Fetal Origins of Mental Health: Evidence from Natural Disaster in Taiwan*

Yu-Ting Huang[1], Elaine M. Liu[2], Jin-Tan Liu[3], Tzu-Yin Hazel Tseng[4], and [2]

[1]Georgia State University
[2]Georgia State University and NBER
[3]National Taiwan University and NBER
[4]Amazon

January 2026

Abstract

This paper examines the impact of poor *in utero* environment caused by severe typhoons on psychological well-being later in life. Exploiting time and geographical variation, we compare the mental health of individuals with higher expected in utero exposure to severe typhoons while *in utero* in landfall counties to those who had no fetal exposure to severe typhoons. We find a one-unit increase in expected *in utero* exposure to severe typhoons in landfall counties increases the likelihood of an adult mental illness diagnosis by 2.2 percentage points, 11% relative to the mean. The incidence of mood disorder (e.g. depression) and the use of antidepressant increased by more than 50%. The effects are more prominent for women.

*We thank Achyuta Adhvaryu, Richard Akresh, Alan Barreca, Prashant Bharadwaj, Hoyt Bleakley, Aimee Chin, Pinka Chatterji, Dennis Epple, Rachel Heath, Chinhui Juhn, Erzo Luttmer, Hani Mansour, Giulia La Mattina, Hitoshi Shigeoka, Hannes Schwandt, and David Simon, and conference participants at SOLE, PAA, and SEA for helpful conversation and comments. All errors and omissions are our own. This paper was previously circulated under the title "The Hidden Costs of Natural Disasters: In Utero Environment and Mental Health in Adulthood". JEL Classification: I12, I15, I19, I31, N35. Keywords: mental health, fetal origins, natural disasters.

1 Introduction

Mental illness affects hundreds of millions of people worldwide. The estimated loss in global output associated with mental health conditions is projected to reach $6 trillion by 2030 (Health 2020). In the US, more than 20 percent of adults live with mental illness (Abuse et al. 2022). Mental well-being is shaped by multiple dimensions, including individual characteristics, socioeconomic circumstances, and environmental factors (WHO 2012). Earlier studies document negative contemporaneous effects of adverse events on psychological well-being, such as natural disasters (Shoaf et al. 2004; Edwards et al. 2015), war and terrorist attacks (Schlenger et al. 2002; Galea et al. 2003; Brattia et al. 2014), and recessions and job loss (Kuhn et al. 2009; McInerney et al. 2013; Bradford and Lastrapes 2014; Currie and Tekin 2015).

More recent medical literature proposes the "Neurodevelopmental Hypothesis," which argues that poor fetal environments can damage neural development and increase the risk of mental illness later in life (Bennet and Gunn 2006).[1] Recent medical and economic research emphasizes the fetal origins hypothesis, which posits that adverse conditions during critical periods of prenatal development can have persistent effects on later-life health and human capital (Almond and Currie, 2011b; Aizer and Currie, 2014). Within this framework, the neurodevelopmental hypothesis represents one important biological channel. Poor *in utero* environments, such as maternal stress, inflammation, or nutritional deprivation, may impair fetal brain development and increase the risk of mental illness later in life (Phillips, 2007b; Schlotz and Phillips, 2009).

The objective of this study is to examine whether poor *in utero* environments induced by severe typhoons affect mental health later in life, consistent with the neurodevelopmental and broader fetal origins frameworks. We exploit temporal and geographic variation to study the impact of *in utero* exposure to severe typhoons in Taiwan on the incidence of mental disorders, psychiatric drug use, and psychiatric-related healthcare utilization in adulthood. Although Taiwan is hit by typhoons every summer, most cause limited damage. We therefore focus on severe typhoons, defined as those causing more than 50 deaths, which occurred five times between 1958 and 1970. The infrequent occurrence of severe typhoons allows us to compare individuals who were *in utero* during these events to those who were not,

[1] The hypothesized mechanism operates through elevated activity in maternal neuroendocrine systems (Phillips 2007a). Clinical studies show that fetal exposure to higher levels of maternal cortisol and prenatal stress is associated with increased social and affective problems and lower cognitive development (Huizink et al. 2003; DiPietro et al. 2006; Buss et al. 2012a). For a review of the medical literature, see Schlotz and Phillips (2009).

while controlling for seasonality of birth. In addition, typhoons cause the most damage at landfall and weaken rapidly inland, allowing us to compare landfall (high-intensity) regions to non-landfall (lower-intensity) regions. Because the timing and landfall location of severe typhoons are largely unpredictable, they are plausibly exogenous to fertility timing and location choices.

Severe typhoons can worsen the prenatal environment through several channels, including maternal stress, nutritional disruptions, reduced access to healthcare, sanitation shocks, and household income losses. These channels should be interpreted as contributors to a poor *in utero* environment that plausibly operates through fetal neurodevelopment and related biological programming, rather than as competing mechanisms. Our empirical strategy therefore identifies the reduced-form effect of poor in utero environments induced by severe typhoons, rather than isolating a single biological mechanism.

Understanding the long-term effects of severe typhoons is particularly important in the context of climate change. Rising global temperatures contribute to warmer ocean waters, which fuel stronger and more destructive typhoons. As extreme weather events become more frequent and intense, it is increasingly important to study their long-term consequences, not only for immediate destruction but also for public health, economic stability, and social well-being. The mental health effects of severe typhoons, especially when exposure occurs during critical developmental periods, highlight the broader implications of climate-related disasters.

Several recent empirical studies examine whether adult mental health outcomes can be traced to *in utero* conditions (Almond and Mazumder 2011; Class et al. 2013; Abel et al. 2014; Adhvaryu et al. 2014; Persson and Rossin-Slater Forthcoming; Adhvaryu et al. 2015; Dinkelman 2015; Maclean et al. 2016). Most rely on self-reported survey measures of mental health (Almond and Mazumder, 2011; Adhvaryu et al., 2014, 2015; Dinkelman, 2015; Maclean et al., 2016). As noted by Bharadwaj et al. (2015), survey-based measures of mental disorders suffer from substantial underreporting, potentially biasing estimates. Another set of papers uses psychiatric hospital admissions as outcomes (Os and Selten 1998; Watson et al. 1999; Class et al. 2013; Abel et al. 2014). However, as we show later, only 0.7% of the population has ever been hospitalized for psychiatric conditions, despite nearly 20% having received a mental health diagnosis. These studies therefore capture only the most severe cases.

Other work uses prescription data to identify mental illness (Persson and Rossin-Slater Forthcoming). However, off-label use of psychiatric drugs is common (Radley et al., 2006; Chen et al., 2006; Chien et al., 2007; Wittich et al., 2012). For example, antipsychotics may

be prescribed for dementia (Leslie et al. 2009) and Alzheimer's medications for psychiatric conditions (Zdanys and Tampi 2008). Moreover, many psychiatric visits do not result in prescriptions. In our data, nearly 20% of individuals with mental-disorder-related visits were never prescribed psychiatric drugs. Prescription data without diagnostic codes may therefore misidentify mental illness.

Taiwan offers several advantages for studying these questions. First, we use comprehensive health insurance claims data covering all inpatient, outpatient, and prescription drug use for a 5% population sample (approximately one million individuals). These records include detailed diagnostic codes and prescriptions for each visit between 1998 and 2002. Combining inpatient, outpatient, and prescription data reduces concerns about misreporting relative to existing studies. Second, stigma surrounding psychiatric care is well documented, even in Western countries (Barney et al., 2006; Schomerus et al., 2009). Although psychiatric visits are uncommon in Taiwan, we observe psychiatric-related care provided by all physicians. In our sample, 25% of antidepressants were prescribed by non-psychiatrists, primarily in family and internal medicine, mitigating concerns about underreporting. Third, we study a wide range of mental illnesses, from anxiety and personality disorders (affecting about 15% of the population) to schizophrenia (affecting less than 1%). The data also capture the full severity spectrum, from outpatient visits to long-term psychiatric hospitalization. Finally, Taiwan's universal health insurance covers over 96% of the population, with very low copayments, reducing concerns about selection driven by healthcare affordability.[2]

The main limitation of our data is that we observe individuals' current county of residence but not their county of birth. If individuals migrate between birth and adulthood, prenatal exposure may be mismeasured. To address this concern, we combine our data with the 2000 Taiwan Census to characterize birth–residence migration patterns by cohort and gender. We then construct migration-adjusted measures of prenatal exposure, defined as the expected probability of *in utero* exposure to severe typhoons in landfall and non-landfall counties conditional on current residence. We discuss this procedure in detail in Section 3.2.1.

A one-unit increase in expected *in utero* exposure to severe typhoons in landfall counties is associated with a 2.2 percentage point increase in the likelihood of being diagnosed with a mental illness in adulthood. Relative to a baseline prevalence of approximately 20 percent, this corresponds to an increase of about 11 percent. In contrast, expected exposure in

[2]Taiwan's National Health Insurance coverage is universal and not conditional on employment or health status. Therefore, psychiatric diagnoses and treatments appear in claims regardless of provider type, reducing concerns about systematic underrepresentation. Any remaining underutilization due to stigma would likely bias estimates toward zero.

non-landfall counties is small and statistically insignificant.[3]

We analyze anxiety and personality disorders, mood disorders, and schizophrenia.[4] Mood disorders increase by 2.1 percentage points associated with a one-unit increase in expected prenatal exposure in landfall counties (mean 3.9 percentage points; 53% increase). Antidepressant use increases by 60% (mean 5 percentage points). Higher expected exposure is also associated with more psychiatric outpatient visits and higher psychiatric expenditures. We find no statistically significant effects on inpatient admissions, likely due to limited power. Adverse effects are concentrated among women. We cannot rule out roles for gender differences in healthcare-seeking, biological responses, or parental son preference and postnatal investment.

Results are robust to alternative definitions of typhoon severity, subsample restrictions, region-by-cohort fixed effects, placebo tests, and event study specifications. Event studies show the largest effects for *in utero* exposure relative to exposure in early childhood.

Even with migration-adjusted exposure, selective migration may remain a concern if migration correlates with unobserved determinants of mental health. We therefore focus on rural residents as a conservative baseline, where mobility is lower. Using census data, we confirm that 77% of rural residents live in their birth county. We further restrict to low-migration areas, exploit event-study designs, and directly test migration responses in the census. We find no evidence that migration patterns differ systematically by severe typhoon exposure.

