2] A number of medical studies documents a negative link between birth weight and mental distress during the first trimester (Schneider et al., 1999; Van den Bergh et al., 2005), while others underline the importance of the second trimester (Field et al., 2006; Field and Diego, 2008).

argue that temperature shocks lead to poor absorption of nutrients and calories, resulting in acute malnutrition in the form of weight loss. Moreover, temperature shocks are reported to worsen multiple aspects of child morbidity (Knowlton et al., 2009; Nastos et al., 2008; Green et al., 2010; Loh et al., 2011; Onozuka and Hashizume, 2011; Bandyopadhyay et al., 2012). For instance, in the context of the U.S., Knowlton et al. (2009) report the increase in the emergency department visits due to electrolyte imbalance among young children during the heatwave periods. Besides, temperature shocks induce more cases of pediatric respiratory diseases in Greece, the U.S., and Singapore (Nastos et al., 2008; Green et al., 2010; Loh et al., 2011). Japanese and African children are also more likely to be afflicted with hand, foot, and mouth disease and diarrheal illness when temperatures increase (Onozuka and Hashizume, 2011; Bandyopadhyay et al., 2012).

Closest to our paper are the studies on the relationship between temperature and birth outcomes. In the context of the U.S., both Deschenes et al. (2009) and Basu et al. (2018) conclude that extremely hot weather during gestation reduces birth weight. Studying the effects of temperature on pregnancy outcomes in sub-Saharan Africa, Davenport et al. (2020) show that temperature hikes decrease the likelihood of a healthy-weight birth.[3] While Deschenes et al. (2009) and Basu et al. (2018) find the impacts concentrated in the third trimester, Davenport et al. (2020) emphasize the effects of the first-trimester exposure.

Differing from prior studies, our paper examines the impacts of in-utero exposure to temperature shocks on birth weight outcomes in the context of Vietnam. Since the U.S. is a high-income country, U.S. women tend to have better resources to protect their fetuses from adverse climatic shocks. Therefore, the impacts on U.S. women and infants are likely to be very different from the

[3] Also related to our paper is the study by Wilde et al. (2017) which examines the long-term impacts of temperature. The authors find that prebirth temperature is positively associated with long-term educational outcomes.

impacts on those from a developing country like Vietnam. Furthermore, given Vietnam's geographic area in the tropical zone that is conducive to diseases and the country's high reliance on agriculture, Vietnam is particularly susceptible to the fluctuation of climatic indicators such as temperature. Moreover, compared to sub-Sahara Africa, one of the poorest regions in the world, the conditions in Vietnam are vastly different. Consequently, temperature shocks might affect Vietnamese and sub-Sahara African babies differently. Therefore, our study adds to the understanding of the potential consequences of climate change on infant health in a vulnerable country from the middle-income group.

3 Data

Data on Birth Cases - Information on birth records are drawn from the Vietnam Multiple Indicator Cluster Survey (MICS) which is carried out by the General Statistics Office of Vietnam (GSO) in collaboration with the United Nations Children's Fund (UNICEF). This rich dataset places focus mainly on mother and children outcomes that are used in monitoring progress towards the Millennium Development Goals. There are four waves of MICS that are publicly available at the moment (MICS-2, MICS-3, MICS-4, MICS-5), but we can only use MICS-3 and MICS-4. The reason is that the other waves do not allow us to back out the geographic locations of the children and their mothers, thus the temperature records. In other words, with MICS-3 and MICS-4, we have the district of residence for the children and their mothers. Therefore, we can identify the latitude and longitude associated with the district's centroid, which allows us to merge the MICS data with the temperature data (discussed in the next section). Besides, we mainly rely on the Woman's Questionnaire file of MICS that surveys women of reproductive age on their demographic characteristics, fertility, birth date, and weight of their children, among others.

