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# Rainfall, Birthweight and Endogenous Pregnancy

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**Abstract**

Several studies examine the impact of rainfall on neonatal health; however, few consider the endogenous nature of pregnancy decisions. Mothers engaged in agriculture often plan their pregnancies around the intensity of expected farm labor. Families who delay childbearing due to favorable weather conditions are likely to earn higher incomes, which may contribute to higher birthweights. This study accounts for the endogeneity of pregnancy decisions and corrects for sample selection bias related to the timing of childbirth. Our findings reveal that the effects of rainfall fluctuations on birthweight vary significantly across different climates and agricultural peak seasons. Notably, in Iran, infants appear more vulnerable to downpours than to droughts, possibly due to the country's reliance on wells and underground water, as well as the labor-intensive nature of traditional farming. These results underscore the importance of considering both climatic conditions and agricultural workload when assessing the environmental determinants of infant health.

**KEY WORDS:** Infant health, rainfall fluctuation, drought, downpour, agricultural employment, climate

# Introduction

Birthweight is a key indicator of newborn health and has been widely studied due to its significant implications for both short-term and long-term health outcomes. Research consistently shows that low birthweight is linked to higher risks of neonatal mortality, developmental delays, and chronic health conditions later in life. The influence of environmental factors, particularly rainfall, on neonatal health has received increasing attention in recent studies. However, the endogenous nature of pregnancy decisions is often overlooked. In agricultural communities, mothers who are actively involved in farming may plan their pregnancies based on the intensity of expected agricultural labor. This strategic planning can significantly impact both the timing of conception and subsequent infant health outcomes.

Our research addresses this endogeneity by correcting for sample selection bias related to the timing of childbearing. This approach enables us to isolate the true impact of rainfall on birthweight while accounting for the complex decision-making processes of mothers in agricultural communities. By incorporating these dynamics, we provide a more precise understanding of the relationship between environmental factors and infant health, emphasizing the importance of contextual factors in public health research.

Families who delay childbearing during periods of favorable weather, which support higher agricultural productivity, are likely to experience increased income. As a result, these delayed pregnancies may lead to newborns with higher birthweights due to improved maternal health and nutrition during gestation. Therefore, to accurately assess the effects of rainfall fluctuations on infant health, it is essential to use a model that accounts for the endogeneity of pregnancy decisions and corrects for sample selection bias.

Our study bridges this gap by employing a two-step Heckman model, specifically designed to identify and correct for endogeneity induced from sample selection. This approach allows us to accurately estimate the impact of rainfall fluctuations on infant health while accounting for the endogenous nature of pregnancy planning. We utilize a comprehensive dataset that integrates administrative birth records from the Iranian Maternal and Neonatal Network (IMaN) with detailed meteorological data and labor force characteristics.

The IMaN dataset provides comprehensive information on over 2.8 million births in Iran from March 20, 2014, to January 20, 2017, including detailed demographics and health conditions of both mothers and newborns. We integrate this dataset with precipitation records from the Iran Meteorology Institute, using interpolated rainfall measurements from 5 nearest stations to obtain more precise local estimates. Additionally, we incorporate labor force survey data to analyze seasonal variations in agricultural workload and their impact on pregnancy decisions.

Our empirical strategy consists of two key steps. In the first stage, we use Census data and a probit model to estimate the probability of conception based on rainfall experienced in the preceding year, segmented into four distinct time periods. This model captures the selection process and generates an inverse Mills ratio to correct for selection bias in the second stage. In the second stage, we apply an OLS regression to examine the primary relationship of interest—the impact of rainfall fluctuations during each trimester on birthweight—while incorporating the inverse Mills ratio to account for endogeneity.

Our findings reveal several key insights. First, agricultural workload and its alignment with gestational age significantly influence the impact of rainfall fluctuations on infant health. Second, the effects of rainfall variations during pregnancy trimesters vary considerably across climatic regions, underscoring the need for region-specific analyses. Third, selection bias is evident and must be addressed to accurately estimate the impact of rainfall on infant health. However, factors such as maternal age, education, and the number of previous deliveries have a stronger influence on pregnancy decisions than rainfall fluctuations, highlighting the predominant role of socioeconomic and demographic factors. Finally, in Iran, infants are more vulnerable to downpours than to droughts. This may be because agriculture relies on wells and underground water to mitigate drought effects, and farmers receive public insurance for crop losses. However, traditional, labor-intensive farming practices require all family members, including pregnant women, to work more during favorable weather, potentially leading to adverse effects on birthweight.

By accounting for these complexities, our study offers a more precise and comprehensive understanding of how environmental factors, particularly rainfall, interact with agricultural labor dynamics to influence newborn health outcomes. These findings have important policy implications, highlighting the need for targeted interventions to support maternal and infant health, especially in agricultural communities.

## Literature Review

Birth weight is a critical indicator of neonatal health, with significant implications for both short-term and long-term outcomes. Heck, Klein, and Taylor (1995) state that children with low birth weight (less than 2,500 grams) are more likely to experience abnormal growth, diseases, and nervous system disorders, with these risks increasing as birth weight decreases. Almond and Currie (2011) highlight that most underweight babies exhibit mild deficits in cognitive skills, concentration, and neuro-motor performance, which can persist for years, affecting their health, education, and economic status. Black et al. (2007), using a twin fixed-effects approach to address endogeneity concerns, confirm these findings. Similarly, Figlio et al. (2014) demonstrate that the negative consequences of low birth weight cannot be mitigated by a family's socioeconomic status or access to quality education. Therefore, understanding the determinants of health at birth is essential for reducing healthcare and social costs while enhancing human productivity and capital accumulation.

An expanding body of research examines the impact of environmental conditions and shocks during the fetal stage on birth outcomes. Studies have investigated various environmental factors, including air quality (Currie and Walker, 2011), water quality (Austin, 2020), temperature (Chen et al., 2020), disease (Zhou et al., 2004), and rainfall—the primary focus of this study. Rainfall can affect fetal health through five key channels: water quality, disease exposure, maternal mental well-being, household income, and maternal employment.

Studies indicate that in the absence of water refining systems, water quality heavily depends on rainfall, decreasing as precipitation diminishes. Lin et al. (2021) show that negative rainfall shocks correlate robustly with lower birth weight. Changes in weather conditions can foster environments conducive to the proliferation of viruses and bacteria. For example, Zhou et al. (2004) found that changes in temperature and precipitation in East Africa led to an increase in outpatient referrals for malaria. Malaria can disrupt the blood supply to the fetus, causing weight loss at birth due to placental issues (Menendez et al., 2000). Yap et al. (2021) provide evidence that drought can negatively impact human mental health, suggesting that a stressed mother may neglect self-care. Trinh et al. (2021) examine the impact of rainfall shocks on child health in Vietnam, finding that improved parental mental health due to rainfall shocks decreases the probability of a child being underweight.

The channels of family income and maternal employment are particularly pertinent to this study. Rainfall is closely linked to agricultural activities and yields. An increase in rainfall can enhance agricultural output, thereby boosting family income, which improves nutrition and care for pregnant women. Maccini and Yang (2009) support this mechanism, indicating that positive rainfall impacts on agricultural output leads to higher household income and better health outcomes for infant girls. However, agriculture, especially in developing countries, is labor-intensive and typically involves all family members. Cai et al. (2020) find that heavy physical workloads during pregnancy are associated with increased risks of preterm delivery and low birth weight. Despite these findings, Peterman et al. (2013), using longitudinal data from China, Mexico, and Tanzania, refute the notion that women reduce labor-intensive work during pregnancy in developing countries.