This study contributes to the literature on the long-term effects of poor *in utero* environments (Almond and Currie 2011a; Currie and Vogl 2013; Aizer and Currie 2014). While prior work focuses on physical health and human capital, evidence on adult mental health remains limited due to data constraints. We provide causal evidence that adverse prenatal environments have persistent effects on mental health in adulthood.

The paper is organized as follows. Section 2 describes the background, the newly constructed severe typhoon dataset and the health insurance claim records. Section 3 outlines the empirical strategy, and section 4 presents the results. Section 5 discusses the mechanisms and selective migration issues, and Section 6 concludes.

[3]Expected exposure measures range from zero to one and reflect the probability of true prenatal exposure conditional on residence and demographics.

[4]Following Kessler et al. (2005), anxiety, mood, and impulse-control disorders are among the most common mental disorders. Anxiety and personality disorders are grouped because diagnostic codes prior to 2000 did not distinguish them.

2 Background and Data

2.1 Background and Context

Taiwan is particularly well suited for studying the impacts of severe typhoons due to its geographic location and repeated exposure to extreme weather events. Taiwan is a mountainous island located along the main typhoon track in East Asia and experiences multiple typhoons each year, primarily between June and October. While most typhoons result in limited damage, a small number of severe events cause substantial destruction through extreme rainfall, flooding, landslides, and infrastructure damage, with impacts concentrated in counties where typhoons make landfall.

Several features of Taiwan's physical environment amplify the local severity of these shocks. Steep terrain increases the risk of landslides and flash floods, while high population density in coastal and low-lying areas raises exposure to housing damage and disruptions to basic services. At the same time, the Central Mountain Range substantially reduces wind speed as typhoons move across the island, generating sharp spatial gradients in damage intensity across counties. As a result, severe typhoons produce highly localized and geographically heterogeneous shocks.

Importantly for identification, during the study period (1958–1970), typhoon timing and landfall locations were largely unpredictable at the monthly scale relevant for fertility decisions. Although basic storm warnings existed, forecasting technology at the time provided limited advance notice and did not allow households to anticipate the exact timing, path, or severity of typhoons several months in advance. Consequently, severe typhoon exposure during specific gestational periods was plausibly orthogonal to childbirth timing and residential location choices.

During this period, severe typhoons often disrupted agricultural production through crop losses, damaged local transportation networks, and temporarily interrupted access to healthcare, clean water, and sanitation services. These disruptions plausibly translated into adverse prenatal conditions through multiple channels, including short-term food insecurity, income losses among agricultural and informal-sector households, and heightened psychological stress following property damage and community disruption. While large-scale permanent displacement was uncommon, temporary displacement and localized disruption were frequent in affected areas, particularly following flooding and landslides.

We provide a map in Figure 1 illustrating Taiwan's terrain and the locations of severe typhoon landfalls. Together, these geographic and institutional features generate plausibly

exogenous, spatially concentrated disruptions that are well suited for identifying the effects of prenatal exposure to extreme weather events.

2.2 Typhoon severity dataset

In general, a typhoon causes more damage when it first makes landfall, after which its structure weakens quickly. Therefore, having detailed data on each typhoon event is extremely crucial since it allows us to separate extreme typhoon events from regular ones, and also to identify high-intensity (landfall) regions from low-intensity (non-landfall) regions. The historical typhoon data used in this study is drawn from the Typhoon Database of the Central Weather Bureau and the 2014 Annual Disaster Report from the National Fire Agency. For each typhoon event, we have information on the date, landfall county (or counties), death toll, and property damage at the national level.[5] The earliest year with detailed information is 1958. Even though the age of onset for most mental illnesses is the mid-twenties, there is often a delay between the onset and the first treatment (Kessler et al. 2007). Therefore, we focus on individuals who were born between 1959 and 1970 to allow some time to elapse in the 1998-2002 insurance claim dataset. During the period of 1959 to 1970, there were 119 typhoons, and 41 result in deaths. Figure 2 depicts death tolls for typhoons during this period. Each solid dot/hollow dot/plus represents the death toll for one typhoon. If there is more than one typhoon in a given year-month, only the one with the most deaths is depicted on this figure. In this study, we focus on only the typhoons causing more than 50 deaths; hereafter, we refer to them as severe typhoons. These are marked as dots in the figure. The solid dot represents those typhoons that made landfall, while hollow dots represent those typhoons that did not make landfall. In our main analysis, since we use the comparison of landfall counties to non-landfall counties as a first difference, the individuals who are exposed to those four severe typhoons that did not make landfall are coded as exposed in non-landfall counties.[6] To confirm that the results are not sensitive to the definition of severe typhoons, we also use alternative definitions for severity such as the number of collapsed buildings or

[5] County is the finest level of geography that was provided for landfall. The reason why landfall township is missing because meteorological agencies define "landfall" based on the storm's center crossing the coastline and note that identifying the exact location is not always straightforward due to observational limitation (China Meteorological Administration, 2012). A typical eye of typhoon would be roughly 60km diameter, which often cover more than one county.

[6] As a robustness check, we use a specification that separates all three exposure statuses–the exposure to a severe typhoon in landfall counties, exposure to a severe typhoon in non-landfall counties, and the exposure to a non-landfall severe typhoon. The results of the latter two are not statistically different. Thus, we decide to combine these two exposure statuses for the sake of simplicity. The results are available upon request.

changing the cutoff for the death tolls in the robustness section.

2.3 Health Insurance Claim Records

The second dataset used in this study includes detailed health insurance claim records of a 5 percent Taiwanese population sample (approximately 1 million individuals) drawn in 2000. Universal health insurance in Taiwan was first introduced in 1995, and the coverage rate was more than 96% within two years of implementation. The dataset has limited information on individual characteristics (i.e., gender, birth date), but it contains all outpatient and inpatient visits and drug prescriptions that were covered by universal health insurance between 1998 and 2002 for these individuals. International Classification of Diseases (ICD-9) codes were used to identify the reasons for each medical visit. Mental illness is identified if physicians diagnosed a mental disorder including psychoses, organic psychotic conditions, other psychoses, neurotic disorders, personality disorders, and other non-psychotic mental disorders.[7]

Drug prescriptions record contains information about the dispensed product, including the compound name, quantity, mode of administration, and cost. Drugs are classified according to the hierarchical anatomic therapeutic chemical (ATC), which allows us to identify psychiatric drugs including antidepressants, antipsychotic, and anxiolytics. We code a patient as ever using psychiatric drugs if an ATC code of psychiatric drugs was recorded and the visit was psychiatric-related based on ICD-9 codes.[8]

In order to identify one's in utero exposure to a typhoon, we need information on one's place of birth. Unfortunately, the health insurance claim records do not contain the county of residence nor the county of birth for individuals. We first proxy the county of residence based on the county of each individual's most frequently visited outpatient hospital/clinic in 2000. However, county of residence might not be the same as county of birth if there is migration. Thus, to minimize the migration issue, we further restrict our sample to only those who currently reside in rural areas. The assumption here is that few people move into rural areas, so if we restrict our analysis to rural residents, we are less likely to misidentify their birth counties.[9] We verify our assumption using the 2000 census—77% of rural

[7]See Appendix A.1 for a list of ICD-9 codes of mental disorders and categorization of the mental disorders that are examined in this study.

[8]The ATC system classification system is published by the World Health Organization Collaboration Center for Drug Statistics Methodology. It is very difficult to identify off-label drug use from the claim records; therefore, we follow the ATC classification for the primary use of drugs. See Appendix A.2 for a list of ATC codes that were used to identify psychiatric and other drugs.

[9]The administrative level for rural areas is township *(shiang)* as opposed to urban areas, which is city

residents stayed in their birth county as opposed to half of urban residents are residing in their birth county. As a robustness check, we also restrict our analysis to residents from areas with low in-migration rates.

Table 1 presents the summary statistics at the individual level for the period between 1998 and 2002. Overall, one in five individuals had a visit related to any mental illness during this period. The prevalence rate is comparable to more developed countries such as the United States.[10] Despite a high prevalence rate, the average cost of psychiatric-related outpatient expenditures per person during these 5 years is only $61 (inflation adjusted to 2011 USD). This is a feature of Taiwan's single-payer health care system: total expenditure on health care is quite low compared to countries with multi-payer systems such as the United States. On average, individuals who were exposed to severe typhoons are slightly older because three out of five severe typhoons occurred in the first few years of the study periods. Those individuals who were exposed to severe typhoons while *in utero* and who were residing in landfall counties have the highest prevalence rates of mental disorders and highest usage of psychiatric drugs, followed by exposed individuals of non-landfall counties, with the unexposed individuals having the lowest prevalence rates. Differences in sex ratios are statistically detectable but economically small. Prenatal exposure to severe typhoons in landfall counties is also associated with more health care utilization and expenditures. However, these differences may be due to factors other than fetal exposure to severe typhoons, such as age differences. Differences in sex ratios are statistically detectable but economically small. Landfall-exposed cohorts display higher raw prevalence of mental illness, psychiatric drug use, and outpatient utilization; however, these descriptive differences do not adjust for cohort effects, geography, or migration and therefore serve only to motivate the regression analysis. All main specifications control flexibly for birth cohort, location, and migration-adjusted exposure, ensuring that baseline differences do not drive the estimated effects. In the next section, we will use regression analysis to estimate the causal effects of severe typhoons.

3 Empirical Strategy

The objective of this study is to estimate the long-term impacts of prenatal exposure to severe typhoons on mental health. In this section, we first present descriptive evidence of prenatal

(shi).

[10]The one-year prevalence rate of mental illness is 20% among U.S. adults in 2021 (Substance Abuse and Mental Health Services Administration 2022).

exposure to severe typhoons. In the second part, we discuss the empirical specification used to uncover the causal impacts of severe typhoons.

3.1 Descriptive Evidence

Figure 3 shows the prevalence of adult mental illness by year-month birth cohort and by *in utero* exposure to severe typhoon status. Prevalence of mental illness is aggregated to year-month of birth and separated by *in utero* exposure status. The dotted lines reflect the timing of severe typhoons. Immediately after the severe typhoon (the vertical dotted line), we see higher prevalent rates of mental illness among those who are in the landfall counties (solid dots). However, we do not observe this pattern in areas with no landfall (solid triangles), nor among those who never had *in utero* exposure to a severe typhoon (plus signs). Overall, the figure is suggestive of a relationship between prenatal exposure to severe typhoons and worse mental health.