It is the survey design that birth weight is gathered only for live birth in two years preceding the survey (i.e. not all children in the MICS data are surveyed for birth weight). The birth weight information is collected from the weight as recorded on a health card (if the child was weighed at birth) or the mothers recall (if the child was not weighed at birth). The proportions of children weighed at birth are 87 and 93% in MICS-3 and MICS-4, respectively. As the majority of children were weighed at birth, the accuracy of our birth weight measure is strengthened. Birth weight is recorded for 813 cases in MICS-3 and 1,235 cases in MICS-4, with a total of 2,048 birth cases.[4] Over 98% of observations (1,961 birth cases) with nonmissing value on all variables enter our effective sample. One disadvantage of the MICS data is that the information on gestational age is unavailable.

Data on Temperature - Temperature data are collected from the Meteorological and Hydrological Administration of Vietnam that provides information on the temperature of 70 weather stations across Vietnam.[5] For each weather station, we have access to the geographic location of the station (a pair of latitude and longitude) and daily average temperature. We proceed to assign each district the temperature records from the station closest to its centroid. Next, we construct our main explanatory variable based on the deviation of temperature from the local norm as follows. First, for each trimester of pregnancy, we calculate the change in local temperature by differencing the average temperature in the referred trimester and the long-run average temperature for those three months in the period 2002-2012. For example, for a child in utero between October 2004 and June

[4] The survey does not contain a question on whether the birth case is singleton or plural. However, upon checking the data, we find that each birth case can be matched to one unique mom, which means that they are all singleton births.

[5] We illustrate the spatial distribution of weather stations (black dots) and residential districts (gray polygons) across Vietnam in Figure 1.

2005, the temperature change between the average temperature in his/her second trimester from January 2005 to March 2005 and the local norm ($\mathrm{TC}^2_{Jan-Mar}$) is given by,

$$\mathrm{TC}^2_{Jan-Mar} = \mathrm{T}^2_{Jan-Mar} - \mathrm{LRT}^2_{Jan-Mar} \quad (1)$$

where the average temperature in the three months of the second trimester ($\mathrm{T}^2_{Jan-Mar}$) is the average of daily temperature from January 2005 to March 2005 in the child's residential district. The local norm, i.e. the three-month long-run average temperature ($\mathrm{LRT}^2_{Jan-Mar}$), is the 2002-2012 mean of temperature for January through March in the child's residential district. Then, for trimesters {1; 2; 3}, we standardize the variables $\{TC^1; TC^2; TC^3\}$ using z-score standardization so that their distributions exhibit zero means and unit standard deviations. We use these variables as our main explanatory variables, referred to as Standardized Temperature Change $\{STC^1; STC^2; STC^3\}$.

Summary Statistics - Our final estimation sample consisting of 1,961 children born during the period of 2004 and 2011. The descriptive statistics of our outcome and control variables are provided in Table 1. On average, children in our sample weighed 3.1 kilograms at birth. Approximately 37% of children live in urban areas. The proportions of Kinh children and male children are 85 and 52%, respectively. On average, mothers in our sample were 28 years old when they gave birth to the corresponding children and their average age at the time of their first birth is 23. Mother's wealth index takes the mean value of 3.2. Around 99% of mothers are married while only 21% of mothers attain at least high school education. Regarding our main explanatory variables, the mean values of temperature change in the first, second, and third trimesters of pregnancy are 0.13, 0.19, and 0.20, respectively. The corresponding standardized measures have zero mean and unit standard deviation.

4 Empirical Methodology

To investigate the impacts of temperature shocks during pregnancy on birth weight outcomes and tackle the lack of consensus on the relative significance of the timing of exposure, we exploit the variation in temperature changes across spatial and temporal dimensions in the following framework,

$$Y_{ist} = \beta_0 + \sum_{j=1}^{3} \beta^j \, \mathrm{STC}_{st}^j + \mathrm{X}'_{ist}\Omega + \lambda_s + \delta_t + \lambda_s \times t + \varepsilon_{ist} \qquad (2)$$

where the subscript *i, s,* and *t* correspond to child, residential district, and conception month-year. The superscript *j* represents trimester. The outcome variable, Y_{ist}, is the child's weight in normal and log forms. Since we are interested in exploring exposure to temperature shocks in which stage of pregnancy affects birth weight, we have trimesterspecific temperature deviations as the key explanatory variables. In particular, the variables $\{STC_{st}^1; STC_{st}^2; STC_{st}^3\}$ are standardized changes in temperature in the mother's residential district during the first, second, and third trimester of pregnancy, respectively.[6]