The magnitude and significance of rainfall effects vary by season and pregnancy stage. As Chambers (1982) indicates, seasonality in studies of health and income in agricultural contexts is a key to understand the mechanisms and patterns. These patterns depend on climate and geographical location. While embryonic development stages are still being explored, it is generally accepted that each trimester of pregnancy corresponds to a different growth stage: organ formation in the first trimester, organ function development in the second trimester, and body growth and weight gain in the third trimester. Rocha and Suarez (2015) found that rainfall impacts on fetal weight are stronger during the second trimester and for children born in the dry season in semi-arid regions of Brazil. Similarly, Leh and Nguyen (2022) report a significant negative effect of rainfall fluctuations during the second trimester in Vietnam. Lin, Liu, and Zhu (2021) found that a 1% decrease in rainfall during the third trimester in a poor Chinese province lacking a piped water system leads to a 1.5% decrease in birth weight. MacVicar et al. (2017) indicate a positive association between precipitation during the third trimester and birth weight in Uganda. Dimond-Smith et al. (2023) found that in Nepal, drought during the first trimester is associated with lower birth weight, whereas excess rainfall in the first trimester is associated with higher birth weight, and in the third trimester, with higher odds of low birth weight.

Research also shows that rainfall fluctuations affect not only health at birth but also the number of births. Abiona (2021) emphasizes the significance of seasons and agricultural context, finding that reduced agricultural yields decrease family income and nutritional status, leading to higher risks of abortion and conception aversion. Hard work during harvest time can similarly increase these risks. Kim (2010) finds that rainfall variations affect birth timing, with women more likely to have children in drier than average seasons in West Africa. Bhalotra (2010) focuses on the relationship between seasonal agricultural work and infant and child survival, concluding that in developing countries like India, the adverse impacts of maternal labor during pregnancy are more pronounced compared to developed countries.

## Data And Empirical Strategy

We compile data from multiple sources to include information on (1) birthweight and neonatal health outcomes, (2) rainfall patterns, (3) pregnancy decisions, and (4) labor force characteristics. The Iranian Ministry of Health and Medical Education collects administrative birth data through the Iranian Maternal and Neonatal Network (IMaN). Pilvar and Yousefi (2021) and Khalili et al. (2019) have previously used the IMaN dataset to study newborn birthweights in Iran.

### Birthweight Data

Our IMaN sample includes over 2.8 million births recorded between March 20, 2014, and January 20, 2017, with detailed demographic and health information on both mothers and newborns. The average birthweight is 3,176 grams, with the 90th and 10th percentiles at 3,750 and 2,600 grams, respectively. Table 1 presents summary statistics on pregnancy characteristics, neonatal health outcomes, and maternal demographics. The average gestational age is 38.52 weeks, and 10.1% of pregnancies are classified as high-risk, with conditions such as pre-eclampsia. Additionally, 15.6% of births occur in private hospitals, and 50.8% are delivered via cesarean section.

On average, mothers in our sample have experienced pregnancy 2.1 times, delivered 0.88 live babies, and undergone 0.21 abortions. Birthweight, along with 5-minute and 10-minute Apgar scores, are key continuous health outcome variables. In our sample, 6.28% of newborns have some form of anomaly, 6.59% are born with low birthweight (<2,500g), 6.95% are preterm (gestational age <37 weeks), 0.45% experience stillbirth or die during delivery, and 2.5% are admitted to the NICU. The average maternal age is 28 years, with 20% having completed college, 21.6% married to a cousin, and 3.57% identified as non-Iranian.

**Table 1- Summary Statistics of IMaN Data**

| VARIABLES | All | Steppe | Arid | Mediterranean | Humid Subtropical |
|---|---|---|---|---|---|
| **Pregnancy characteristics** | | | | | |
| Gestational Age (Weeks) | 38.52 | 38.459 | 38.735 | 38.498 | 38.471 |
| High Risk Pregnancy % | 10.1 | 8.4 | 11.3 | 10.5 | 10.3 |
| Private Hospital % | 15.6 | 11 | 11 | 16.9 | 26 |
| Cesarian Section% | 50.8 | 46.7 | 45.8 | 52.1 | 60.1 |
| Number of Pregnancies | 2.091 | 2.2 | 2.194 | 2.045 | 1.943 |
| Number Delivered | 0.878 | 0.98 | 0.965 | .84 | .728 |
| Number Aborted | 0.213 | 0.22 | 0.229 | .205 | .214 |
| **Health Outcomes** | | | | | |
| Birthweight (Grams) | 3,176 | 3,151 | 3,174 | 3,172 | 3,262 |
| Apgar 5 Minutes | 8.82 | 8.83 | 8.88 | 8.82 | 8.76 |
| Apgar 10 Minutes | 9.82 | 9.84 | 9.77 | 9.83 | 9.76 |
| Anomaly % | 6.28 | 8.6 | 5.9 | 5.6 | 5.4 |
| Low Birthweight % | 6.59 | 7.3 | 6.7 | 6.5 | 5.3 |
| Preterm % | 6.95 | 7.5 | 5.9 | 7 | 6.9 |
| Still Birth or Death During Delivery% | 0.45 | 0.5 | 0.4 | 0.5 | 0.4 |
| NICU Admission% | 2.5 | 2.5 | 3.7 | 2.4 | 1.4 |
| **Mother Demographics** | | | | | |
| Mother Age | 27.97 | 27.83 | 27.89 | 28.11 | 27.56 |
| College Graduate Mothers% | 19.9 | 20.1 | 17.6 | 20.3 | 20.3 |
| Cousin Husband % | 21.6 | 32.2 | 20.8 | 18.4 | 15.7 |
| Non-Iranians % | 3.57 | 2.3 | 5.5 | 4 | 0.7 |
| Number of Observations | 2,809,728 | 619,788 | 385,834 | 1,552,524 | 251,582 |

Note: The IMAN dataset includes 2,809,728 births from March 20, 2014, to January 20, 2017 of all babies born in Iran. Steppe provinces include Khuzestan, Fars, Kohgiluyeh, Bushehr, Hormozgan and Kerman. Arid provinces include Qom, Khorasan Razavi and Khorasan Jonubi. Humid Subtropical provinces are Golestan, Mazandaran, Gilan and Ardebil. The rest of the provinces are Mediterranean.

## Rainfall Data

Meteorological data, collected by the Iran Meteorology Institute from 414 stations across the country, is publicly available and has been used in several studies, including Amanzadeh et al. (2021), to investigate the economic impact of climate change. The average precipitation in Iran is 366 mm, indicating an overall arid climate. However, some cities exhibit a more pluvial environment, with the 95th percentile of annual rainfall reaching 873 mm. For our analysis, we interpolate precipitation data from the five nearest stations for each city. Table 2 presents the summary statistics for quartile areas based on rainfall. The table demonstrates that the observations are well-distributed across regions, supporting identification. It also suggests a positive relationship between higher rainfall and increased average newborn weights, as well as a reduced incidence of low birth weight.