3.2 Empirical Specification

In this study, we exploit two sources of variation, geographical variation of typhoon landfall location and the timing of severe typhoon, to examine the treatment effects of *in utero* exposure to severe typhoons on the likelihood of mental illness. This is not a standard difference-in-differences setup since the landfall location changes in every typhoon. Unlike the typical difference-in-differences set up, within the same county, the treatment status might turn on and off depending on the specific typhoon and when it was making landfall.

As nature tends to be smooth and the location/timing of severe typhoons is unexpected, any deviation from a smooth trend that is sharply timed after the typhoon's landfall and especially pronounced in counties hardest hit by the typhoon would be interpreted as a causal effect of the typhoon. Therefore the key parallel trend assumption of difference-in-differences is unlikely to be violated.

Specifically, we compare the mental health of individuals who were exposed to severe typhoons while *in utero* in landfall counties and non-landfall counties to those who had no fetal exposure to severe typhoons, respectively. Those individuals who were not exposed to severe typhoons while *in utero* are the comparison group, and this group consists of cohorts who were older and younger than those in the treatment groups.

3.2.1 Main Specification and Migration-Adjusted Exposure

We examine the likelihood of mental disorders and the use of psychiatric drugs as outcomes. For individual i born in year t and month m and residing in county c, our baseline specification is:

$$\begin{aligned} Y_{icmt} = \alpha &+ \beta_1 \, I(\text{In Utero Exposure to Severe Typhoon})_{mt} \times I(\text{Landfall County})_{cmt} \\ &+ \beta_2 \, I(\text{In Utero Exposure to Severe Typhoon})_{mt} \times I(\text{Non-landfall County})_{cmt} \\ &+ \delta \, Male_i + \omega_t + \zeta_m + \eta_c + \sum_c County_c \times BirthYear_t + u_{icmt}, \end{aligned} \tag{1}$$

where Y_{icmt} denotes indicators for diagnosed mental disorders or psychiatric drug use. We include county fixed effects (η_c), birth-year fixed effects (ω_t), and birth-month fixed effects (ζ_m) to control for time-invariant regional characteristics and common cohort-specific shocks. We additionally allow for county-specific linear birth cohort trends through $County_c \times BirthYear_t$ to flexibly account for differential evolution of mental health outcomes across areas.

$I(\text{In Utero Exposure to Severe Typhoon})_{mt}$ is an indicator equal to one if individual i was born within the first 252 days following the landfall of a severe typhoon.[11] $I(\text{Landfall County})_{cmt}$ and $I(\text{Non-landfall County})_{cmt}$ indicate whether county c is the typhoon's landfall county or a non-landfall county affected by the storm system.

The coefficients β_1 and β_2 are interpreted as the total effects of severe typhoon exposure in landfall and non-landfall counties, respectively, relative to individuals with no in utero exposure. Standard errors are clustered at the county level to allow for arbitrary within-county correlation.

Adjusting for Migration Using Birth–Residence Transition Weights. A key limitation of our data is that we do not directly observe individuals' county of birth. Instead, prenatal exposure is assigned based on county of residence observed in adulthood. If individuals migrate across counties between birth and adulthood, this induces measurement error in exposure assignment. Moreover, if migration is selective with respect to mental health or correlated with in utero exposure to severe typhoons, this misclassification may generate

[11] It is possible that gestational length may have changed as a result of typhoon-related stress or adverse *in utero* conditions. However, prior work (Liu et al. (2015); Torche (2011)) finds that the impact of environmental shocks on gestational length is extremely small (on the order of 0.07–0.1 weeks). As a result, any misclassification of the *in utero* window is likely to be limited. We also verify robustness to alternative exposure windows of 8 and 10 months.

bias rather than simple attenuation.

To address this concern, we implement a correction following the approach of Card and Krueger (1992), which accounts for exposure misclassification arising from migration by integrating over the distribution of likely birth counties conditional on current residence. Using the 2000 Taiwan Census, which reports both county of birth and current county of residence, we construct a birth–residence transition matrix separately by gender and age group. For each current county of residence, this matrix provides the empirical distribution of counties of birth among individuals with similar demographic characteristics.

Let $p_{j|csa}$ denote the probability that an individual with sex s and age cohort a currently residing in county c was born in county j, as estimated from the census. We use this matrix to construct migration-adjusted expected exposure measures that integrate over the set of possible birth counties. Specifically, for each individual born in year t and month m, we define expected landfall and non-landfall exposure as:

$$\begin{aligned} \widetilde{Landfall Exposure}_{icmt} &= \sum_j p_{j|csa} \cdot I(\text{In Utero Exposure to Severe Typhoon in } j)_{mt} \\ &\quad \times I(\text{Landfall County})_{jmt}, \\ \widetilde{Nonlandfall Exposure}_{icmt} &= \sum_j p_{j|csa} \cdot I(\text{In Utero Exposure to Severe Typhoon in } j)_{mt} \\ &\quad \times I(\text{Non-landfall County})_{jmt}. \end{aligned} \tag{2}$$

These migration-adjusted measures represent the expected probability of true in utero exposure to severe typhoons in landfall and non-landfall counties, conditional on current county of residence and demographic characteristics, rather than imposing the assumption that county of residence equals county of birth with probability one.

Our main specification therefore replaces the indicator-based measures in Equation 1 with these expected exposure variables:

$$\begin{aligned} Y_{icmt} = \alpha + \beta_1 \widetilde{Landfall Exposure}_{icmt} + \beta_2 \widetilde{Nonlandfall Exposure}_{icmt} \\ + \delta\, Male_i + \omega_t + \zeta_m + \eta_c + \sum_c County_c \times BirthYear_t + u_{icmt}. \end{aligned} \tag{3}$$

This procedure follows Card and Krueger (1992) in replacing mismeasured location-based exposure with its conditional expectation given observed residence. It directly adjusts for exposure misclassification induced by migration patterns and provides a more accurate mea-

sure of prenatal exposure. We use these migration-adjusted exposure measures as our main specification throughout the paper.

Finally, we propose two testable predictions. First, if adverse in utero environments worsen adult mental health, we expect $\beta_1 > 0$. Second, because typhoon-related damage and disruption are concentrated in landfall counties, we expect $\beta_1 - \beta_2 > 0$. The results will be shown in Table 2.

3.2.2 Special Considerations for Discrete and Continuous Outcomes (Number of Visits and Expenditures)

Estimates from Equation 3 would inform us whether *in utero* exposure to a severe typhoon could affect the prevalence of mental disorder at an extensive margin. We are also interested in examining the effect for other dimensions, such as the number of psychiatric-related medical visits and psychiatric-related expenditures as outcomes of interest.

The number of psychiatric-related medical visits is a count variable. It consists of non-negative integer values and are not normally distributed. For this type of data, more appropriate approaches to estimate the effects are the Poisson and negative binomial regression models.

On the other hand, psychiatric-related health care expenditures are highly right-skewed and also include a substantial fraction of zero observations. We therefore estimate treatment effects on expenditures using Poisson pseudo-maximum likelihood (PPML), which consistently estimates the conditional mean of the outcome under correct specification of the mean function and is robust to arbitrary patterns of heteroskedasticity. Unlike log transformation, PPML accommodates zero outcomes without requiring ad hoc adjustments and delivers a scale-invariant estimand that can be interpreted as the percentage change in mean expenditures. As emphasized by Chen and Roth (2024), this approach avoids the unit dependence and implicit weighting of extensive- and intensive-margin responses inherent in log-like transformations when outcomes include zeros. The results will be shown in Table 3.

3.2.3 Event Study (Timing of Exposure)

We employ event study specification to examine the impact of exposure to severe typhoons at various ages, specifically from two years before birth to two years after birth. By estimating age-specific effects of severe typhoon exposure, we can see whether the incidence of mental illness is more affected while *in utero*, and if the deviation from the smooth trend is indeed

sharply timed after the typhoon incident. The specification is as follows:

$$\begin{aligned} Y_{icmt} =& \alpha \\ &+ \sum_{x=-24}^{24} \beta_{1x} * \widetilde{LandfallExposure}_{icmt} \\ &+ \sum_{x=-24}^{24} \beta_{2x} * \widetilde{NonlandfallExposure}_{icmt} \\ &+ \delta * Male_i + \delta_t + \zeta_m + \eta_c + \sum_c County_c * BirthYear_t + u_{icmt} \end{aligned} \tag{4}$$

The estimate β_{1x} captures the change in mental illness associated with a one-unit increase in the expected probability of exposure to severe typhoons at age x, where x ranges from -24 to 24 months. The reference group consists of individuals with zero expected exposure to severe typhoons during the period from two years before birth to two years after birth. These individuals include birth cohorts that are older or younger than the treatment groups.

4 Results

4.1 Mental Illness and Use of Psychiatric Drugs

The regression results from Equation 3 are shown in Table 2. Panel A presents the results from diagnosis while Panel B presents the results for psychiatric drug use. A one-unit increase in expected in utero exposure to severe typhoons in landfall counties is associated with a 2.2 percentage point increase in the likelihood of being diagnosed with a mental illness in adulthood. Relative to a baseline prevalence of approximately 20 percent, this corresponds to an increase of about 11 percent. In contrast, the coefficient on expected exposure in non-landfall counties is small and statistically insignificant. For reference, Adhvaryu et al. (2014) find the likelihood of mental severe distress reduced by 3 percentage points (50% of the mean) resulting from a one standard deviation increase in cocoa price. Mental illness is a broad term that includes psychoses, organic psychotic conditions, other psychoses, neurotic disorders, personality disorders, and other non-psychotic mental disorders. In Columns 2-4 of Panel A, we break down mental illness into the three common mental disorders: anxiety and personality disorders, mood disorders, and schizophrenia. The results show an increase in the prevalence of anxiety and mood disorders, and schizophrenia increases by 0.5-2.1 percentage points as a result of one unit increase in expected prenatal exposure to a severe

typhoon.[12] Another interesting point worth noting is that β_1 and β_2 are statistically different from each other at 10% for most outcomes. The impacts of severe typhoons are much more pronounced for landfall counties relative to non-landfall counties, which also suggests that the main findings cannot simply be explained by unobserved secular changes between birth cohorts.

We further investigate the likelihood of psychiatric drug use in Panel B of Table 2. A one-unit increase in the expected probability of *in utero* exposure to severe typhoons is associated with increases of more than 3.1 percentage points (roughly an 60% increase) use of antidepressant. The magnitude is larger than the finding by Persson and Rossin-Slater (Forthcoming), who find a 0.7 percentage point increase (or 7-11% of the mean) in the use of anxiety and depression drugs resulting from prenatal bereavement. The impacts on use of anxiety and psychosis drugs are positive although the estimates are statistically insignificant.