Vector X'_{ist} captures demographic characteristics of children and mothers, such as child's locational status (urban/rural), ethnicity, gender, mother's age at birth (and its squared term), age at first birth (and its squared term), wealth index, marital status, and educational attainment. The variables λ_s and δ_t denote district and month-year of conception fixed effects, respectively. We also include the district-specific birth cohort trend, represented by the interaction $\lambda_s \times t$, to account for differential trends across cohorts and spatial units. Finally, we denote by ε_{ist} the idiosyncratic error term. The standard errors throughout this study are clustered at the weather station level.

[6] Following prior studies such as Sorg and Taylor (2011), Dell et al. (2012), and Wilde et al. (2017), we control for temperature in a linear manner in our main regression. The nonlinearity analysis is conducted in Section 5.2.

The coefficients of interest are $\{\beta^1;\ \beta^2;\ \beta^3\}$ which quantitatively represent the relationship between birth weight and temperature shocks in each of the pregnancy trimesters. In the difference-in-differences setup in equation (2), our identification hinges upon the comparison of the birth weight of children born to mothers exposed to temperature shocks during pregnancy with the birth weight of children born to mothers unexposed to such events during pregnancy within the same district, relative to the analogous differences for mothers residing in other districts. Women exposed to temperature shocks during pregnancy constitute the treatment group. The control group includes women subject to temperature shocks before conception, those exposed to temperature shocks after birth delivery, and those totally unexposed to temperature shocks.

5 Results

5.1 Main Results

The quantified association between temperature shocks and birth weight outcomes is presented in Table 2. Results on birth weight outcomes in normal form (kilograms) and log form are provided in Columns 1-3 and Columns 4-6, respectively. The estimates for the most parsimonious specification are reported in Columns 1 and 4 in which only district effects are included. Next, in Columns 2 and 5, we control in our regressions a set of mother characteristics such as mother's age at birth (and its squared term), age at first birth (and its squared term), wealth index, marital status, and educational attainment. Lastly, Columns 3 and 6 are our most extensive specifications in which we add to the previous specifications (Column 2 and 5) a set of child characteristics such as child's locational status (urban/rural), ethnicity, gender, district-specific birth cohort trend, and month-year of conception fixed effects.

As shown in Columns 1 and 4, our most parsimonious specification points to the negative relationship between in-utero exposure to temperature shocks and child's weight at birth.

Specifically, a one standard deviation increase in temperature relative to the long-run local average (approximately 0.52 degree Celsius) during the first trimester is associated with the decrease in birth weight by 0.05 kilograms (Column 1) or 1.9% (Column 4). Temperature shocks in the second and the third trimesters also have negative impacts on birth weight; however, point estimates are statistically and economically insignificant.

With the inclusion of mother's characteristics, we continue to find inimical consequences of first-trimester exposure to temperature shocks on birth weight (Columns 2 and 5). In particular, children tend to weigh 0.05 kilograms (Column 2) or 1.8% (Column 5) less at birth, in response to a one standard deviation increase in temperature relative to the historical norm during the first trimester. Again, there is no evidence that temperature shocks in other trimesters affect child's weight at birth.

According to our most extensive specification (Columns 3 and 6), prenatal exposure to temperature shocks is detrimental to birth weight and the impacts are mainly concentrated in the first trimester. Specifically, a one standard deviation increase in temperature relative to the long-run local mean during the first trimester of pregnancy leads to a 67 gram reduction in weight at birth (Column 3) or a decline in birth weight by 2.2% (Column 6). Coefficient estimates on temperature shocks in the second and the third trimesters are indistinguishable from zero. The joint significance tests have p-values of 0.041 and 0.039 for birth weight in normal form and in log form, respectively, thus rejecting the joint equality of the effects of temperature shocks across trimesters. Taken together, Table 2 emphasizes the damaging ramifications of temperature shock exposure during the first three months of pregnancy on the health outcome of newborns.