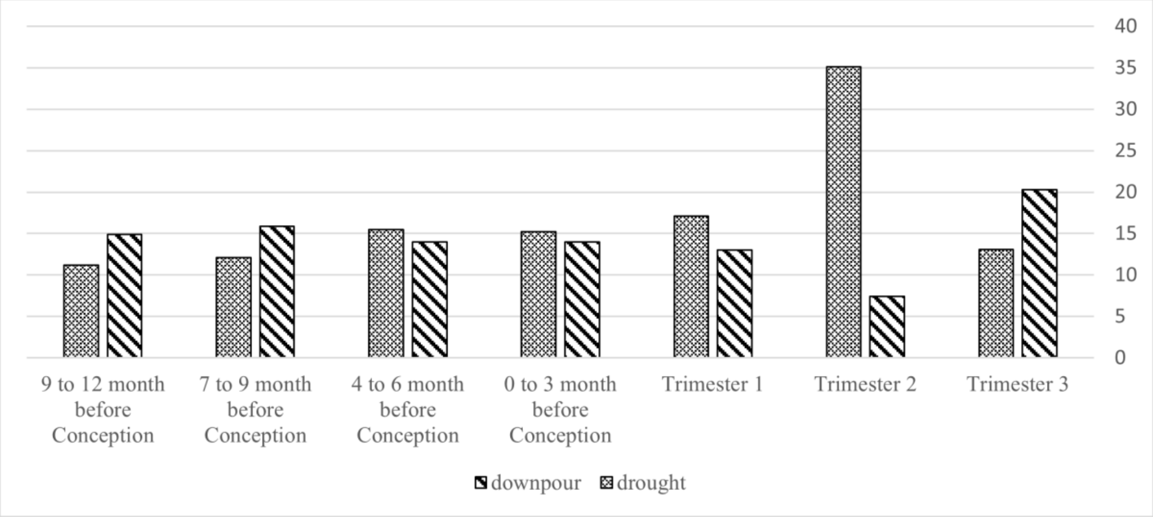
**Table 2- Summary Statistics by Rainfall Group**

| Rain Percentile by County | % Population | % Birth | % Rural | Mean BW(gr) | %Mean LBW rate (<2500gr) |
|---|---|---|---|---|---|
| | | | | | |
| <25% | 24.5 | 20.7 | 19.9 | 3,106 | 8.27 |
| 25%-50% | 22.4 | 31.0 | 22.0 | 3,173 | 6.68 |
| 50%-75% | 32.1 | 31.1 | 26.9 | 3,195 | 6.0 |
| >75% | 21.0 | 17.2 | 33 | 3,231 | 5.40 |
| All | 100% | 100% | 25% | 3,176 | 6.59% |

Note: BW(birthweight) and LBW(low birthweight). infants weigh under 2500 gram are considered low birthweight.

Although counties vary in their average annual rainfall, people in each county have adapted their agricultural practices and daily routines to the levels of rainfall they typically expect. Therefore, rather than analyzing the effect of the exact amount of rainfall on birthweight, this study focuses on the impact of substantial deviations from the ten-year average rainfall for a given time of year. These deviations are meaningful because individuals organize their lives and agricultural activities based on expected seasonal rainfall. To capture these variations, we use two terms drought and downpour in this study, which describe periods of significantly lower or higher rainfall than usual. Drought is defined a period when rainfall is more than one standard deviation below the ten-year county mean, and downpour is a period when rainfall exceeds one standard deviation above the ten-year county mean. Figure 1 illustrates the share of droughts and downpours incidents across trimesters up to childbirth, as well as in the four 3-month periods preceding conception. Considering these four time periods is essential, as rainfall patterns prior to conception can influence a family's decision to conceive. Rainfall in the earlier periods affects current income and access to nutritional resources, while rainfall in the later periods provides a clearer indication of anticipated workload and future income. Families observe recent rainfall, form expectations about their economic and labor conditions, and incorporate these factors into their decision-making process regarding childbearing. As Figure 1 shows, precipitation exhibits sufficient variation in our data, which enables us to identify the impact of rainfall on newborn weights.

**Figure 1- Share of Infants Experienced Rainfall Fluctuations %**

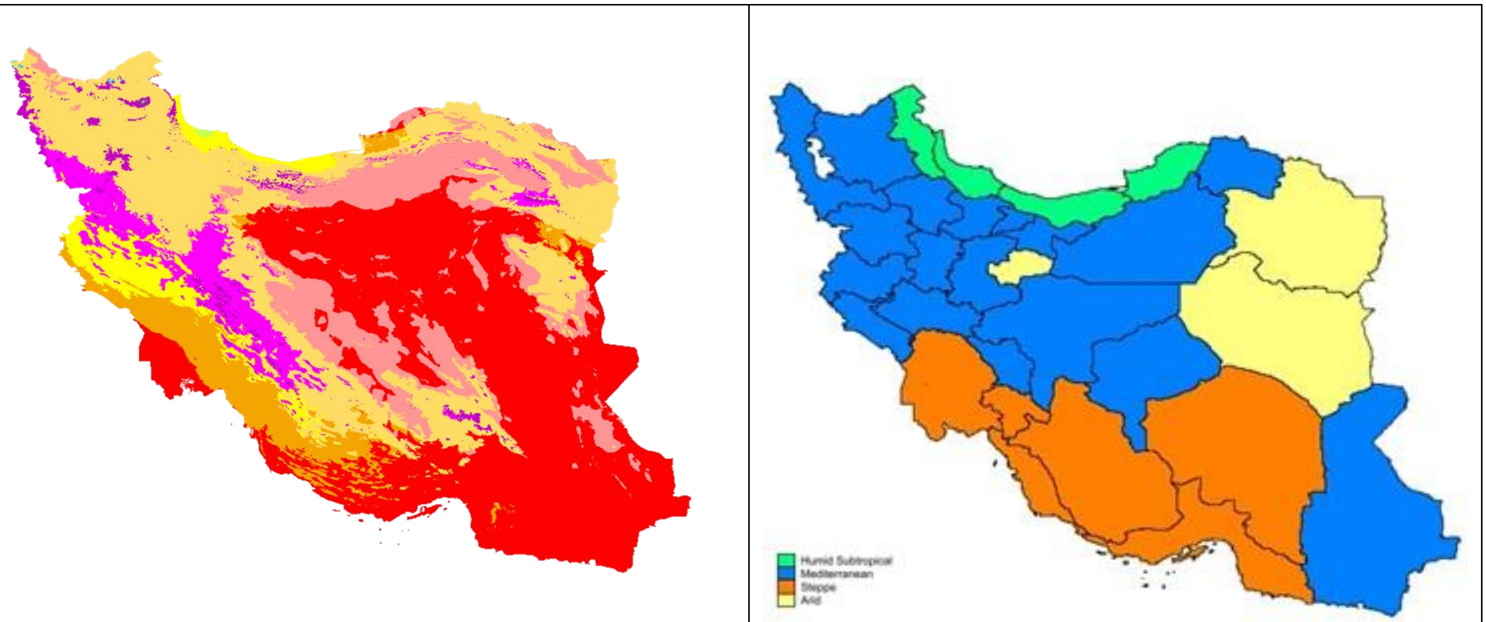


## Agricultural Activity Data

We are interested in examining the impact of rainfall on birthweight through the lens of maternal agricultural activity. Since the agricultural workload varies by season, mothers may choose to avoid conception during peak agricultural periods. To account for geographic variation in agricultural workload, we utilize the Labor Force Survey (LFS), a seasonal and rotational panel survey. We define female agricultural workload as the two seasons with the highest female employment over a ten-year period in each province. Based on this classification, we distinguish between four groups of provinces in Iran, as shown in Figure 2. Interestingly, this grouping aligns closely with the Köppen-Geiger climate classification (Beck et al., 2018).