Comparing magnitudes across disorders, mood disorders (which include depression) appear to be the most affected by adverse *in utero* conditions. Moving from zero to one in the expected probability of *in utero* exposure to severe typhoons is associated with increases of more than 50 percent in both mood disorder diagnoses and antidepressant use.

4.2 Psychiatric-Related Health Care Utilization and Expenditures

We have shown the effects of severe typhoons on the incidence of mental illness. It is of interest to see if *in utero* exposure to severe typhoons also increases psychiatric-related visits and associated medical expenditures. Columns 1 and 2 of Table 3 present the estimation results from Poisson and negative binomial regression models, investigating the number of psychiatric-related visits. Although the Poisson variance assumption is not supported by the data, the estimation results from Poisson and negative binomial regression models are similar. The results show that prenatal exposure to severe typhoons in a landfall county is likely to increase the number of psychiatric-related outpatient visits by 35% (=exp(0.30)-1). We present the results from estimating Poisson pseudo-maximum likelihood (PPML) in Columns 3 and 4 of Table 3. The results suggest that individuals who were exposed to severe typhoons in landfall counties would spend 36% (=exp(0.308)-1) more on total psychiatric-related outpatient care and 70% more on out-of-pocket psychiatric-related expenses.

[12] Papers in the medical/psychiatric literature also find similar results. For example, a paper by Khashan et al. (2008); Brown et al. (2000b) finds that maternal stress or maternal infection is associated with increased risk for schizophrenia; Brown and his coauthors in a series of papers find evidence for increased risk of mood disorder (Brown et al. (2000a, 1995)).

In regressions not shown here, we examine the impact on more serious psychiatric events—such as hospital admission for a psychiatric-related event, a hospital bed-day, or a psychiatric-related inpatient expenditure. While the coefficients are positive, they are not statistically significant. It is likely that we do not have enough statistical power since only 0.7% of the individuals included in this sample have ever been hospitalized in a psychiatric ward or facility. These results are presented in the web appendix.[13]

4.3 Heterogeneous Effects by Gender

We next examine whether the effects differ by gender. Table 4 presents estimates of Equation 3 separately for men and women. Overall, the results indicate that prenatal exposure to a severe typhoon has a larger impact on women across most outcomes. We further examine heterogeneity by trimester of exposure. Figure 4 shows that, for women, expected exposure during the second and third trimesters is associated with marginally worse outcomes than exposure during the first trimester. In contrast, for men, second-trimester exposure is associated with better outcomes, reflected in a lower likelihood of mental health treatment.[14]

This finding echoes earlier papers that also find a stronger impact on females for poor *in utero* conditions (Field et al., 2009; Maccini and Yang, 2009; Lavy et al., 2016). In Section 5.1, we discuss the potential mechanism for why the results are gender-specific in our context.

4.4 Timing of Exposure

Although this study focuses on the effects of a poor *in utero* environment, it is reasonable to ask whether exposure to severe typhoons at other stages of life also impacts mental health later on. Therefore, we will examine this question using an event study approach. Specifically, we compare individuals based on the timing of their exposure to severe typhoons.

Additionally, there is another reason for comparing coefficients within the event study framework. One limitation of our dataset is the absence of birthplace information, which raises concerns about endogenous migration. To address this, we compare individuals residing in the same landfall counties but exposed to the typhoon at different points in time.

[13]The null result on inpatient care is consistent with Abel et al. (2014)and Class et al. (2013), who also find little effects based on hospital admission data.

[14]Appendix Table A.1 shows evidence of culling among males exposed during the second trimester and among females exposed during the first trimester, consistent with positive selection among surviving males in the second trimester and surviving females in the first trimester. However, these differences are generally not statistically significant.

Since factors influencing migration are likely similar among families with children of slightly different ages, this comparison helps mitigate concerns about endogenous migration.

Lastly, we focus on women for two reasons. First, since our main findings are concentrated on women, we investigate the effects of exposure timing specifically within this group. Second, migration patterns, including its prevalence and underlying selection mechanisms, may differ significantly between men and women. For these reasons, we limit our analysis to women.

Since three out of five severe typhoons occurred in consecutive years of the earlier period, it would prevent us from clearly identifying one's timing exposure to severe typhoon. In this part of the analysis, we focus on women who were born between 1964 and 1970 to avoid overlapping of severe typhoon exposure at different ages. Figure 5 presents the estimation results of Equation 4. While the coefficients were not precisely estimated, the general pattern seems to indicate that those who had in utero exposure had more negative shocks (positive significant coefficients) than those who had early childhood exposure. We should remind the readers that the "neurodevelopment hypothesis" is about the fact that maternal cortisol and prenatal stress could affect fetal neurodevelopment. While early childhood exposure to a severe typhoon may also affect one's outcome, it would not be through the same channel as the *in utero* exposure. The comparison between early childhood exposure (0 to 24 months) to in utero exposure (-12 to 0 months) would also help address the concern regarding endogeneity migration. The selection in migration after typhoons would have worked similarly for those who had early childhood exposure and in utero exposure. Therefore, this pattern is difficult to reconcile with migration-based explanations alone. In sum, although exposure to a severe typhoon at age one has some positive yet statistically insignificant effects on mental illness, exposure in the fetal life has the most striking impacts.

4.5 Robustness of the Results

For the sake of simplicity, the rest of this section presents the robustness results only on the main outcome, the prevalence of mental illness, for female since there seem to be no significant impact on male. To see whether the baseline results are sensitive to the definition of severity, we use alternative proxies of severity of typhoons, and the results are presented in Table 5. Columns 2 and 3 of Table 5 consider different cutoffs of death tolls, and columns 4 and 5 use numbers of collapsed buildings. The number of severe typhoon incidents vary under each alternative measure, ranging from four to eight. In five official severe typhoon reports, one or more counties are identified as the most severely damaged. We use this information to

construct alternative exposure definitions as a robustness check. (Taiwan Provincial Weather Bureau, 1960, 1961, 1962, 1965, 1969). The results are robust to alternative definitions of severe exposure.

Further, Table 6 examines the effects on various subgroups to verify that the impacts are not due to different characteristics between exposed and unexposed birth cohorts. First, Taiwan is an island and it is unusual for typhoons to make landfall in the north and central regions due to its location. Thus, Column 2 excludes regions that did not experience landfall of a severe typhoon between 1958 and 1970. Second, Figure 2 shows that since most of the severe typhoons occurred in earlier years, it appears that those who were exposed to severe typhoons are older than those who are not affected by severe typhoons. In Column 3, we exclude individuals who were born after 1966 to confirm that the impacts are not resulting from a slightly older treatment group. Compared to the baseline results, the effect is larger. It could be the case that some mental illness has not been diagnosed yet among the younger cohorts; thus, the effect of a typhoon is not as pronounced. As mentioned in section 2, there were a few severe typhoons that did not make landfall. In baseline specification, individuals who were in utero during these non-landfall typhoons are being recorded as exposed to severe typhoon in non-landfall region. In column 4, we estimate the effect excluding those individuals. The estimation results remain comparable to the baseline.

We have discussed the downside of using the insurance claim dataset–we do not know one's birth location. We try to minimize migration issues in the baseline by restricting to people who live in rural areas and utilizing expected exposure to severe typhoons. To further reduce the migration issue, we restrict the sample to those residing in areas with little in-migration. We use the 2000 census to calculate in-migration rates based on the share of current residents that were born in the same county. We restrict our empirical analysis to those *counties* where in-migration rate is less than 20%. This reduces our sample size by more than half. The regression results are shown in Column 5. Column 6 of Table 6 includes region-by-year fixed effects to further control region-specific cohort differences in mental health outcomes. The results are consistent with the main results.

Lastly, as a placebo test and to address concerns over statistical inference in small number of clusters, we implement permutations tests. In the permutation test, the timing of severe typhoons and landfall counties are randomly drawn without replacement. For each permutation, the timing and landfall location of severe typhoons are randomly chosen. Individuals' prenatal exposures are then assigned accordingly.[15] We then estimate the effects of severe

[15]Permutation tests have been used recently in the following papers: Agarwal et al. (2015), Bloom et al.

typhoons based on placebo exposure status. Figure 6 displays the empirical distributions of the placebo treatment effects on outpatient psychiatric-related visits from 1,000 permutation tests. The fact that the distribution is centered at zero is comforting as these placebo tests are expected to find no impacts. When we compare the treatment effects that are based on actual exposure, the results indicate that less than 3% of the time permutation estimates are larger than the estimates of actual treatment. This result, based on permutation tests, reassures us that the effect of a severe typhoon is statistically significant.

5 Discussion

5.1 Mechanism and Gender Specific Finding

We consider several possible explanations for why estimated effects are larger for females.

Sex-specific fetal programming and neurodevelopment. The medical literature suggests that male and female fetuses can respond differently to adverse prenatal environments, including differences in stress regulation and neurodevelopment (Clifton, 2010; Bale, 2016). [16] Taken together, this literature provides a biologically plausible rationale for heterogeneous effects by gender, without implying a uniform direction of vulnerability across all outcomes.

Gender differences in healthcare-seeking behavior. Because our outcomes are based on healthcare utilization and diagnoses, rather than latent mental health status, differential healthcare-seeking behavior by gender may mechanically attenuate estimated effects. We examine this possibility by comparing outpatient and inpatient mental-health-related visits and expenditures by gender, as shown in Table A.2. We find that men are less likely to have outpatient psychiatric visits and less likely to be prescribed psychiatric medications. However, conditional on having an outpatient visit, men incur higher costs per visit and are more likely to have inpatient psychiatric admissions. This pattern suggests that men tend to delay seeking care until symptoms become more severe. As a result, differences in healthcare-seeking behavior may partially contribute to weaker measured effects for men, particularly for outpatient-based outcomes.

(2013), and Chetty et al. (2011).

[16] The medical evidence on sex-specific effects is mixed. Our finding of female-concentrated effects is consistent with studies such as Buss et al. (2012b) and Graham et al. (2019), while other work finds no sex-specific effects or effects concentrated among males (Sutherland and Brunwasser, 2018).

Selection: mortality and migration. We next assess two potential selection mechanisms. First, we examine mortality selection. If male fetuses (or male survivors) were more negatively selected following severe typhoon exposure, gender differences in adult mental health outcomes could arise mechanically. Our results do not support mortality selection as a primary explanation. Using cohort size and sex ratios from the 1980 Census, we find that exposure to severe typhoons do not significantly reduces cohort size. If anything, the reduction is slightly larger among females as indicated by an increase in male-to-female sex ratio (Table A.1). This pattern would bias estimates toward finding a smaller effects for female. Second, we examine selective migration by gender. We find no evidence that exposure to severe typhoons induces differential migration responses by gender that could explain the main results (see Appendix Table A.3).