5.2 Non-Linearity Analyses

In this section, we proceed to examine the nonlinear impacts of temperature during the in-utero period on birth weight. It is because both extremely hot and extremely cold weather is bad for health. Furthermore, controlling for temperature in a nonlinear manner allows us to distinguish between the effects of temperature fluctuation across different ranges. For instance, the impacts of going from hot to very hot might be different from those going from cold to pleasant.

To capture the nonlinear impacts of temperature, we divide temperature into five bins, namely, Very Hot (>31°C), Hot (28−31°C), Moderately Hot (25−28°C), Room Temperature (18−25°C), Cool (<18°C). We replace the standardized temperature change with five variables indicating the number of days with temperature falling within the corresponding ranges. We construct these five variables for each trimester of pregnancy, leaving us with a total of 15 main explanatory variables in the non-linearity regression. It is worth noting that in this specification, we assume that the time of exposure is linear, whereas the main regressions (Table 2) rest on the linear temperature assumption. Moreover, since temperature in Vietnam rarely falls below 10°C, cold shock is unlikely.

The estimating results are reported in Table 3. The dependent variables are birth weight in normal form and birth weight in log form in Columns 1 and 2, respectively. For each dependent variable, we display 15 coefficients corresponding to 15 explanatory variables indicating five temperature bins for each of the three trimesters. We find that the effects of rising temperature started to kick in around 28°C during the first trimester. We do not have enough statistical evidence to conclude the impacts of lower temperature ranges.

5.3 Heterogeneity Analyses

Next, we investigate the heterogeneous effects of intrauterine exposure to temperature shocks on birth weight along the lines of locational status, family wealth, and maternal education, employing our most extensive specifications (similar to Columns 3 and 6 of Table 2). The effects of interest are reported in Table 4. Here, the dependent variables are the child's birth weight in normal form (Panel a) and log form (Panel b). Each column reports a separate regression, and its heading represents the subgroup level.

First, we are interested in exploring the potential heterogeneous impacts of intrauterine exposure to temperature shocks by locational status. To put it differently, we want to know if infants in rural areas and those in urban areas are differentially affected. Evident from Columns 1 and 2, we find that the impacts of temperature shocks fall disproportionately on infants living in rural areas. Specifically, rural infants tend to weigh 89 grams less or 2.8% less in response to a one standard deviation increase in temperature relative to the local norm (approximately 0.52 degree Celsius) during the first trimester (Column 1). However, the point estimate is statistically insignificant and smaller in magnitude for the urban sample (Column 2). The larger consequences on infants from rural areas could be explained by the fact that rural women may lack the resources for proper prenatal care, compared to urban women. It could also be the case that household incomes in rural areas are more sensitive to climatic indicators such as temperature than those in urban areas (because of the dependence on agriculture), making rural infants especially vulnerable to temperature shocks.

We proceed to explore whether the impacts of intrauterine exposure to temperature shocks differ by family wealth level (Columns 3 and 4). Poor families are categorized as families in the bottom and second quintiles of the wealth distribution. Likewise, non-poor families are families in the upper three quintiles. We find that infants from poor families are more severely affected by temperature shocks than those from non-poor families. Particularly, a one standard deviation increase in temperature relative to the historical norm during the first trimester of pregnancy is associated with a 98 gram reduction or 3.3% decline in birth weight for infants from poor families. Nevertheless, the impacts on infants from non-poor families are indistinguishable from zero in both economic and statistical senses. The results suggest that while non-poor mothers could protect their babies from the adverse temperature shocks, infants born to poor mothers are especially vulnerable.