The steppe regions, which are warm southern areas, experience peak agricultural activity in winter and spring (BSh or BWh climate in the Köppen classification). Cold desert or arid regions (BSk or BWk climate in the Köppen classification) see peak agricultural activity in spring and fall. Other provinces, which are a combination of Mediterranean (Csa climate in the Köppen classification) and Humid Subtropical (Cfa climate in the Köppen classification) climates, experience peak agricultural activity in spring and summer. As shown in Figure 2, this pattern aligns with Iran's climate map. Table 1 also presents summary statistics for the IMaN across the climate groups. It demonstrates that average baby weights are significantly higher in the Mediterranean and humid subtropical group (t-stat: 41.85), and the incidence of low birth weight is significantly lower compared to the arid and steppe regions (t-stat: 23.41). Additionally, the table shows that the four regions are balanced across other dimensions.

**Figure 2 – Accordance of Köppen climate classification with our classification based on peak season of agricultural activity for women**



Köppen Climate Classification

Source: "Present and future Köppen-Geiger climate classification maps at 1-km resolution". *Nature Scientific Data*. DOI:10.1038/sdata.2018.214

Classification Based on Peak Season of Agricultural Activity for Women. Green: Humid Subtropical, Blue: Mediterranean, Yellow: Arid and Orange: Steppe

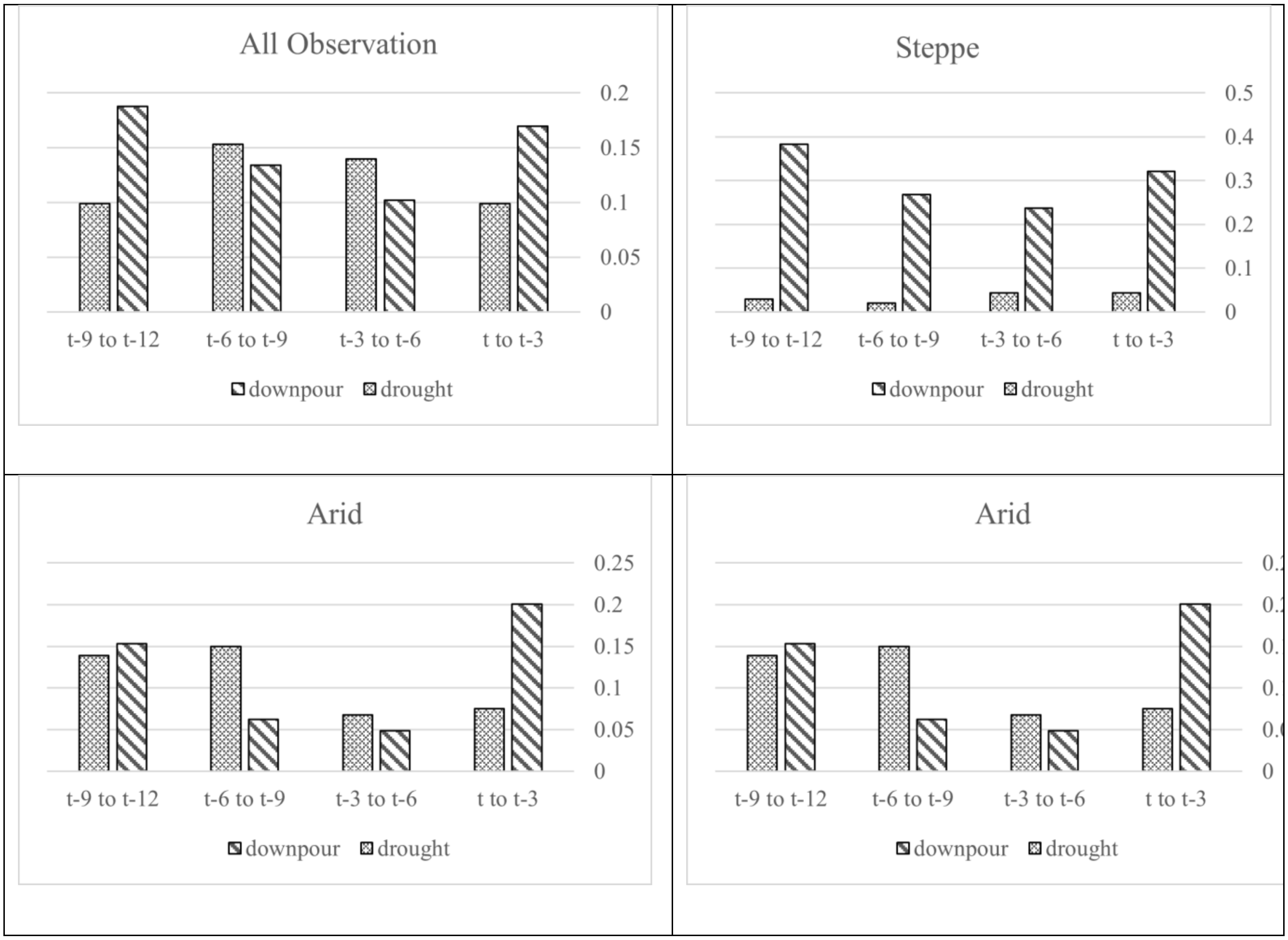
**Do mothers adjust their prenatal period based on rainfall?** Using the climate groups defined earlier, Figure 3 reveals that the pattern of rainfall fluctuations experienced in the periods before conception differs significantly among the four groups. This difference suggests the presence of sample selection bias, which must be accounted for in our estimations.

These four climatic regions in Iran differ in both their primary agricultural outputs and the timing of their agricultural calendars. In the steppe regions, which are warm southern areas with peak agricultural activity in winter and spring, we observe that mothers who experienced drought in this region tended to avoid conception. This may be due to reduced agricultural output and lower family income during drought periods. Furthermore, the average temperature in these regions is high enough to make living conditions uncomfortable, and rainfall typically correlates with lower temperatures, which improve living conditions. In the steppe region, the main agricultural product is dates, which typically do not require substantial female labor.

In the desert or arid regions, where peak agricultural activity occurs in spring and fall, drought conditions 6 to 9 months prior to conception may signal less agricultural work during the subsequent months, thereby increasing the likelihood of conception. Conversely, increased rainfall in the three months leading up to the peak agricultural season suggests higher output and expected income 6 to 9 months later, which in turn increases the probability of conception. In arid counties, the main agricultural product is saffron, a crop that is highly dependent on female labor.