Parental response and son preference In the context of son preference, if both male and female fetuses are adversely affected in utero, we might expect that parents' reinforcing parental responses could further disadvantage daughters and amplify gender differences observed later in life. Taken together, the evidence suggests that female-concentrated effects are unlikely to be driven by selective migration or mortality selection. Gender differences in healthcare-seeking behavior and medical literature on sex-specific fetal programming provide a biologically plausible interpretation for heterogeneous vulnerability by gender. Finally, we cannot rule out the role of parental responses to gender-specific endowments. Importantly, these explanations are not mutually exclusive: biological vulnerability may interact with gendered health-seeking behavior and parental responses, jointly amplifying female-specific effects observed in adulthood.

5.2 Selective Migration and Institutional Context

Our identification strategy assigns in utero exposure based on county of residence observed in adulthood. This raises the concern that internal migration could bias exposure measurement. Specifically, if healthier or wealthier individuals tend to migrate and only the less healthy ones stay in their birth counties, that can possibly bias our results. Earlier sections address this issue directly using migration-weighted exposure measures, explicit tests for selective migration, event study evidence, and a range of robustness checks. Here, we briefly summarize how these results, together with Taiwan's institutional and geographic context, inform the interpretation of our findings.

First, direct tests using census data show no evidence that in utero exposure to severe

typhoons predicts subsequent inter-county migration. We also find no differential migration responses by gender. Second, our event study specifications indicate that the effects are concentrated among individuals exposed *in utero*. At the same time, the main results are driven primarily by women, despite the absence of gender differences in migration patterns. Third, our findings are robust to excluding counties with high migration rates and to restricting the sample to eastern and southern regions.

These empirical patterns are consistent with Taiwan's institutional and geographic context. Most severe typhoons in our sample made landfall along the eastern coast. During the study period, eastern Taiwan was separated from the west and north by the Central Mountain Range, and major road and rail connections remained limited until substantial expansions after the 1980s. These constraints likely reduced short-run inter-county migration in response to typhoon shocks. Consistent with this, prior work documents historically low rates of internal migration in Taiwan, particularly in eastern regions and among older cohorts.

Taken together, while we cannot fully rule out measurement error arising from internal migration, and potential selective migration. However, the convergence of evidence across multiple empirical approaches, robustness checks, and institutional features suggests that selective migration is unlikely to be the primary driver of our main findings.

6 Conclusion

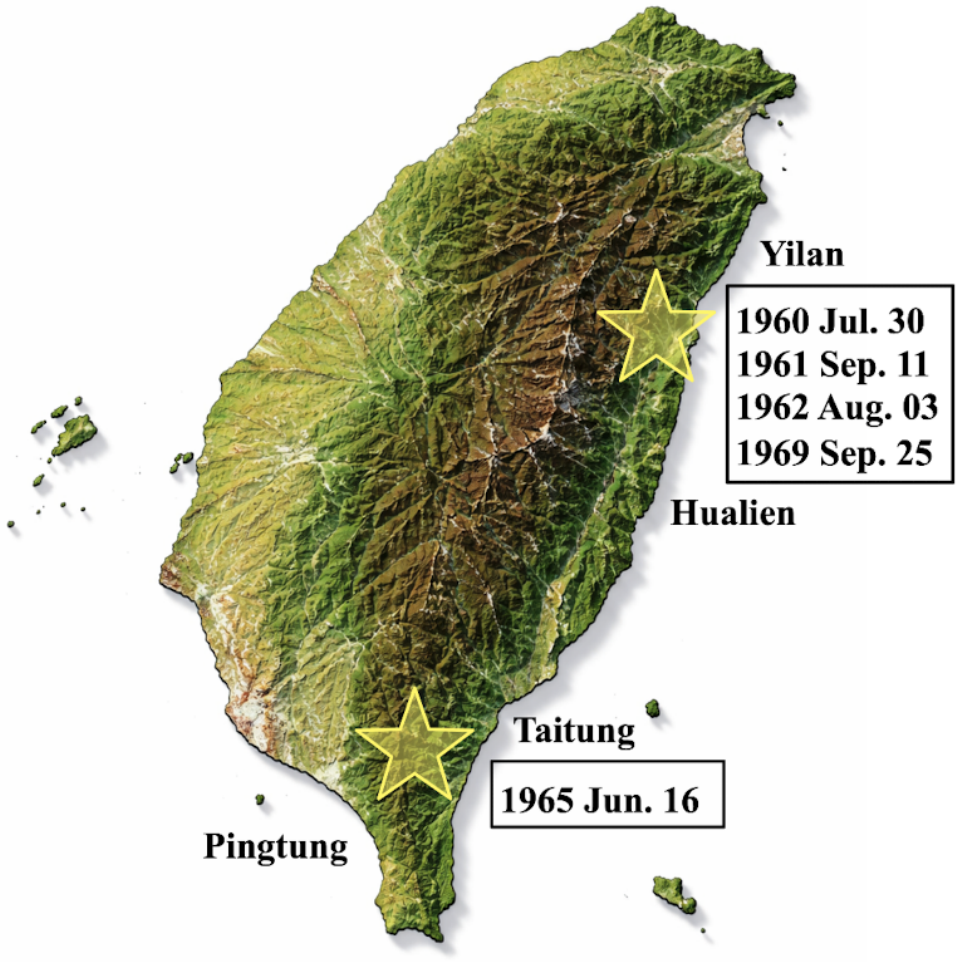
There is a large literature examining the long-term consequences of adverse *in utero* environments, with much of the existing work focusing on education, physical health, and labor market outcomes. This paper contributes to that literature by providing new evidence on the long-run mental health effects of poor prenatal environments. Using severe typhoons in Taiwan as plausibly exogenous shocks, we find that increases in expected *in utero* exposure to severe typhoons in landfall counties substantially raise the likelihood of mental illness in adulthood and lead to higher psychiatric-related health care utilization. These effects are considerably larger than those associated with exposure during the first few years of life, highlighting the particular importance of the prenatal period for mental health development. We also document pronounced gender differences: the adverse effects of prenatal exposure are concentrated among women, while effects for men are substantially smaller and often statistically insignificant. Taken together, our findings underscore the lasting mental health consequences of early-life environmental shocks and point to the importance of prena-

tal conditions as a key channel through which climate-related disasters may affect long-run population health.

In a regression not shown here, we also examine various physical health outcomes. Papers by Mazumder et al. (2010) and Lin and Liu (2014) find that poor prenatal environment causes cardiovascular/circulatory problems later in life. Given the health claim data available, we also look at the cardiovascular/circulatory problem. However, among the age group we examine (between age 28 and 43), the incidence of heart diseases and hypertension is extremely low. We find a small positive insignificant result, probably due to the lack of statistical power.

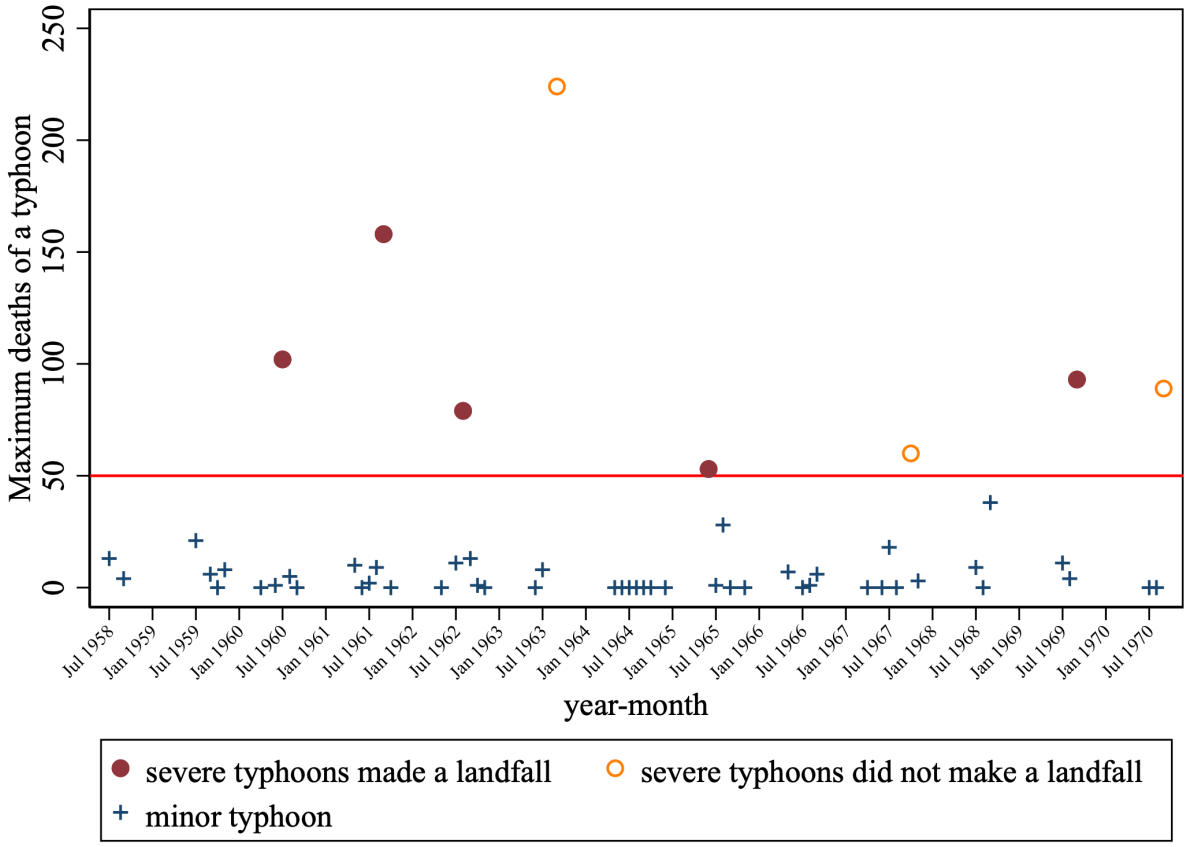
There are many possible reasons why in utero exposure to a severe typhoon can cause poor outcomes. A severe typhoon can lead to worse sanitation environment, lack of access to health care, household income shocks, worse parental health, maternal stress, and disruption of nutritional intake. These channels should be interpreted as contributors to a poor prenatal environment, which may affect later mental health in part through fetal neurodevelopment and related fetal programming. However, due to data limitation, we cannot further explore the specific channels, but it should be of interest for future research. The adverse mental health effects are concentrated among women. While we cannot attribute this pattern to a single mechanism, additional analyses suggest that it is unlikely to be driven by selective migration or mortality selection. Gender differences in healthcare-seeking behavior may contribute to attenuated estimates for men, and existing medical evidence on sex-specific fetal programming provides a biologically plausible interpretation for heterogeneous vulnerability. More broadly, our findings highlight that extreme weather events can generate lasting mental health consequences through prenatal pathways, underscoring the importance of considering early-life exposure in assessments of the long-run costs of climate-related shocks.