Given the importance of maternal education to the health outcomes of children (Keats, 2018; Le and Nguyen, 2020b), in the last two columns of Table 4, we examine if infants born to low educated mothers are differentially affected by temperature shocks compared to those born to highly educated mothers. Low education is defined as education less than the high school level. High education is defined as education at the high school level and above. Evident from Columns 5 and 6, the adverse consequences of temperature shocks fall disproportionately on infants born to mothers with low education. Low-educated women who experienced a one standard deviation increase in temperature relative to the long-run local average during the first trimester of pregnancy tend to give birth to newborns weighing 85 grams or 2.8% less. The impacts are almost non-existent among infants born to highly educated mothers. The results underline the role of maternal education in counteracting the consequences of adverse shocks on infant health.

5.4 Robustness Checks

Next, we examine the robustness of our estimates by imposing several restrictions on our variables and samples. The results from this exercise are reported in Table 5 in which the estimates results from our most extensive specifications. Each of the columns is from a separate regression with the column headings displaying the type of exercise. Columns 1 and 2 present the results for birth weight in normal form while Columns 3 and 4 report the estimates for birth weight in log form.

First, since intrauterine exposure to adverse events might result in the reduction of male births, prior studies recommend not including child's gender in the regression (Catalano et al., 2006; Sanders and Stoecker, 2015). Thus, we pull out the child's gender from our regressions as a robustness check. As evident from Columns 1 and 3, the practice of removing the child's gender does not change our estimates significantly (compared to Columns 3 and 6 of Table 2). In particular, a one standard deviation increase in temperature relative to the local norm (approximately 0.52 degree Celsius) during the first trimester of pregnancy reduces the child's weight at birth by 69 grams (Column 1) or 2.2% (Column 3).

Second, prior studies also report that teen pregnancy is associated with poor birth outcomes (Chen et al., 2007; Gibbs et al., 2012), thus raising a concern that our quantified impacts of temperature shocks are driven by teenage mothers. To address this concern, we remove teenage mothers from our sample and consider only mothers aged greater than or equal to 20 when giving birth. As reported in Columns 2 and 4, the first-trimester exposure to a one standard deviation increase in temperature relative to the local norm reduces the child's weight at birth by 65 grams (Column 2) or 2.1% (Column 4). Taken together, our results are robust to different independent variable and sample restrictions.

5.5 Discussion

Collectively, we find that intrauterine exposure to temperature shocks is damaging to the health outcome of newborns and the impacts are mainly concentrated in the first trimester. Particularly, a one standard deviation increase in temperature relative to the long-run local mean (approximately 0.52 degrees Celsius) during the first trimester of pregnancy is associated with a 67 gram reduction or a 2.2% decline in birth weight. Our nonlinear analyses show that the impacts of rising temperature started to kick in around 28°C during the first trimester. Exploring the heterogeneous effects of temperature, we find that children from disadvantaged backgrounds are especially vulnerable. Specifically, infants in rural areas, those from poor families, and those born to low educated mothers tend to weigh 89, 98, and 85 grams (or 2.8, 3.3, and 2.8%) less, in response to a one standard deviation increase in temperature. Nevertheless, the impacts are both statistically and economically insignificant among infants in urban areas, those from non-poor families, and those born to highly educated mothers.

There are potentially four mechanisms through which temperature shocks could deteriorate birth weight. First, lower household incomes due to temperature shocks could exert deteriorating impacts on infant health. Specifically, temperature shocks can lead to the declines in agricultural output and yields, thus depressing incomes (Guiteras, 2009; Feng et al., 2010; Schlenker and Lobell, 2010; Dell et al., 2012; Kubik and Maurel, 2016). Lower incomes limit household ability to ensure nutritional intake and afford prenatal care for pregnant women, which will lead to unfavorable birth outcomes (Tayebi et al., 2013; Woldeamanuel et al., 2019). Moreover, in terms of timing, first-trimester nutritional deprivation has been shown to reduce birth weight and raise the risk of fetal growth restriction (Rodriguez-Bernal et al., 2010).