In other provinces (Figure 3, bottom right), which combine Mediterranean and humid subtropical climates, with spring and summer as peak agricultural seasons, the situation differs. These regions experience cold falls and winters and dry summers. Downpours 9 to 12 months before conception lead to higher agricultural output and income, promoting conception. However, droughts during the colder fall and winter months reduce agricultural output, which may allow mothers more flexibility in their schedules, thus preventing conception. In humid subtropical regions, the main agricultural output is rice, a labor intensive crop that heavily relies on female labor. In contrast, the dominant crop in Mediterranean regions is wheat, which typically requires minimal involvement from women in its cultivation

**Figure 3 - Share of infants experienced drought and downpour among all observations, steppe regions, arid regions and other regions (t in the time of conception)**



## Census Data

To account for pregnancy sample selection, we need information on both mothers with children and those without. To construct this dataset, we use the Census data for married women of fertility age, as having children out of wedlock is rare in Iran. The Statistical Center of Iran (SCI) conducts a census every ten years and releases a 2 percent sample. The 2016 sample coincides with our study period. Table 3 presents the summary statistics for the Census data and compares it with the IMaN dataset.

Using the birthdates of each child born, we created monthly data for married women of fertility age in Iran, including their demographic factors, whether they were in the agricultural peak work season, the rainfall they experienced at that month, whether conception occurred in a given month, and whether they were pregnant. Rainfall data from one year prior to the month in question is divided into four variables: rainfall in the 3 months before, rainfall in the 4 to 6 months before, rainfall in the 7 to 9 months before, and rainfall in the 10 to 12 months before. As previously explained, rainfall during these periods can shape household income and influence female workload in the subsequent months. These variables will be used in our selection equation.

**Table 3 - Summary Statistics of mutual variables in IMaN Data and Census data for all observations and climate specific observations**

| Regions | All Observations | | | Steppe | | Arid | | Other | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| Married Women in Fertility Age | Census All Women | Census Mothers | IMaN | Census | IMaN | Census | IMaN | Census | IMaN |
| | | | | | | | | | |
| Mother's Age | 34.54 | 27.45 | 27.97 | 27.36 | 27.83 | 27.37 | 27.89 | 27.5 | 28.03 |
| College Graduate Mothers% | 20.6 | 28 | 19.9 | 27.7 | 20.1 | 24.7 | 17.6 | 28.8 | 20.3 |
| Number Delivered | 1.913 | 0.824 | 0.878 | 0.917 | 0.98 | 0.968 | 0.965 | 0.763 | 0.825 |
| Rural% | 19.9 | 25 | 25 | 32.7 | 31.2 | 22.9 | 22.8 | 22.8 | 23.3 |
| Number of Observations | 218,120 | 39,711 | 2,809,728 | 8,657 | 619,788 | 5,416 | 385,834 | 25,638 | 1,804,106 |

In summary, our primary dataset is the IMaN, which provides detailed health information for mothers and babies, as well as precipitation data for all regions. To address selection bias in the pregnancy decision, we incorporate the Census data to construct the first stage of our Heckman procedure. To account for regional variations in agricultural peak seasons, we utilize the Labor

Force Survey, which reports sector-specific work hours and individual labor participation. In the following section, we explain how we conduct our estimation strategy.

## Empirical Strategy

As discussed earlier, we aim to identify the impact of rainfall fluctuations on infant health. However, mothers may plan their pregnancies based on weather conditions and anticipated agricultural workload. Unlike previous studies, we address this potential endogeneity in decision-making by employing a two-step Heckman model. Heckman (1979) developed a method to identify and mitigate sample-induced endogeneity. Selection bias occurs when a sample is not randomly generated, resulting in a sample that does not accurately represent the population.

In the first stage, we estimate the selection process using a probit model, which captures the decision-making process underlying pregnancy timing. In the second stage, we analyze the primary relationship of interest. The selection parameter from the first stage enters the second-stage OLS model, capturing unobservable characteristics that contribute to endogenous covariates in the primary regression's error term. Finally, since we are using two different data sources, the covariance matrix generated by OLS estimation in the second stage is inconsistent. Therefore, we use a bootstrap resampling method to generate correct standard errors.

For the first stage, we utilize a monthly panel of all married women of fertility age to estimate the impact of rainfall on conception in a given month. Rainfall experienced in the year prior to this month is divided into four variables: rainfall in the 3 months before, rainfall in the 4 to 6 months before, rainfall in the 7 to 9 months before, and rainfall in the 10 to 12 months before. These four variables serve as our exclusion restrictions. They predict the selection process but do not appear in the second-stage regression model where we try to estimate the impact of rainfall on birthweight.

Therefore, in the first step we estimate the parameters of the following equation by a probit regression:

$$Pr\left(concieve_{ijm} = 1 \middle| drought_{jm-k}, downpour_{jm-k}, X_i, W_j, Y_m\right) =$$

$$\Phi(\sum_{k=1}^{4}(\alpha_k \times PeakSeason_{jm} \times drought_{jm-k} + \beta_k \times PeakSeason_{jm} \times downpour_{jm-k})$$

$$+\ \omega_1 X_i + \omega_2 W_j + \omega_3 Y_m + v_{ijm})$$

Assuming that $v_{ijm}$ is distributed normally, we are trying to estimate probability that in peak season of agricultural activity, mother $i$ living in region $j$ at year-month $m$ conceives this month if she observes drought or downpour 3 months before this month (k=1), drought or downpour 4 to 6 month before this month (k=2), drought or downpour 7 to 9 month before this month (k=3) and drought or downpour 10 to 12 month before this month (k=4), controlling for her demographics $X_i$, region specific variables $W_j$ and year-month fixed effects.

- Drought and downpour variables are dummy variables indicating that the mother has experienced more than one standard deviation decrease or increase in region's historical rainfall in the time periods before year-month m.
- Variables $X_i$ are number of delivered babies, college graduated mother, mother's age, square of mother's age and being rural.
- Variables $W_j$ are the type of climate, the average share of agricultural income in household income in the region, average share of agricultural sector employment from the whole employment in the region, the average real income in the region, number of obstetrician and midwifes in the region, and the mean temperature of each time period in the region.
- Variables $Y_m$ are year and month fixed effects.

- Standard errors are clustered at the medical university level.

Medical universities are the representative of health ministry and usually located at the capital of a province and all hospitals in the province have to be coordinated with that university, however some major cities within a province have their own universities. In general, there are 31 provinces and 55 medical universities in Iran.