Figure 1: Map of typhoon landfalls and affected counties



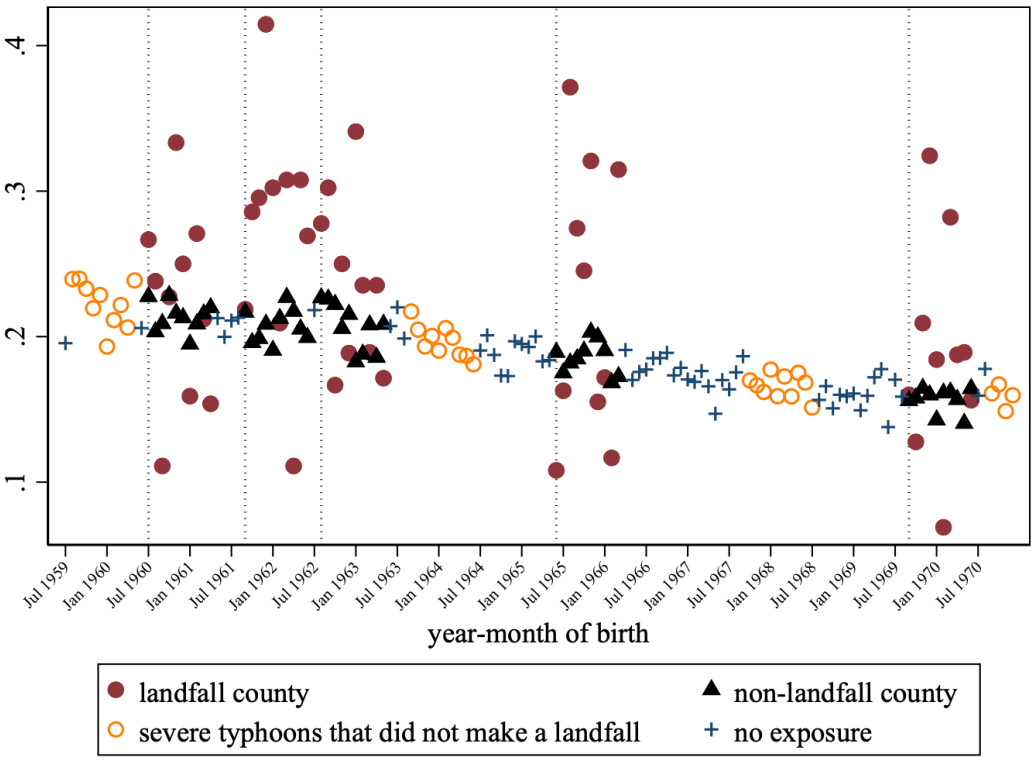
Notes: By Authors (2026). The sample includes only typhoons between 1959 and 1970 that made landfall and caused more than 50 deaths.

Figure 2: Death Tolls from Typhoons by Year-Month, 1958-1970



Notes: Data Source: The Typhoon Database of the Central Weather Bureau and the 2013 Annual Disaster Report from the National Fire Agency. Each point represents the number of deaths caused by a given typhoon at the national level. Solid circles indicate typhoons that made landfall and caused more than 50 deaths. Hollow circles show the typhoons that did not make landfall and caused more than 50 deaths. Pluses refer to the typhoons that caused fewer than 50 deaths. When there are multiple typhoons in a given year-month, only the typhoon that caused the most deaths is presented in this figure. In the main analysis, a severe typhoon is defined as one causing more than 50 deaths. Y-axis represents the deaths toll for a given typhoon. X-axis indicates year and month.

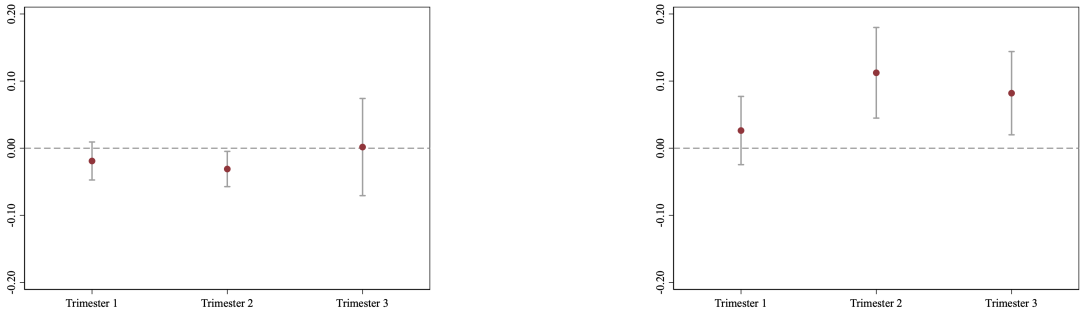
Figure 3: The Likelihood of Mental Illness by Intrauterine Exposure to Severe Typhoon



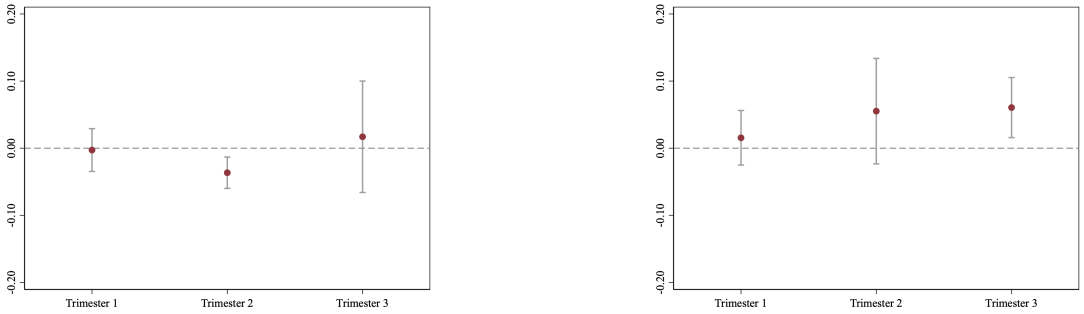
Notes: Data source: 5% Health Insurance Claim Records, 1998-2002. Mental illness is measured as ever been diagnosed with mental disorders based on ICD-9 codes (physician diagnosis). Likelihood of mental illness is aggregated to year-month of birth and *in utero* exposure to severe typhoons status. Severe typhoon is defined as a typhoon that caused 50 deaths. Each point represents a given birth cohort (at the year-month level) and its exposure to severe typhoon. The dotted lines show when severe typhoons made landfall. Solid circles refer to the cohorts that had fetal exposure to severe typhoons in landfall county. Triangles show the cohorts that had fetal exposure to severe typhoons in non-landfall county. Hollow circles indicate the cohorts that had fetal exposure to severe typhoons that did not make landfall. Pluses show the cohorts that had no fetal exposure to severe typhoons. Y-axis represents the share of mental illness for a given birth cohort. X-axis indicates year-month of birth.

Figure 4: Impact of Expected Exposure to Severe Typhoon on Mental Illness by Gender by Trimester of Exposure

(A) Ever been diagnosed with any mental: Male (Left) Female (Right)

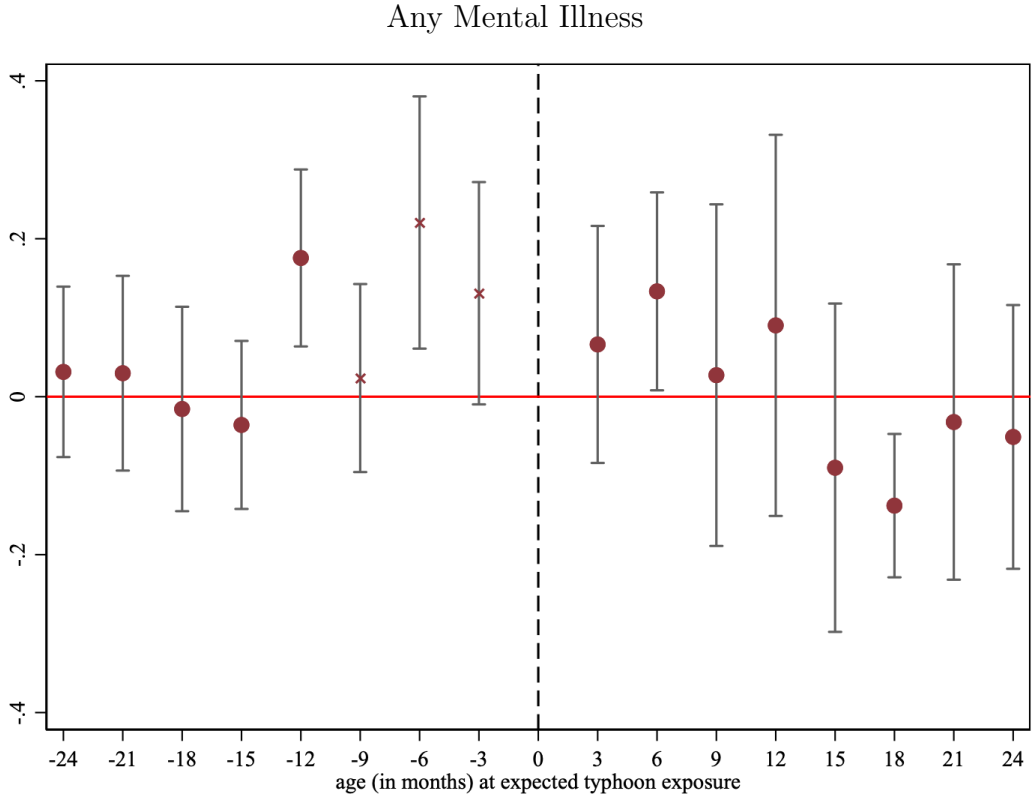


(B) Ever been diagnosed with any drug: Male (Left) Female (Right)