Second, the disproportionate stress on pregnant women created by temperature shocks can hurt newborns' health as it facilitates the production of hormones that are damaging to fetal development and elevate the probability of early labor (Gluckman and Hanson, 2004; Basu et al., 2010; Carolan-Olah and Frankowska, 2014). While maternal stress is generally bad for fetal development, prior studies especially highlight the risk of poor infant health due to the first-trimester exposure to mental distress (Schneider et al., 1999; Van den Bergh et al., 2005).

Third, the prevalence of infectious diseases such as malaria and diarrhea brought about by adverse temperature fluctuations might aggravate birth weight by threatening the health of the mothers (Bandyopadhyay et al., 2012; Levy et al., 2016; Endo and Eltahir, 2020). A healthy first trimester is crucial to fetal development since many important organs of the fetus are formed during this time. Therefore, disease contraction in the first trimester could exacerbate the health outcomes of newborns (Silasi et al., 2015).

Finally, temperature shocks can be injurious to birth outcomes through altering women's time use. Particularly, temperature shocks may force pregnant women to be engaged in physically demanding work (Grace et al., 2017; MacVicar et al., 2017), which could potentially impair the babies in utero (Rao et al., 2003). Given the deep sensitivity of the fetus in the first trimester, high levels of job strain during this three-month interval can lead to reduced child's weight at birth (Vrijkotte et al., 2009).

Our findings are in line with prior studies on the adverse consequences of temperature shocks on the health outcomes of children. Specifically, excessive heat is reported to compromise children's weight at birth in the context of the U.S. (Deschenes et al., 2009; Basu et al., 2018) and in sub-Saharan Africa (Davenport et al., 2020). Besides, hiking temperatures lead to the increases in children's hospital admission due to electrolyte imbalance, respiratory diseases, hand, foot, and mouth disease as well as diarrheal illness (Knowlton et al., 2009; Nastos et al., 2008; Green et al., 2010; Loh et al., 2011; Onozuka and Hashizume, 2011; Bandyopadhyay et al., 2012). Moreover, temperature shocks are negatively associated with children's growth and development indicators such as weight-for-age and height-for-age (Baker and Anttila-Hughes, 2020).

Our study further complements the literature that explores the impacts of in-utero shocks on infant health. Extreme events such as explosion, terrorism, pandemic, and natural disasters, if exposed to during gestation, could result in the decreases in birth weight and the increases in premature births (Camacho, 2008; Simeonova, 2011; Quintana-Domeque and Rodenas- Serrano, 2017; Dorelien, 2019; Le and Nguyen, 2020b). Fetal exposure to other mild shocks such as nutritional deprivation, pollution, and climatic conditions can also be damaging to newborns' health (Currie et al., 2009; Almond and Mazumder, 2011; Basu et al., 2018).

Our study also contributes to this stream of literature on the relative importance of exposure timing. Specifically, Almond and Mazumder (2011) show that the impacts of nutritional deprivation occur from exposure during the first and the second trimesters while Simeonova (2011) point to the relevance of the second and the third trimesters. Dorelien (2019) reports that exposure to influenza in all three trimesters is associated with unfavorable birth outcomes. Whereas third-trimester exposure to pollution is documented to decrease birth weight (Currie et al., 2009), there is evidence that it is shocks during the first trimester of pregnancy that affect newborns' health (Camacho, 2008; Quintana-Domeque and Rodenas-Serrano, 2017; Le and Nguyen, 2020b). Among the studies on the impacts of temperature shocks, Davenport et al. (2020) emphasize the effects of the first-trimester exposure while Deschenes et al. (2009) and Basu et al. (2018) find the impacts concentrated in the third trimester. Our findings support the group of studies showing the importance of the first trimester.