The coefficients $\alpha_1$, $\alpha_2$, $\alpha_3$ and $\alpha_4$ are the impact of drought in respected three-month time spans prior to conception on conceiving this month if we are in peak season of female agricultural work load. Similarly, the coefficients $\beta_1$, $\beta_2$, $\beta_3$ and $\beta_4$ are the impact of downpour in respected three-month time periods prior to conception on conceiving this month if we are in peak season of female agricultural work load. A positive (negative) coefficient means that the rainfall fluctuation in period $k$ prior to this year-month $m$, increases (decreases) the probability of conceiving this month. After estimating the coefficients of the equation above, we construct the inverse Mills ratio by predicting the expression inside the parentheses and computing the ratio of its probability density function (PDF) to its cumulative distribution function (CDF) for each mother included in the second step. We denote his term as

In the second step we try to estimate our primary parameters of interest, the impact of rainfall fluctuations in each trimester of pregnancy on birthweight, and how it differs with peak season of agricultural employment, using an OLS model. Assuming that $u$ , the error term of the second stage is also normally distributed and $E(u|v) = \varphi v$, the following equation represents our second step regression.

$$BW_{ijt} = \sum_{l=1}^{3} (\gamma_l \times PeakSeason_{jt} \times drought_{jtl} + \delta_l \times PeakSeason_{jt} \times downpour_{jtl}) + \varphi\lambda$$
$$+ \mu_1 Z_i + \mu_2 X_i + \mu_3 W_j + \mu_4 Y_t + u_{ijt}$$

- The coefficients $\gamma_1, \gamma_2$ and $\gamma_3$ indicate that for baby $i$ at region $j$ conceived in time $t$, if it is conceived at region's peak agricultural season, what is the effect of drought in the first, second and third trimester of pregnancy on its weight, respectively.
- The coefficients $\delta_1$, $\delta_2$ and $\delta_3$ indicate that for a baby conceived at peak agricultural season, what is the effect of downpour in the first, second and third trimester of pregnancy on its weight, respectively.
- Furthermore, now we have also calculated and included the inverse Mills ratio $\lambda$ for mothers in the second step. A negative estimated coefficient for inverse Mills ratio ($\varphi < 0$) suggests that the variable that increases (decreases) birthweight, makes it less likely (more likely) for an observation to be in the selected sample.
- Variables $Z_i$ in this step are gestational age (weeks), gestational age squared, cousin husband, non-Iranian mother, C-section delivery, girl baby, high-risk pregnancy and hospital type. Type of hospital chosen by mothers represents their socioeconomic status.
- Variables $X_i$ are number of delivered babies, college graduated mother, mother's age, square of mother's age and being rural.
- Variables $W_j$ are the type of climate, the average share of agricultural income in household income in the region, average share of agricultural sector employment from the whole employment in the region, the average real income in the region, number of obstetrician and midwifes in the region, and the mean temperature of each time period in the region.
- Variables $Y_t$ are year and month fixed effects.

- In addition, standard errors are clustered at the unversity level.

Finally, since we used two different datasets to run a two-step Heckman model, we corrected the standard errors by the means of bootstrap method.

## Results

Implementing the above empirical strategy, our main findings are as follows:

1. **Agricultural Workload and Gestational Age:** The timing of agricultural workload relative to gestational age is crucial in estimating the impact of rainfall fluctuations on infant health.
2. **Climate-Specific Impact:** The effect of rainfall fluctuations during each trimester of pregnancy varies significantly among mothers living in different climates.
3. **Vulnerability to Downpours:** Infants in Iran are more vulnerable to downpours than to droughts, highlighting a unique context compared to other regions.
4. **Selection Bias:** There is evidence of selection bias, which must be accounted for when estimating the impact of rainfall fluctuations on infant health.
5. **Influence of Other Factors:** Factors such as the mother's age, education level, and the number of previously delivered babies play a much more significant role in the decision to conceive than rainfall fluctuations. Our channel of interest is weaker compared to these other selection variables.

In order to correct for sample selection induced in our study of estimating the impact of rainfall fluctuation on birthweight, we utilize a two-step Heckman model. Rainfall variation prior to conception serves as an instrument that influences a family’s decision to conceive but is unlikely to have a direct effect on birthweight, allowing for a more accurate identification of the causal relationship. Therefore, we begin by estimating a probit model in the first step. This model predicts the probability of conception during the peak season of agricultural activity. Specifically, it estimates the likelihood that mother $i$, residing in region $j$, conceives in year-month $m$, based on her demographic characteristics and the rainfall conditions observed over the previous year. These factors are assumed to influence her decision-making process regarding childbearing.

**Table 4 - Estimated selection model results for the full sample and across climate classifications**

| VARIABLES | All Obs. | Steppe | Arid | Med. | Humid Sub. |
|---|---|---|---|---|---|
| Peak Season × Drought 0-3 | -0.0273 | -0.0416 | -0.0535 | -0.0114 | 0.00675 |
| | (0.0180) | (0.0388) | (0.0876) | (0.0214) | (0.0288) |
| Peak Season × Drought 3-6 | -0.0163 | -0.0204 | 0.0229 | -0.0246 | -0.0306 |
| | (0.0148) | (0.0153) | (0.0314) | (0.0204) | (0.0496) |
| Peak Season × Drought 6-9 | 0.0129 | 0.00216 | -0.00886 | 0.0215 | 0.0110 |
| | (0.0155) | (0.0572) | (0.0378) | (0.0165) | (0.0356) |
| Peak Season × Drought 9-12 | 0.00598 | 0.0556 | -0.0162 | 0.0271 | -0.0126 |
| | (0.0199) | (0.0413) | (0.0396) | (0.0257) | (0.0515) |
| Peak Season × Downpour 0-3 | 0.00552 | -0.0357 | 0.0556 | 0.0166 | -0.00472 |
| | (0.0190) | (0.0383) | (0.0547) | (0.0361) | (0.0376) |
| Peak Season × Downpour 3-6 | 0.0348 | 0.0279 | 0.00946 | 0.0597 | 0.00377 |
| | (0.0263) | (0.0234) | (0.0755) | (0.0426) | (0.0632) |
| Peak Season × Downpour 6-9 | -0.0597*** | -0.0927*** | -0.0687*** | -0.0571 | 0.0188 |
| | (0.0218) | (0.0260) | (0.0191) | (0.0546) | (0.0486) |
| Peak Season × Downpour 9-12 | 0.00766 | 0.00500 | 0.000323 | -0.0164 | 0.0935* |
| | (0.0176) | (0.0186) | (0.0413) | (0.0411) | (0.0530) |
| Year & Month FE | Yes | Yes | Yes | Yes | Yes |
| Clustered by Univ. | Yes | Yes | Yes | Yes | Yes |
| Obs. | 3.93M | 737k | 435k | 2.29M | 461k |

The results of this estimation are presented in the Table 4. The results reveal that a downpour occurring 6 to 9 months before conception is associated with a decrease in the number of babies conceived during the peak agricultural workload season. This effect is observed across all observations, with a particularly strong influence seen in families residing in steppe and arid regions.

After estimating the first-stage selection equation, we use the resulting coefficients to calculate the inverse Mills ratio, which is then included as an additional regressor in our primary outcome equation. Table 5- Results for the impact of rainfall fluctuations in each trimester of pregnancy for all observations and observations in each climate. presents the estimates for all observations in column one, and for steppe, arid, Mediterranean, and humid subtropical climates in columns two, three, four, and five, respectively. Column one shows that pooling all observations yields an average effect of rainfall fluctuation on infant health, with a coefficient of approximately 1% (31 grams) of the average birth weight (3176 grams).

However, when disaggregating by different climates, substantial differences emerge. Despite the absence of direct information on maternal employment in the agricultural sector and reliance on regional averages for agricultural employment and income dependency, the coefficients remain large and economically significant. The impact is likely even greater if more specific data on maternal agricultural employment were available. Our second result underscores the significant role of climate conditions, particularly the specific agricultural seasons and outputs, in estimating the impact of rainfall fluctuations during each trimester of pregnancy.