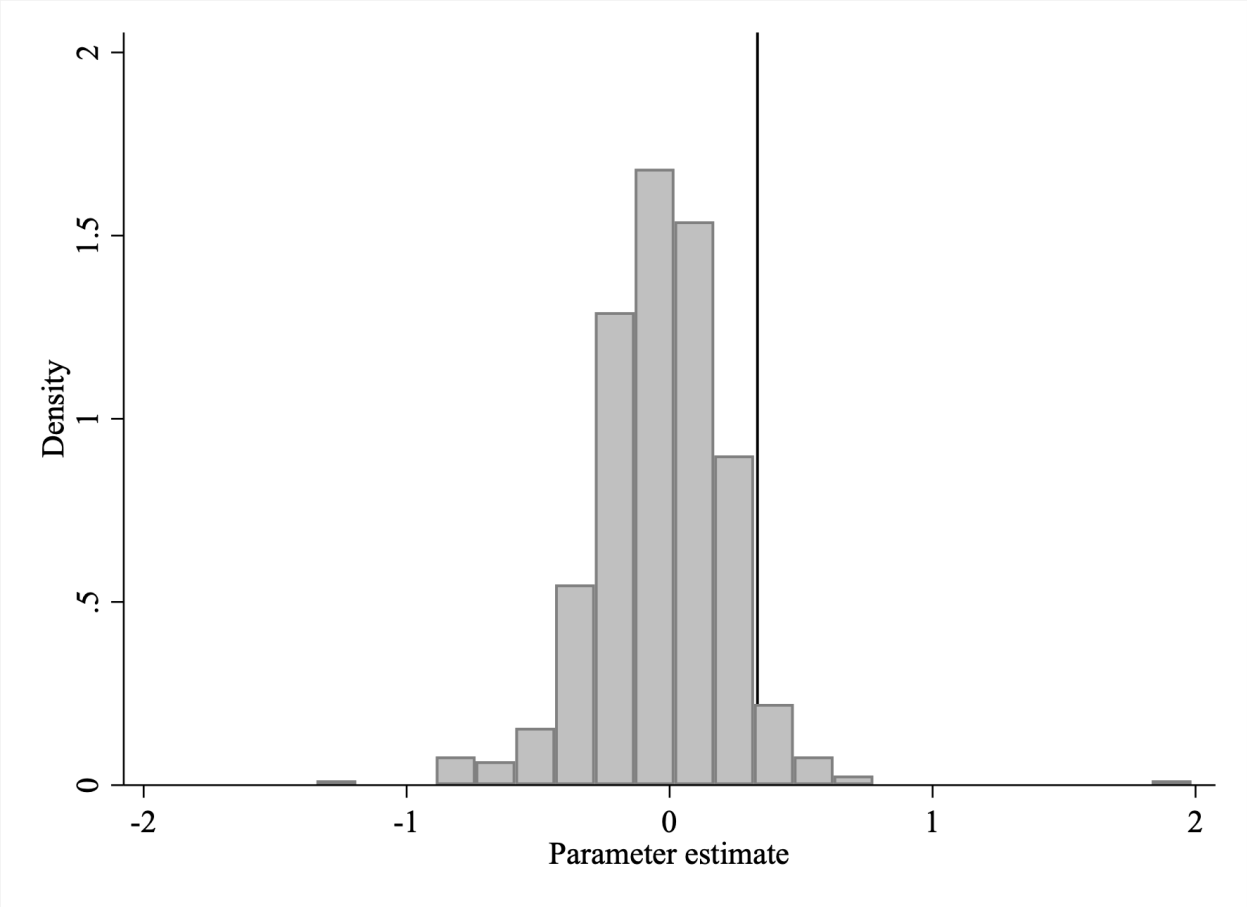
Notes: Sample is as described in Table 1. N = 34,811 (male) and N = 34,738 (female). Analysis separate for three trimesters (1-3, 4-6, 7-10 months). Expected exposure measures integrate county-specific in utero typhoon exposure over the distribution of likely birth counties conditional on current residence using a birth–residence transition matrix (see Section 3.2.1). Models also control for year of birth FE, month of birth FE, county FE, county-specific cohort trends, and a set of interaction terms between non-landfall county and in utero exposure to severe typhoon (same as Table 2). Standard errors are clustered at the county level. *** p<0.01, ** p<0.05, * p<0.1

Figure 5: Impacts of Exposure to Severe Typhoon by Birth Cohort
Coefficient of (Expected Exposure to Severe Typhoon * Landfall County), β_{1x}



Notes: Sample comprises female individuals who were born between 1964 and 1970. Regression estimates of Equation 4 from linear probability models are plotted. The dots, crosses, and bars correspond to the coefficient estimates with 95% confidence intervals. The estimate illustrates the difference in outcome variables between those individuals who were expected exposed to severe typhoons at age x relative to individuals who were not expected exposed to severe typhoons at age x. The dot represents the differences in outcomes between individuals who were expected exposed to severe typhoons and individuals who were not expected exposed to severe typhoons within one year before birth, which covers the *in utero* period. Omitted group is individuals who did not have severe typhoon exposure between two years before and two years after birth. Expected exposure measures integrate county-specific in utero typhoon exposure over the distribution of likely birth counties conditional on current residence using a birth–residence transition matrix (see Section 3.2.1). The covariates include year of birth fixed effects, month of birth fixed effects, county fixed effects, county-specific cohort trends, and a set of interaction terms between non-landfall county and exposure at age x to severe typhoon (see Equation 4).

Figure 6: Permutation Test Result for Outpatient Psychiatric-Related Visits
Coefficient of (Exposed)*(Landfall County), β_1



Notes: We assigned placebo treatment (prenatal exposure to severe typhoons) in randomly selected year-month and county drawn without replacement. The histogram displays the coefficient estimates of an interaction term between *in utero* exposure to severe typhoon and landfall county from 1,000 permutations. The vertical line shows the estimates of the actual prenatal exposure. Exposure to severe typhoons is a dummy variable, which equals 1 if one was *in utero* during a severe typhoon. Severe typhoon is defined as a typhoon that caused 50 deaths. Landfall county equals to 1 if one resides in the landfall county for the given typhoon. Omitted group is individuals who were not exposed to a severe typhoon while *in utero*. The results show that 23 out of 1,000 permutation estimates are greater than that of actual treatment.

Table 1: Descriptive Statistics, Health Insurance Claim Records 1998-2002

	(1)	(2)	(3)	(4)	(5)	(6)
		W/ inutero exposure				
	All	Landfall County	Non-Landfall County	W/o inutero exposure	P-value of $H0:(2)=(4)$	P-value of $H0:(3)=(4)$
Individual characteristics						
Age	37.545	38.046	37.992	37.088	0.030	0.000
	(3.420)	(3.165)	(3.549)	(3.232)		
Male	0.501	0.512	0.496	0.505	0.460	0.092
	(0.500)	(0.500)	(0.500)	(0.500)		
Health Outcomes						
Ever had any mental disorders	0.204	0.253	0.209	0.199	0.089	0.007
	(0.403)	(0.435)	(0.407)	(0.399)		
Ever been prescribed psychiatric drugs	0.164	0.206	0.170	0.158	0.161	0.004
	(0.370)	(0.405)	(0.375)	(0.364)		
Ever been hospitalized in psychiatry	0.007	0.016	0.006	0.007	0.006	0.050
	(0.082)	(0.126)	(0.078)	(0.084)		
Number of psychiatric-related outpatient visits	1.583	2.656	1.557	1.576	0.001	0.798
	(8.291)	(11.581)	(7.636)	(8.777)		
Total psychiatric-related outpatient expenditures	61.264	115.881	58.774	62.050	0.000	0.412
	(460.128)	(679.472)	(431.747)	(478.535)		
N	69549	1056	34047	34446		

Notes: Data source: 5% Health Insurance Claim Records, 1998–2002. Unit of observation is individual. Analytical sample includes individuals who were born between 1959 and 1970 and currently reside in rural townships (shiang). Individual characteristics are observed in 2002, and health outcomes are aggregated across 1998-2002 based on claim records. Standard deviations are reported in parentheses.

Table 2: Effects of Expected In Utero Typhoon Exposure on Adult Mental Health

Panel A: Ever been diagnosed with:

	(1) Any mental disorders	(2) Anxiety and personality disorders	(3) Mood disorders	(4) Schizophrenia
Expected Landfall Exposure, $\beta 1$	0.022*	0.021***	0.021***	0.005**
	(0.013)	(0.007)	(0.006)	(0.002)
Expected Non-Landfall Exposure, $\beta 2$	0.003	0.005*	0.003	-0.001
	(0.003)	(0.003)	(0.002)	(0.001)
Mean	0.204	0.146	0.039	0.011
$H0 = \beta 1 - \beta 2$	0.145	0.038	0.003	0.011

Panel B: Ever been prescribed:

	(1) Any psychiatric drugs	(2) Antidepressants	(3) Anxiolytics	(4) Antipsychotics
Expected Landfall Exposure, $\beta 1$	0.016	0.031***	0.010	0.003
	(0.013)	(0.010)	(0.014)	(0.010)
Expected Non-Landfall Exposure, $\beta 2$	0.006*	0.004**	0.005	-0.002*
	(0.003)	(0.002)	(0.003)	(0.001)
Mean	0.164	0.052	0.149	0.035
$H0 = \beta 1 - \beta 2$	0.518	0.011	0.736	0.620

Notes: The sample is as described in Table 1. $N = 69{,}549$. Expected exposure measures integrate county-specific in utero typhoon exposure over the distribution of likely birth counties conditional on current residence using a birth–residence transition matrix (see Section 3.2.1). Models control for an indicator for male, year-of-birth FE, month-of-birth FE, county FE, and county-specific cohort trends. The omitted group is individuals not exposed to severe typhoons in utero. Standard errors are clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 3: Impact of Intrauterine Exposure to Severe Typhoon on Psychiatric-Related Health Care Utilization

	(1)	(2)	(3)	(4)
	Number of Psychiatric-Related Number			
	Poisson	Negative Binomial	Total Outpatient Psychiatric-Expenditure	Out of Pocket Psychiatric-Expenditure
Expected Landfall Exposure, $\beta 1$	0.334**	0.349**	0.308***	0.622***
	(0.135)	(0.169)	(0.113)	(0.191)
Expected Non-Landfall Exposure, $\beta 2$	-0.066	-0.063	-0.153**	-0.032
	(0.055)	(0.052)	(0.069)	(0.079)
Mean	1.583	1.583	61.264	4.961