Our study emphasizes the hidden yet serious cost of temperature shocks to early human capital formation in Vietnam. To the extent that poor infant health leaves persistent consequences over the life cycle in the forms of lower educational attainment, labor productivity, and earnings (Black et al., 2007; Oreopoulos et al., 2008; Xie et al., 2019), our findings also underline the detrimental ramifications of temperature shocks on long-term human capital. Given 70% of the country's population living in rural areas and the geographic area in the disease conducive tropical zone, Vietnam is especially vulnerable to the consequences of climate variability such as temperature shocks. Therefore, our findings are of meaningful implications for Vietnamese policymakers. Agricultural adaptation strategies such as changes in cropping pattern and calendar of planting, the utilization of varieties of crops that can be resistant to temperature fluctuations, among others, could alleviate the adverse impacts on infant health by minimizing household income losses. Public provision of nutritional intake and prenatal care for pregnant women could also be helpful. It is also important to incorporate disease control features into the health care system to protect pregnant women from being afflicted with weather-induced diseases like malaria and diarrhea. Priorities should be given to women of disadvantaged backgrounds (those living in rural areas, being poor, and having low educational level) as this is the most vulnerable group.

5.6 Limitations

There are two limitations in our study. First, the MICS data do not provide any information on gestational age. The lack of gestational age information might lead to the miscategorization of trimester exposure for some fractions of the sample. However, this is possibly not an issue because the miscategorization of trimester exposure (arising from the technical weakness of the survey) is unlikely to be jointly correlated with our main explanatory variables (the standardized temperature change in each of the trimesters) and the dependent variable (birth weight). In other words, the miscategorization of trimester exposure may possibly not bias our estimates.

The second limitation is the migration concern since the child's birthplace and the mother's migration history are unavailable in the MICS data. Ideally, to estimate the effects of in-utero exposure to temperature shocks on birth weight, we should use the district of birth instead of the district of residence of the child. It is possible that mothers might have migrated to different areas in response to temperature shock. Their children could have been exposed to such an adverse condition in the in-utero period before the migration took place and they are not observed in the sample. The omission of such children might narrow the gaps in birth weight between infants severely affected by temperature shock and those hardly affected during the intrauterine period. In other words, the migration concern could bias our estimates toward zero, thus our estimated impacts might be smaller than the true impacts.

6 Conclusion

This paper evaluates the extent to which in-utero exposure to temperature shocks influences birth weight in the context of Vietnam. The data utilized in this paper come from the Vietnam Multiple Indicator Cluster Survey (MICS) and Vietnam's Meteorological and Hydrological Administration's weather stations. We adopt the difference-in-differences model to tease out the impacts of interest where the birth weight of children born to mothers exposed to temperature shocks during pregnancy is compared with the birth weight of children born to mothers unexposed to such events during pregnancy within the same district, relative to the analogous differences for mothers residing in other districts.

Our study reaches the following findings. First, we detect inimical repercussions of fetal exposure to temperature shocks during the first trimester on birth weight. Specifically, a one standard deviation increase in temperature relative to the local norm (approximately 0.52 degree Celsius) during the first trimester of pregnancy reduces the childs weight at birth by 2.2% or 67 grams. Second, our nonlinear analyses show that the impacts of rising temperature started to kick in around 28°C during the first trimester. Third, exploring the heterogeneous effects of temperature, we detect the vulnerability to temperature shocks of children from disadvantaged backgrounds. In particular, the birth weight of those living in rural areas, being poor, and born to low educated mothers are 2.8, 3.3, and 2.84% (or 89, 98, and 85 grams) lower in response to a one standard deviation increase in temperature. Meanwhile, the effects of interest are both statistically and economically smaller for those living in urban areas, being non-poor, and born to highly educated mothers.

To the extent that poor infant health persists into adulthood and adversely affects educational attainment and labor market outcomes (Black et al., 2007; Oreopoulos et al., 2008; Xie et al., 2019), our study underlines the substantial cost of temperature shocks from both private and social perspectives. According to FAO's predictions, the hike in annual mean temperatures in Vietnam could be from 0.8 to 1.3 degrees Celcius by 2050 (FAO, 2011). As one of the most affected countries by climate change, Vietnam should have immediate policy actions to minimize the costs of climate change. Programs that aim to provide nutrition and health care for pregnant women could alleviate the threats to infant health. Agricultural adaption strategies can also be helpful in protecting household incomes, thus securing access to health inputs for pregnant women. Extra attention should be given to women of disadvantaged backgrounds since they tend to be the most vulnerable.

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