**Table 5- Results for the impact of rainfall fluctuations in each trimester of pregnancy for all observations and observations in each climate.**

| Two-Step Heckman Birthweight (gr) VARIABLES | (1) All Observations | (2) Steppe | (3) Arid | (4) Mediterranean | (5) Humid Subtropical |
|---|---|---|---|---|---|
| Peak Season × drought in trimester 1 | 3.650 | 43.56*** | 3.228 | -3.824 | -17.88 |
| | (6.219) | (13.80) | (11.12) | (4.716) | (12.71) |
| Peak Season × drought in trimester 2 | -3.893 | -16.91** | -17.27*** | 4.099 | 15.82** |
| | (3.760) | (7.487) | (5.011) | (4.428) | (6.942) |
| Peak Season × drought in trimester 3 | -4.768 | 9.972 | -0.678 | -8.282 | -3.562 |
| | (5.192) | (9.231) | (9.690) | (6.526) | (10.59) |
| Peak Season × downpour in trimester 1 | 25.60** | 1.761 | 37.86 | 42.40*** | -7.732 |
| | (10.10) | (13.35) | (32.45) | (14.11) | (13.74) |
| Peak Season × downpour in trimester 2 | -17.67 | -17.89 | -118.4*** | -24.84 | -151.2* |
| | (14.47) | (11.94) | (30.23) | (23.13) | (78.88) |
| Peak Season × downpour in trimester 3 | -30.97*** | -25.80** | -46.90*** | -26.55*** | -15.49 |
| | (7.697) | (9.947) | (12.77) | (6.884) | (11.74) |
| Inverse Mills Ratio | -256.8*** | -395.3*** | -321.2*** | -209.8*** | -3,297*** |
| | (14.45) | (26.61) | (38.06) | (17.79) | (497.8) |
| Year & Month FE | Yes | Yes | Yes | Yes | Yes |
| Clustered at Univ. | Yes | Yes | Yes | Yes | Yes |
| Obs. | 2.46M | 542k | 338k | 1.36M | 221k |
| R-squared | 0.286 | 0.280 | 0.271 | 0.296 | 0.277 |

In steppe regions, where peak agricultural activity occurs during winter and spring, the timing of rainfall fluctuations significantly affects birthweight outcomes. For babies conceived during these peak seasons, drought conditions in the first trimester are associated with reduced maternal workload, which may lead to an increase in birthweight. Conversely, droughts in the second trimester result in hot, unpleasant weather, which likely contributes to a decrease in birthweight. Furthermore, downpours during the third trimester indicate increased agricultural output and maternal labor, leading to reduced birthweights for babies born in these regions. It is important to note that the presence of multiple climates within major provinces, such as Fars and Khuzestan, may introduce some limitations to the overall coefficient estimates due to potential low resolution. In arid regions, where peak agricultural seasons occur in spring and fall, droughts during the second trimester for babies conceived during these seasons result in unfavorable dry conditions, potentially reducing agricultural output and lowering birthweight by approximately 17.27 grams. On the other hand, downpours during the second and third trimesters increase maternal workload, further contributing to reductions in birthweight. These effects are substantial, with birthweight decreasing by -118.4 grams and -46.9 grams, respectively—much larger than findings from previous studies or other climates. Saffron, the primary agricultural output in arid regions, relies heavily on female labor. As a result, favorable weather conditions increase workloads for women, leading to lower birthweights for their babies.

In humid subtropical and Mediterranean climates, spring and summer represent the peak agricultural activity seasons for women. Similar to arid regions, the coefficient for downpours during the second trimester is approximately -115 grams (3.5% of the average birthweight), a result that is both statistically and economically significant. In the humid regions along the Caspian Sea, rice is the primary agricultural output and is traditionally cultivated by women. Therefore, favorable weather conditions increase their workload, which is associated with lower birthweights for their babies.

In Mediterranean regions, downpours during the first trimester indicate favorable summer weather, leading to an increase in birthweight by approximately 42.40 grams. However, downpours in the third trimester signal an increase in workload, resulting in a reduction in birthweight by roughly 27 grams. The overall impact in this region is relatively modest, as most of Iran’s developed cities are situated in Mediterranean areas, where the economy is primarily driven by industry rather than agriculture.

The effects of downpours and droughts on birthweight in Iran are asymmetrical. Unlike many other contexts, Iranian babies appear to be more vulnerable to downpours than to droughts. This can be attributed to two primary reasons. First, most agricultural activities in Iran rely on wells and underground water sources, meaning that during droughts, farmers can mitigate losses by accessing these water reserves. Second, farmers in Iran are publicly insured against crop losses due to droughts, which provides a financial safety net and helps maintain household stability. However, Iranian agriculture remains predominantly traditional and labor-intensive, involving the active participation of all family members, including pregnant women. During periods of favorable weather and abundant harvests, the entire family, including expectant mothers, must contribute to the increased workload. This additional physical strain and labor demands during downpours may adversely affect maternal health, which, in turn, could negatively impact newborn birthweight.

The synchrony of agricultural peak seasons with pregnancy trimesters significantly influences the magnitude and significance of coefficients when estimating the impact of rainfall fluctuations on infant health. Table 6 illustrates two approaches: column one presents the conventional OLS regression estimating the impact of rainfall fluctuation on birthweight while controlling for related variables, while column two also incorporates the timing of conception, specifically during peak agricultural seasons. The first column suggests that an increase of more than one standard deviation in rainfall during the first trimester of pregnancy, compared to historical averages, generally reduces birthweight. However, the second column reveals a contrasting dynamic for babies conceived during peak agricultural seasons. Mothers conceiving in these peak seasons might face adverse effects from downpours in the first trimester due to reduced agricultural output and income. Conversely, they could benefit from lighter workloads and more favorable weather conditions.

**Table 6– Comparison between primary model that does not take agricultural activity in to consideration and second model that enters interaction of peak season with rainfall fluctuations in each stage of pregnancy.**

| VARIABLES | (1)<br>Primary Model | (2)<br>Interaction |
|---|---|---|
| drought in trimester 1 | 17.49*** | 23.89*** |
| | (5.587) | (7.470) |
| drought in trimester 2 | 22.70*** | 25.95*** |
| | (5.297) | (4.579) |
| drought in trimester 3 | 23.75*** | 17.65** |
| | (5.138) | (7.071) |
| Peak Season × drought in trimester 1 | | -10.56 |
| | | (11.05) |
| Peak Season × drought in trimester 2 | | -5.857 |
| | | (6.331) |
| Peak Season × drought in trimester 3 | | 7.250 |
| | | (10.62) |
| downpour in trimester 1 | -15.25** | -34.66*** |
| | (7.182) | (11.89) |
| downpour in trimester 2 | -3.367 | 1.983 |
| | (8.613) | (9.684) |
| downpour in trimester 3 | -4.011 | 8.346* |
| | (4.973) | (4.714) |
| Peak Season × downpour in trimester 1 | | 31.13** |
| | | (14.75) |
| Peak Season × downpour in trimester 2 | | -24.47 |
| | | (19.40) |
| Peak Season × downpour in trimester 3 | | -30.21*** |
| | | (9.643) |
| Observations | 2,461,663 | 2,461,663 |
| R-squared | 0.281 | 0.281 |

Our hypothesis regarding the existence of sample selection bias is not rejected. Table 5 shows that the estimated coefficient for the inverse Mills ratio is large; however, applying the two-step Heckman procedure results in minimal differences in the desired coefficients, if any. This suggests that our primary channel of study does not significantly influence the selection sample when compared to other factors such as the mother's age, education, and number of previous deliveries. Consistent with global trends, Iran has witnessed a decline in fertility rates, with families having fewer than two children on average. Furthermore, Iran’s economy is not predominantly agriculture-dependent, making it unsurprising that other factors play a more significant role in mothers' decisions to have children.