Notes: Sample is as described in Table 1. N=69,549. Use ordinary least square model. Expenditures are inflation-adjusted and in 2011 USD. Column 1 use Poisson specification, column 2 uses negative binomial FE models. Column 3-4 use the Poisson PML specification. Expected exposure measures integrate county-specific in utero typhoon exposure over the distribution of likely birth counties conditional on current residence using a birth–residence transition matrix (see Section 3.2.1). We also control for an indicator for male, year of birth FE and month of birth FE, county FE, and county-specific cohort trends. Omitted group is individuals who were not exposed to severe typhoons while in utero. Standard errors are clustered at the county level. *** p<0.01, ** p<0.05, * p<0.1

Table 4: Impact of Intrauterine Exposure to Severe Typhoon on Mental Illness by Gender

Panel A: Ever been diagnosed with:

	(1) Any mental disorders	(2) Anxiety and personality disorders	(3) Mood disorders	(4) Schizophrenia
Male				
Expected Landfall Exposure, $\beta 1$	-0.013	0.008	0.025***	0.008
	(0.023)	(0.012)	(0.009)	(0.006)
Mean	0.162	0.110	0.030	0.013
Female				
Expected Landfall Exposure, $\beta 1$	0.075***	0.042**	0.015*	-0.000
	(0.017)	(0.017)	(0.009)	(0.006)
Mean	0.247	0.181	0.048	0.010

Panel B: Ever been prescribed:

	(1) Any psychiatric drugs	(2) Antidepressants	(3) Anxiolytics	(4) Antipsychotics
Male				
Expected Landfall Exposure, $\beta 1$	-0.005	0.024	-0.004	-0.006
	(0.019)	(0.017)	(0.016)	(0.013)
Mean	0.127	0.042	0.113	0.033
Female				
Expected Landfall Exposure, $\beta 1$	0.048***	0.040***	0.034*	0.015*
	(0.012)	(0.007)	(0.020)	(0.008)
Mean	0.201	0.061	0.185	0.037

Panel C: Expenditure and Outpatient Visit:

	(1) Number of Psychiatric-related outpatient visits	(2) Total outpatient Psychiatric-expenditure	(3) Ever hospital expenditure	(4) Cost per outpatient visit
Male				
Expected Landfall Exposure, $\beta 1$	0.301	0.289	0.002	-1.764
	(0.326)	(0.416)	(0.008)	(4.451)
Mean	1.481	62.708	62.708	386.497
Female				
Expected Landfall Exposure, $\beta 1$	0.414***	0.354	0.003	-0.223
	(0.106)	(0.425)	(0.003)	(2.865)
Mean	1.685	59.817	59.817	242.351

Notes: The sample is as described in Table 1. $N = 69{,}549$. Expected exposure measures integrate county-specific in utero typhoon exposure over the distribution of likely birth counties conditional on current residence using a birth–residence transition matrix (see Section 3.2.1). Models control for measure of expected non-landfall exposure to severe typhoon, male, year-of-birth FE, month-of-birth FE, county FE, and county-specific cohort trends. The omitted group is individuals not exposed to severe typhoons in utero. Standard errors are clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 5: Robustness Checks with Alternative Definition of Severe Typhoons

	(1) Baseline Specification	(2) Deaths >= 20	(3) Deaths >= 70	(4) Collapsed Buildings >= 2000	(5) Collapsed Buildings >= 4000	(6) Redefine Most Severe
Expected Landfall Exposure, $\beta 1$	0.075***	0.048**	0.055***	0.063***	0.073***	0.069***
	(0.017)	(0.024)	(0.016)	(0.022)	(0.023)	(0.009)
Expected Non-Landfall Exposure, $\beta 2$	-0.001	-0.001	-0.004	-0.004	-0.004	0.000
	(0.005)	(0.004)	(0.007)	(0.005)	(0.005)	(0.005)
Severe Typhoons	5	7	4	8	7	5

Notes: Sample is as described in Table 1, but female only. N=34,738. This table presents the estimation results from linear probability models. Dependent Variable is ever been diagnosed with any mental disorders. Expected exposure measures integrate county-specific in utero typhoon exposure over the distribution of likely birth counties conditional on current residence using a birth–residence transition matrix (see Section 3.2.1). Models also control for year of birth FE, month of birth FE, county FE, and county-specific cohort trends. Baseline definition of severe typhoon indicates a typhoon that caused 50 or more deaths. This table use alternative measures including 20 and 70 deaths, and 2,000 and 4,000 collapsed buildings. The redefine of the most severe diaster and its corresponding landfall county is following by government diaster summary (Taiwan Provincial Weather Bureau, 1960, 1961, 1962, 1965, 1969). Omitted group is individuals who were not exposed to severe typhoons while in utero. All models weight by "migration matrix", the structure same as table 2. Standard errors are clustered at the the county level *** p<0.01, ** p<0.05, * p<0.1

Table 6: Robustness Checks with Subsamples and Additional Controls

	(1) Baseline Specification	(2) Excluding north and central regions	(3) Excluding non-landfall regions	(4) Excluding year of birth >= 1966	(5) Excluding cohorts exposed to no-landfall severe typhoons	(6) Excluding counties with migration rate>=20%	(7) Including region-year of birth FE
Expected Landfall Exposure, $\beta 1$	0.075***	0.081***	0.066***	0.133***	0.075***	0.058**	0.078***
	(0.017)	(0.021)	(0.015)	(0.042)	(0.022)	(0.027)	(0.025)
Expected Non-Landfall Exposure, $\beta 2$	-0.001	-0.012**	-0.031*	-0.004	0.002	0.004	-0.001
	(0.005)	(0.006)	(0.017)	(0.006)	(0.007)	(0.012)	(0.005)
N	34738	13711	3859	20513	26362	11620	34738

Notes: All regression are restricted to female only. Columns 1 to Column 67 of this table present the estimation results from linear probability models. Expected exposure measures integrate county-specific in utero typhoon exposure over the distribution of likely birth counties conditional on current residence using a birth–residence transition matrix (see Section 3.2.1). All models also control for year of birth FE, month of birth FE, county FE, and county-specific cohort trends. Columns 1–7 cluster standard errors at the county level. Omitted group is individuals who were not exposed to severe typhoons while in utero. Note the column (3) "excluding non-landfall regions" means sample only include east region and pintong (four counties are labeled as landfall county for at least one typhoon). Standard errors are shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1

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A Online appendix: Additional figures and tables

A.1 Tables and Figures

Table A.1: Sex Ratio and Cohort Size

	(1) M-F Sex Ratio	(2) M-F Sex Ratio	(3) Log total cohort	(4) Log female cohort	(5) Log male cohort
Exposed × landfall	0.0079**				
	(0.0037)				
Tri 1 × landfall		0.0086	-0.0127	-0.0218***	-0.0052
		(0.0175)	(0.0135)	(0.0082)	(0.0194)
Tri 2 × landfall		-0.0101	-0.0219	-0.0077	-0.0355
		(0.0212)	(0.0254)	(0.0256)	(0.0285)
Tri 3 × landfall		0.0195***	-0.0081	-0.0155	-0.0011
		(0.0073)	(0.0135)	(0.0130)	(0.0150)
N	1596	1596	1596	1596	1596

Notes: The sample is 1980 census with born after 1964 (age <= 16). Also, the county will be replaced as old one if individual move 5 years ago. Expected exposure measures integrate county-specific in utero typhoon exposure over the distribution of likely birth counties conditional on current residence using a birth–residence transition matrix (see Section 3.2.1). Models control year-of-birth FE, month-of-birth FE, county FE, and county-specific cohort trends. The omitted group is individuals not exposed to severe typhoons in utero. Standard errors are clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A.2: Likelihood of Seeking Treatment by Gender

	(1) Any mental disorders	(2) Any psychiatric drugs	(3) Number of psychiatric visits	(4) Cost per outpatient visit	(5) Ever Inpatient visits	(6) Total outpatient expenditures
Male	-0.085***	-0.076***	-0.211***	4.087***	0.003***	29.14***
	(0.003)	(0.003)	(0.081)	(0.571)	(0.001)	(7.994)
N	69549	69549	69549	14222	69549	69549
Mean	0.204	0.164	1.583	24.089	0.007	68.907

Notes: The sample is as described in Table 1. Dependent variable is Male, which present whether male is more likely to have treatment compared to female. Model includes year of birth FE and month of birth FE, county FE, and county-specific cohort trends. tandard errors are clustered at the county level. *** p<0.01, ** p<0.05, * p<0.1

Table A.3: Severe Typhoon Exposure and Migration

	All respondents			Currently Rural		
	All	Female	Male	All	Female	Male
Exposed to Severe Typhoon Landfall County	-0.000	-0.002	0.002	-0.005	-0.005	-0.004
	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.005)
N	4272046	2118537	2153509	2026205	953762	1072443

Notes: Dependent variable is whether an individual has moved out of their birth county. Columns (1)–(3) use the full sample; columns (4)–(6) restrict to respondents currently living in rural areas. Columns labeled Female/Male restricted sample by gender. All regressions include birth county fixed effect, birth year, and male fixed effects, education level and disability indicator and cluster standard errors at the birth county level. Census 2000 only reports age.

A.2 ICD-9 Diagnosis Codes

Any mental disorder: 290.xx-312.xx

Anxiety and personality disorders: 300.xx, 301.xx

Mood disorders: 296.xx, 300.4x, 311.xx

Schizophrenia: 295.xx

Illnesses classified as anxiety disorders: generalized anxiety disorder, panic disorder, Obsessive-compulsive disorder (OCD), PTSD, and phobias

Illnesses classified as personality disorder: paranoid personality disorder, schizoid personality disorder, schizotypal personality disorder, antisocial personality disorder, borderline personality disorder, histrionic personality disorder, narcissistic personality disorder, avoidant personality disorder, dependent personality disorder, obsessive-compulsive personality disorder.

Illnesses classified as mood disorder: depression, bipolar disorder

Prior to 2000, most physicians and clinics/hospitals used A-codes before 1999. Starting from 2000, classifications were switched to ICD-9 codes. We converted the relevant A-codes to ICD9 codes for the analysis. For most part, we follow the same categorization as Reeves et al. (2011). However, A-code does not distinguish anxiety and personality disorder, so we cannot separately analyze these two categories.

A.3 ATC Codes

Antidepressants: N06A, N06CA

Anxiolytics: N05B

Antipsychotic: N05A

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