Table 7, columns 1 and 2, presents the coefficient estimates for the variables used in both steps of the two-step Heckman model, comparing OLS and the two-step Heckman model for all observations. While the coefficients for rainfall fluctuations remain largely consistent between the models, there are notable differences in the coefficients for mothers' personal variables, such as the number of deliveries, mother's age, squared age, and college education. Once we control for sample selection, the mother's age no longer significantly influences the baby’s birthweight. However, the mother’s education and the number of previous deliveries become much more influential on infant health. Specifically, the effect of education increases by 25%, underscoring its policy implications.

Additionally, region-related variables provide insightful findings. Agricultural income appears to serve as an important supplementary income source for Iranian households, contributing to higher family income and assets, which, in turn, increases baby birthweight. The average income of counties, along with the insignificant coefficient for rural areas, suggests that family patterns regarding the number of children are relatively consistent among Iranian households.

**Table 7- Impact of other selection channels and their strength and significance**

| Two-Step Heckman Birthweight (gr)<br>VARIABLES | (1)<br>OLS | (2)<br>Heckman |
|---|---|---|
| Number Delivered | 40.12*** | 88.75*** |
| | (2.695) | (4.067) |
| Mother's Age | 15.13*** | 2.260 |
| | (1.609) | (1.579) |
| Mother Age Squared | -0.246*** | -0.00966 |
| | (0.0238) | (0.0247) |
| College Graduated Mother | 20.10*** | 25.91*** |
| | (3.912) | (4.297) |
| Rural | 16.02 | 15.79 |
| | (31.19) | (31.24) |
| Agricultural Employment Dependence | -0.904 | -0.951 |
| | (0.760) | (0.760) |
| Agricultural Income Share | 2.126*** | 2.319*** |
| | (0.613) | (0.612) |
| Average County Income | 965.0** | 966.0** |
| | (397.2) | (390.5) |
| Observations | 2,461,663 | 2,461,663 |
| R-squared | 0.281 | 0.282 |

As a robustness check for our results, we also conducted a panel regression using data from 26,427 mothers who gave birth in two consecutive years. While there are some differences in the significance of the coefficients between the panel regressions and the estimates from the Heckman model, the signs and magnitudes of the coefficients remain consistent across both models. This consistency further strengthens the reliability of our findings. The detailed results of the panel regression are presented in Table 8.

**Table 8 – Panel model results to estimate the impact of rainfall fluctuations on birthweight**

| Panel Regression of Birthweight (gr) VARIABLES | (1) All Observations | (2) Steppe | (3) Arid | (4) Mediterranean | (5) Humid Subtropical |
|---|---|---|---|---|---|
| Peak Season × drought in trimester 1 | -39.47*** | 72.06** | -14.95 | -63.11*** | -75.29* |
| | (12.53) | (30.07) | (43.24) | (16.57) | (42.24) |
| Peak Season × drought in trimester 2 | -6.725 | 12.03 | -42.12 | -8.095 | 29.53 |
| | (9.654) | (21.85) | (27.60) | (14.05) | (35.13) |
| Peak Season × drought in trimester 3 | 23.61 | 65.76 | -55.22 | 29.98 | 37.96 |
| | (18.73) | (56.63) | (87.18) | (24.48) | (68.35) |
| Peak Season × downpour in trimester 1 | 10.81 | -8.166 | 72.36 | 40.35** | -22.65 |
| | (12.46) | (20.76) | (65.29) | (19.98) | (60.47) |
| Peak Season × downpour in trimester 2 | -41.82* | -2.215 | -- | -79.85*** | -- |
| | (21.49) | (32.58) | | (30.00) | |
| Peak Season × downpour in trimester 3 | -37.57*** | -29.76 | -78.57** | -43.40*** | -30.12 |
| | (10.79) | (18.86) | (34.37) | (15.93) | (43.59) |
| Observations | 40,538 | 11,399 | 5,156 | 20,916 | 3,067 |
| Number of MotherID | 26,731 | 7,545 | 3,477 | 13,995 | 2,072 |

# Conclusion

This study has examined the relationship between rainfall fluctuations, pregnancy timing, and birth outcomes in Iran using a rich monthly panel dataset of women of childbearing age from diverse climatic and agricultural regions. The dataset integrates detailed birth records, maternal demographic characteristics, regional agricultural activity calendars and rainfall data, enabling an analysis of how weather variability before and during pregnancy shapes newborn health. By segmenting rainfall exposure into specific preconception and trimester intervals, and combining this with regional climate classifications and agricultural seasonality patterns, we were able to capture both temporal and spatial heterogeneity in the effects of weather on birthweight.

A central challenge in this context is the endogenous nature of pregnancy decisions, which may be influenced by anticipated agricultural labor demands or economic conditions linked to rainfall.

To address potential selection bias, we employed a two-step Heckman model, using rainfall fluctuations before conception as a factor affecting the decision to conceive but not directly influencing birthweight. This approach allowed us to estimate the net impact of rainfall shocks during different stages of pregnancy while accounting for the non-random timing of conception.

Our results reveal three key patterns. First, the effects of rainfall shocks are trimester-specific and vary across climatic zones, highlighting the importance of timing in weather and health linkages. Second, the impacts of downpour and drought are asymmetric. Downpours tend to reduce birthweight more substantially than droughts. This asymmetry may reflect Iran's reliance on underground water sources and public insurance schemes, which buffer households against drought impacts, whereas heavy rainfall increases agricultural labor intensity and involves pregnant women in physically demanding tasks, ultimately impairing fetal growth. Third, while rainfall variability influences pregnancy timing to some extent, socioeconomic factors such as maternal education, age, and parity remain stronger determinants of conception decisions.

These findings carry important policy implications. While downpours currently pose the most immediate risk to birth outcomes, Iran has also been experiencing persistent droughts and declining well water levels. Recent changes in climate and episodes of extreme drought could make water scarcity a severe threat in the near future. It is therefore critical to implement policies that protect maternal and child health under both drought and downpour conditions. Targeted health programs, particularly in agricultural areas during labor-intensive periods, could help mitigate the adverse effects of these climate extremes on birth outcomes. Protecting infant health is not only essential for immediate wellbeing but also supports long term development, as neonatal health influences future educational attainment, productivity, and economic participation.

By providing evidence from a context that combines rainfall stress with agricultural dependence, our study contributes to the understanding of how environmental factors influence maternal and neonatal health in developing economies. The results underscore the need to integrate maternal health protection into climate adaptation strategies, ensuring that rising drought and water scarcity do not exacerbate health inequalities or hinder human capital formation.

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